# “Hydrogen as the ultimate fuel: Challenges and Opportunities”

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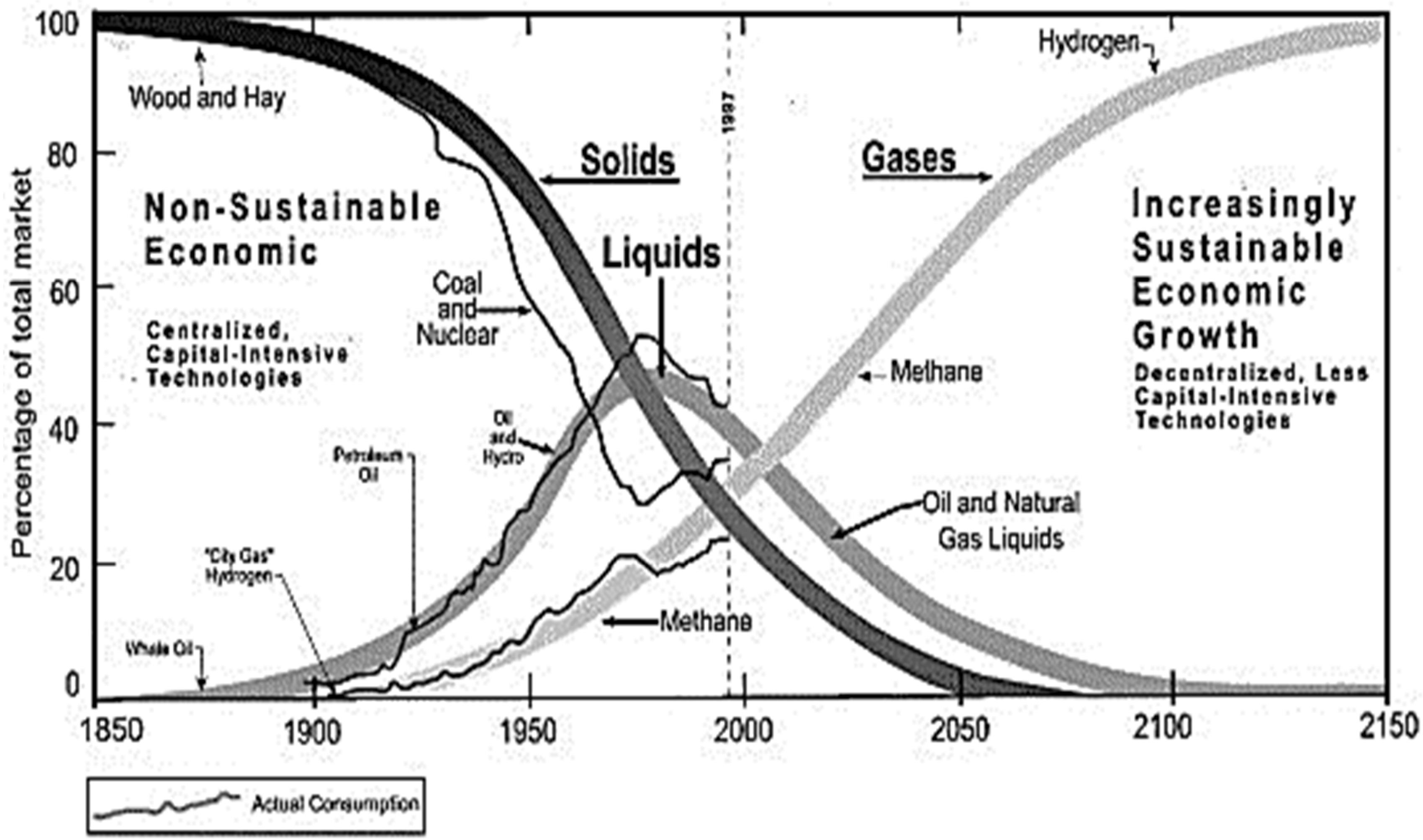
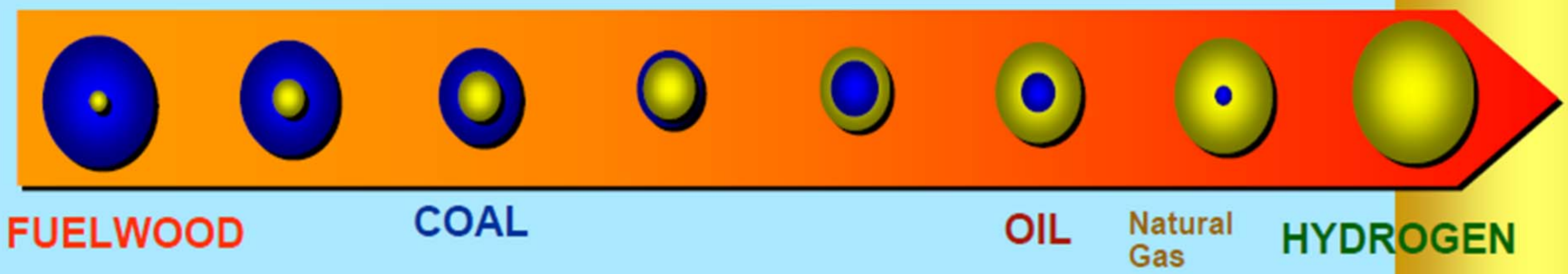
# Transition in Global Energy Systems




**In the age of energy gases, the transition on global energy systems, Dunes (2001)**

# Transition to Hydrogen Energy




- **Present Scene :**

  **Petrol /Diesel /CNG based Automobiles & Power Generation**

- **Intermediate Stage :**

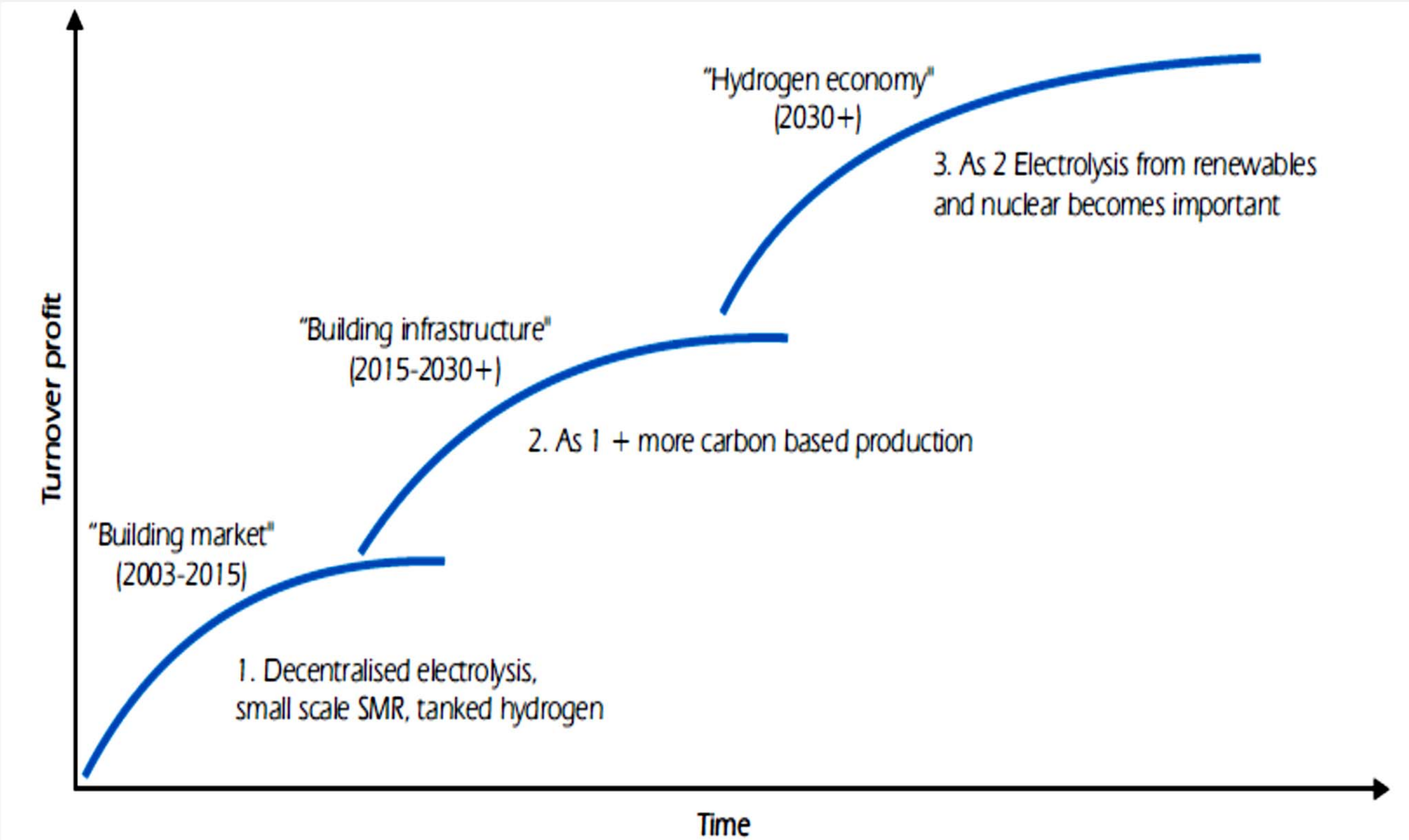
  **Electric & Hybrid Vehicles; Bio-Fuel / Synthetic Fuel based Vehicles & Power Generation**

- **Ultimate Objective :**

  **Environment Friendly and Carbon Free Hydrogen Based Vehicles & Power Generation**

HC1

# Main Hydrogen Pathways: The Long Term Perspective




- **Web Source: IEA, France. Report on "Hydrogen Production R&D: Priorities and Gaps", 2006 under Hydrogen Implementing Agreement**

**Slide 4**

**HC1** Hewlett-Packard Company, 8/20/2019

# Hydrogen: The Ultimate Energy (Carrier)

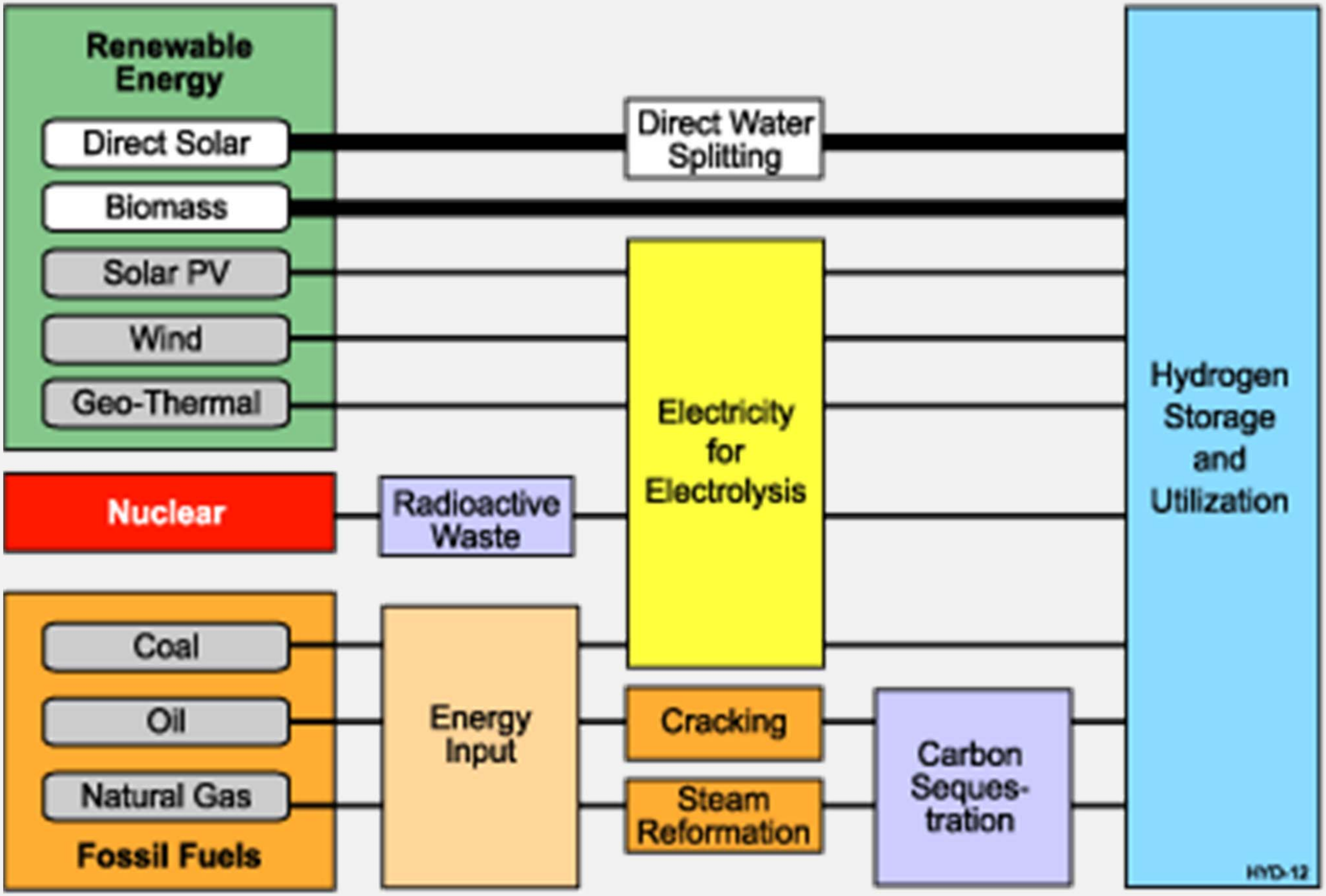
Water + Energy ⟶ Hydrogen + Oxygen

Hydrogen + Oxygen ⟶ Water + Energy

**Reaction:**

$$H_2\ (g) + \tfrac{1}{2}\ O_2\ (g) \Longleftrightarrow H_2O\ (l) + 286\ \text{kJ/mole}$$

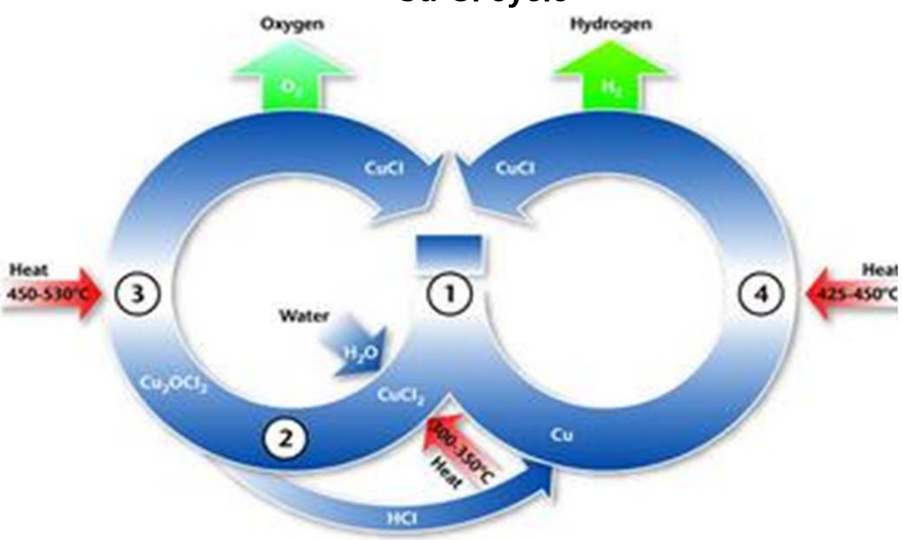
# Hydrogen production paths



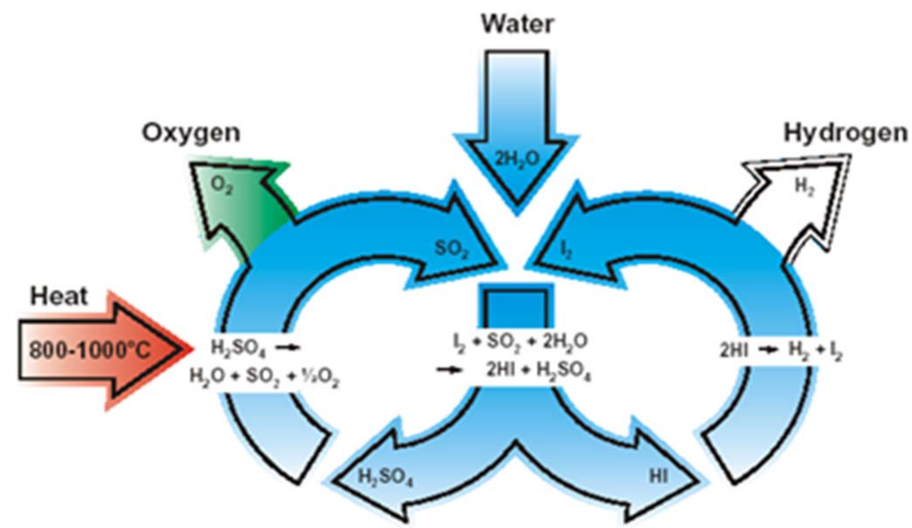
# Thermochemical Hydrogen Generation


**Chemical Processes Convert High-Temperature Heat and Water to Hydrogen and Oxygen**

**Cu-Cl cycle**




**I-S Cycle**




Technologies are yet to be commercialized

# Energy Source for Hydrogen

**Heat /Electricity**

**Nuclear:**

- Cheaper and reliable in long run.
- Availability of Super-Critical Water Reactor (SCWR) that can deliver temperature up to 600 $^{0}$C but reactor temperature specific to application.
- The issue is safely coupling with the thermo-chemical cycle.

**Solar:**

- Totally safe and reliable and will work out comparable with Nuclear in long run.
- Temperature has no limitation - with proper combination of concentrators, can provide >2000K.
- Need for storage, which is also required to supply heat for Hydrogen production process cycles.

**Other sources**

**Wind:** Electricity Generation

**Geo-Thermal:** Electricity Generation /Heat Supply

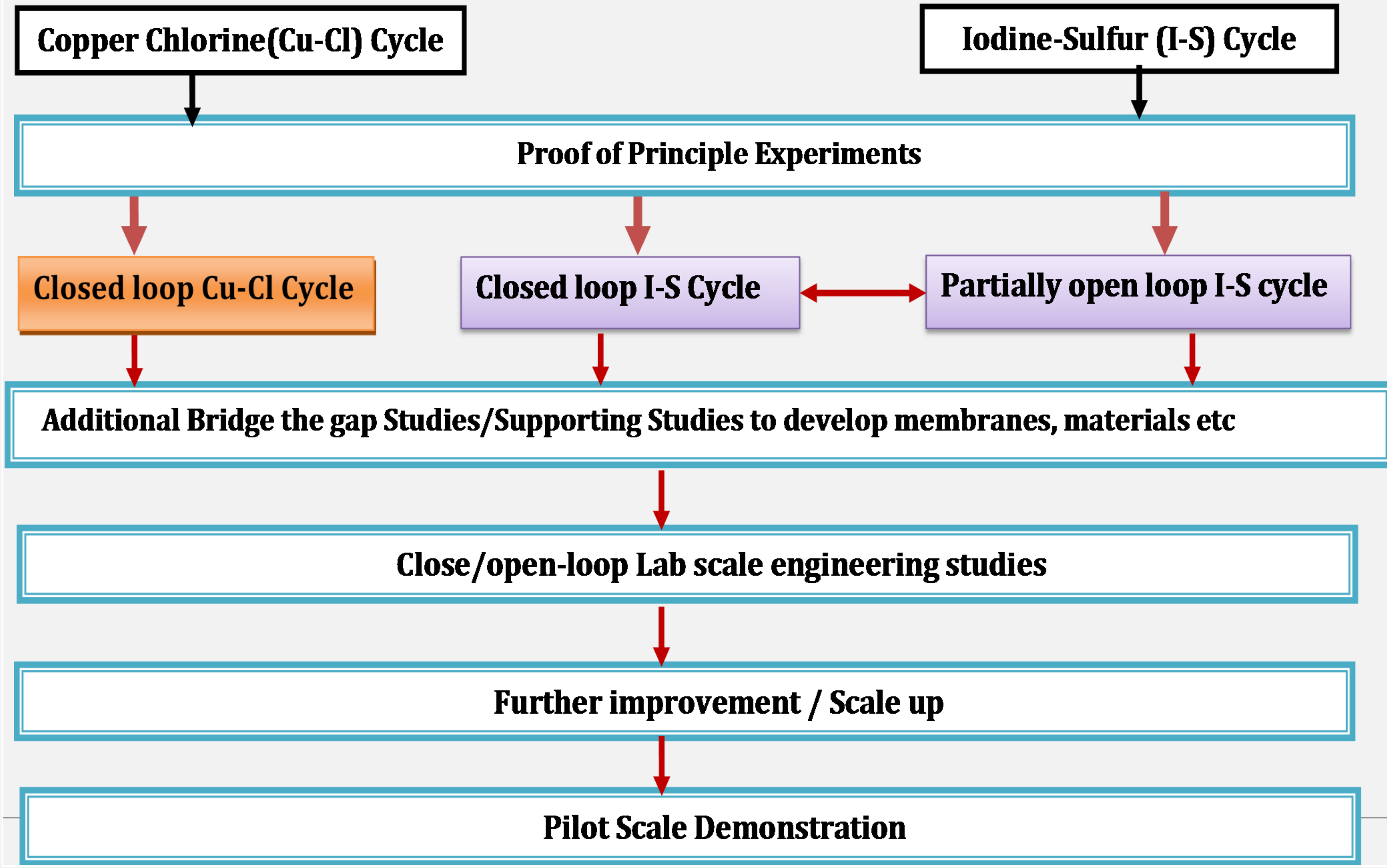
# Technical Challenges

- Technologies are under development in laboratory
- Corrosion problems (Material selection & availability)
- Cost-effective catalysts, membranes and electrodes
- Electrochemical Simulations/Modeling
- Integration of electrochemical reactors with thermal reactors
- Energy efficient separations/purifications
- Heat source identification, selection and management
- Equipment availability (Design & Develop Indigenous Equipment)

**ONGC Energy Centre (OEC) has initiated indigenous technology development drive in 2007.**

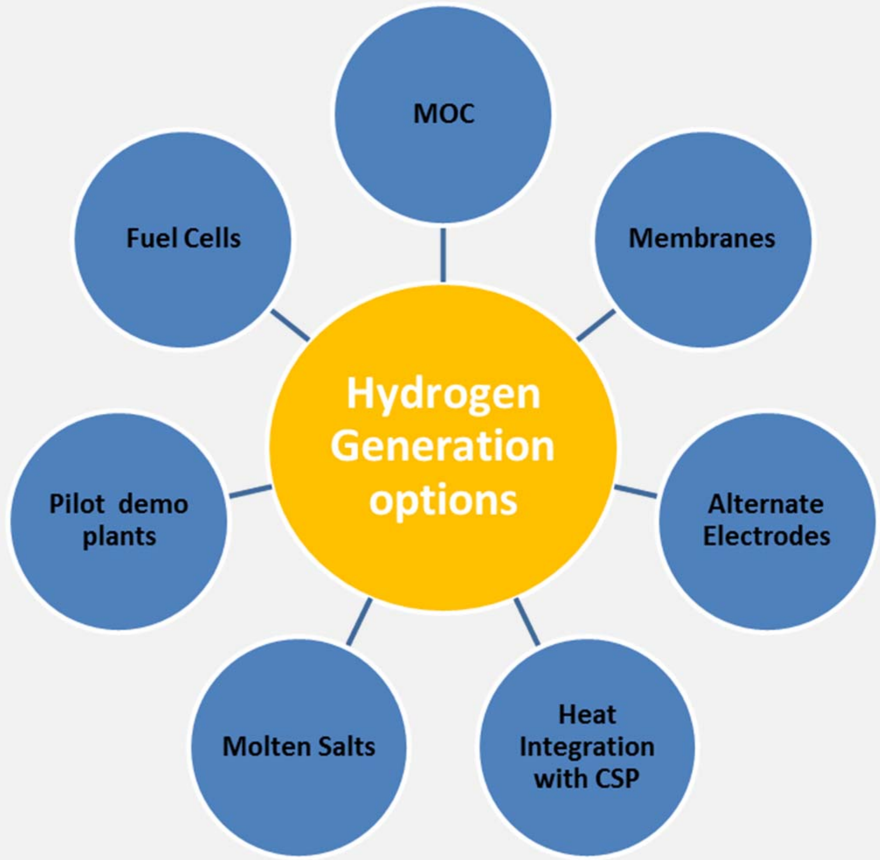
# OEC approach

## Development of Thermochemical Hydrogen Generation program

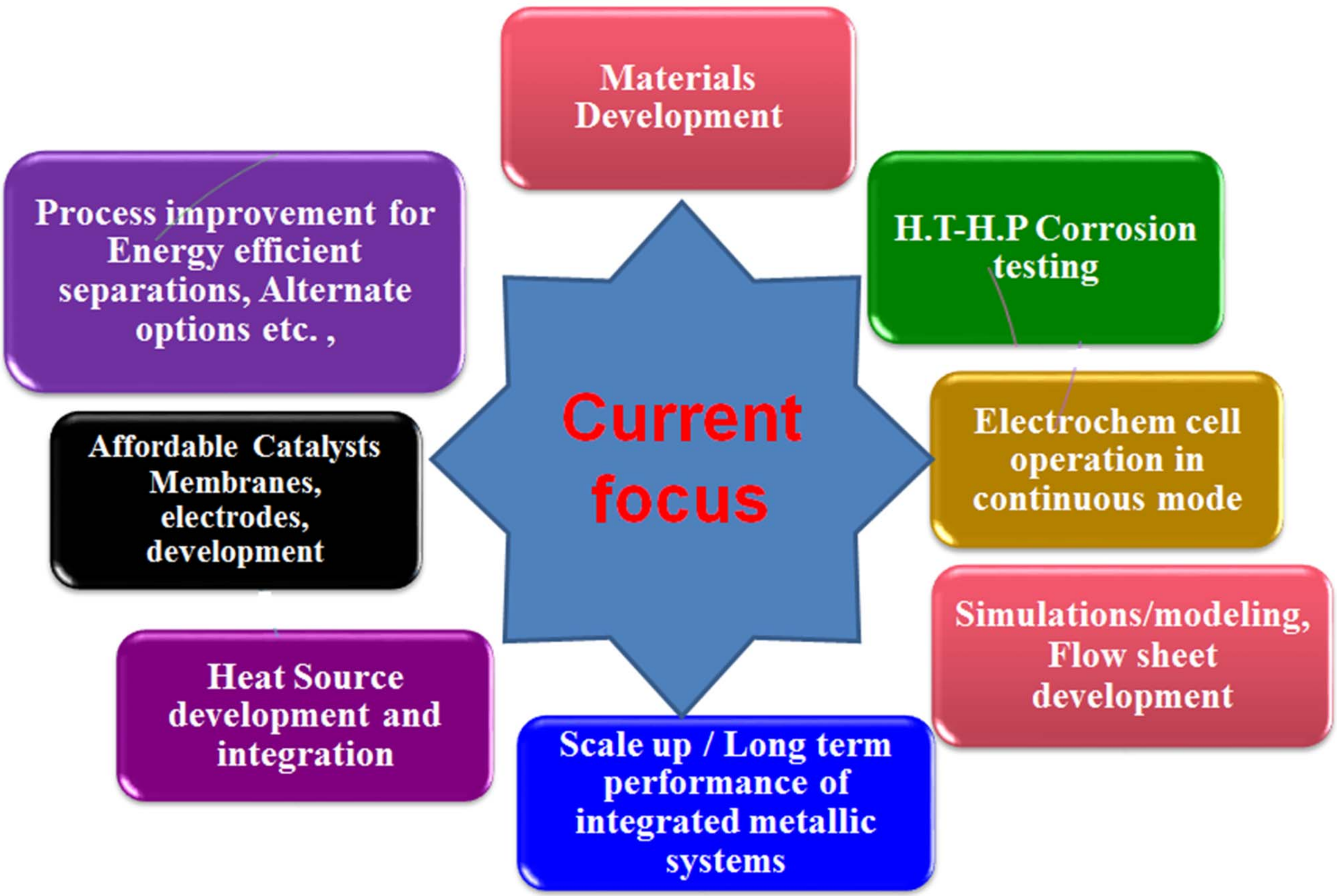


# Hydrogen Generation Ecosystem- Integrative Projects in hand

- ✓ Studies on integration of heat source with Cu-Cl cycle
- ✓ Studies on alternative approaches to reduce heat requirement to I-S cycle
- ✓ Studies on alternative approaches to improve separation strategies in Cu-Cl cycle
- ✓ Simulation/Modeling studies on both cycles to improve process, separations, etc.
- ✓ Development of SOEC / SOFC systems
- ✓ Development of other processes and materials for $H_2$ storage



# Activities


Materials Development
H.T-H.P Corrosion testing
Electrochem cell operation in continuous mode
Simulations/modeling, Flow sheet development
Scale up / Long term performance of integrated metallic systems
Heat Source development and integration
Affordable Catalysts Membranes, electrodes, development
Process improvement for Energy efficient separations, Alternate options etc. ,
Current focus

# Cu-Cl cycle

# New Cu-Cl cycle by OEC-ICT

| | Reactions | Cu-Cl Cycle |
|---|---|---|
| 1 | Hydrogen Generation (475 ± 25°C) | $2Cu_{(s)} + 2HCl_{(g)} \rightarrow 2CuCl_{(l)} + H_{2(g)}$ |
| 2 | Electrochemical (ambient temperature) | $4CuCl_{(l)} \rightarrow 2CuCl_{2(aq)} + 2Cu_{(s)}$ |
| 3 | Drying (120 ± 20°C) | $2CuCl_{2(aq)} \rightarrow 2CuCl_{2(s)}$ |
| 4 | Hydrolysis (375 ± 25°C) | $CuCl_{2(s)} + H_2O_{(g)} \rightarrow CuO_{(s)} + 2HCl_{(g)}$ |
| 5 | Decomposition (475 ± 25°C) | $CuCl_{2(s)} \rightarrow CuCl_{(l)} + ½ Cl_{2(g)}$ |
| 6 | Oxygen Generation (500 ± 25°C) | $CuO_{(s)} + ½ Cl_{2(g)} \rightarrow CuCl_{(l)} + ½ O_{2(g)}$ |

# Progress: Cu-Cl cycle

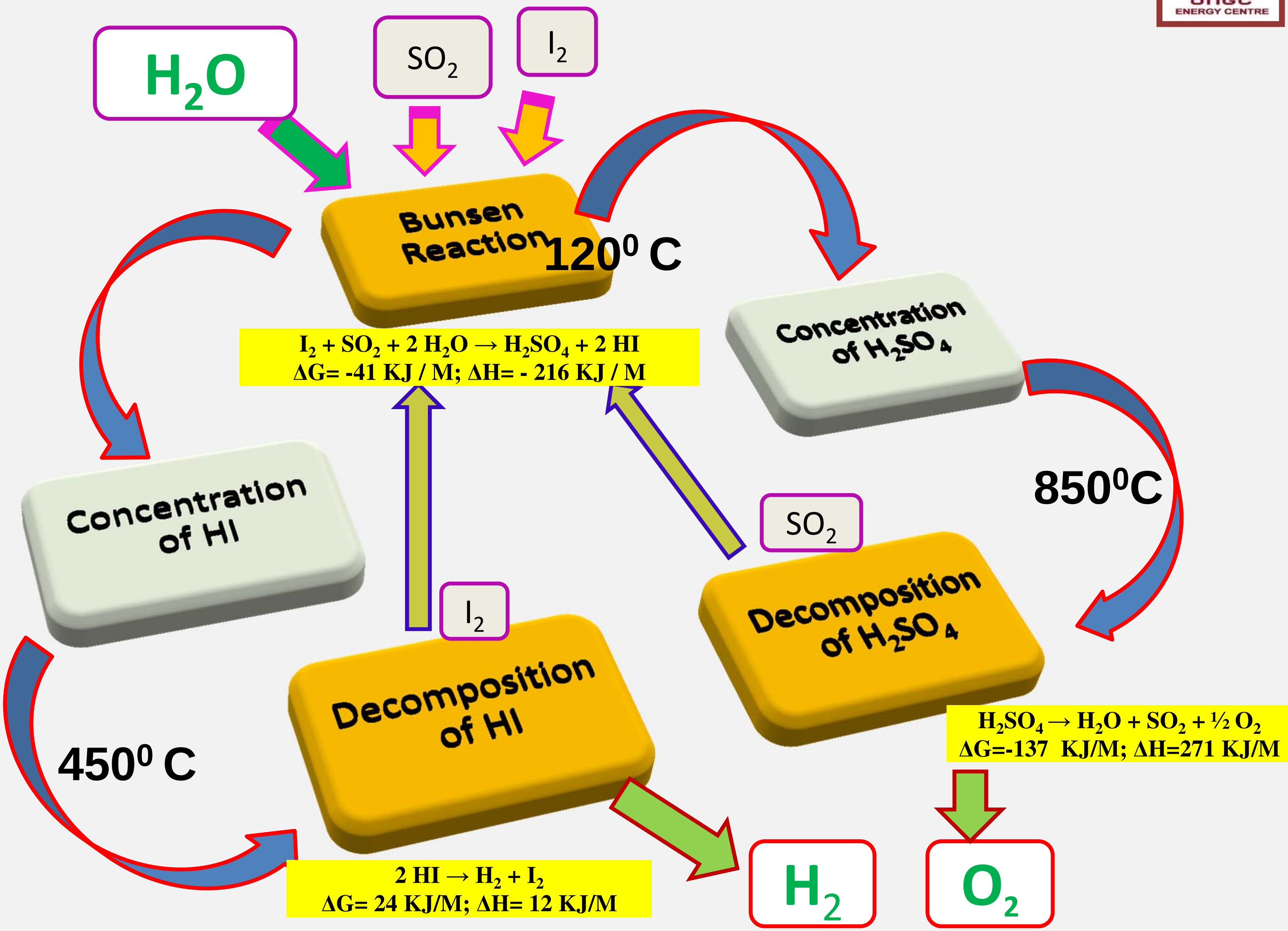
- ✓ A new multi-step Cu-Cl cycle has been established. Patented the process in 7 countries viz., USA, Canada, UK, Japan, China, Korea and India.
- ✓ An integrated lab scale engineering facility in metallic system has been developed and demonstrated for $H_2$ generation@ 25 lph for Cu-Cl cycle using indigenous resources.
- ✓ Long term performance data being generated for last 2 years for designing a 12 MT / year hydrogen generation plant to be set up by OEC.
- ✓ A new electrochemical cell has been designed / fabricated for CuCl electrolysis (60A stack developed) and already patented in 5 countries viz., USA, Canada, UK, Japan, China.
- ✓ Developed cost-effective alternative materials for platinum viz., MMO coated Ti, Graphite electrode materials that yielded 700 $mA/cm^2$ current density at ~1.0 V; further integration with main cycle in progress.
- ✓ Created High Temperature corrosion testing facilities for screening materials with and without coating in molten Cu-Cl environment at $550^oC$.
- ✓ Developed indigenous polymeric membranes for electro-chemical process.
- ✓ Developed molten salt system for application in Cu-Cl cycle in conjunction with solar heat.
- ✓ Designed Pressure Swing Distillation system for HCl-Water separation process.

# OEC-ICT Closed-Loop metallic facility: Cu-Cl cycle

**$H_2$ generation @25lph: Closed-loop metallic facility is operational at ICT, Mumbai since 2015; planning for 12 MT/day facility at OEC using Solar power**

# I-S cycle

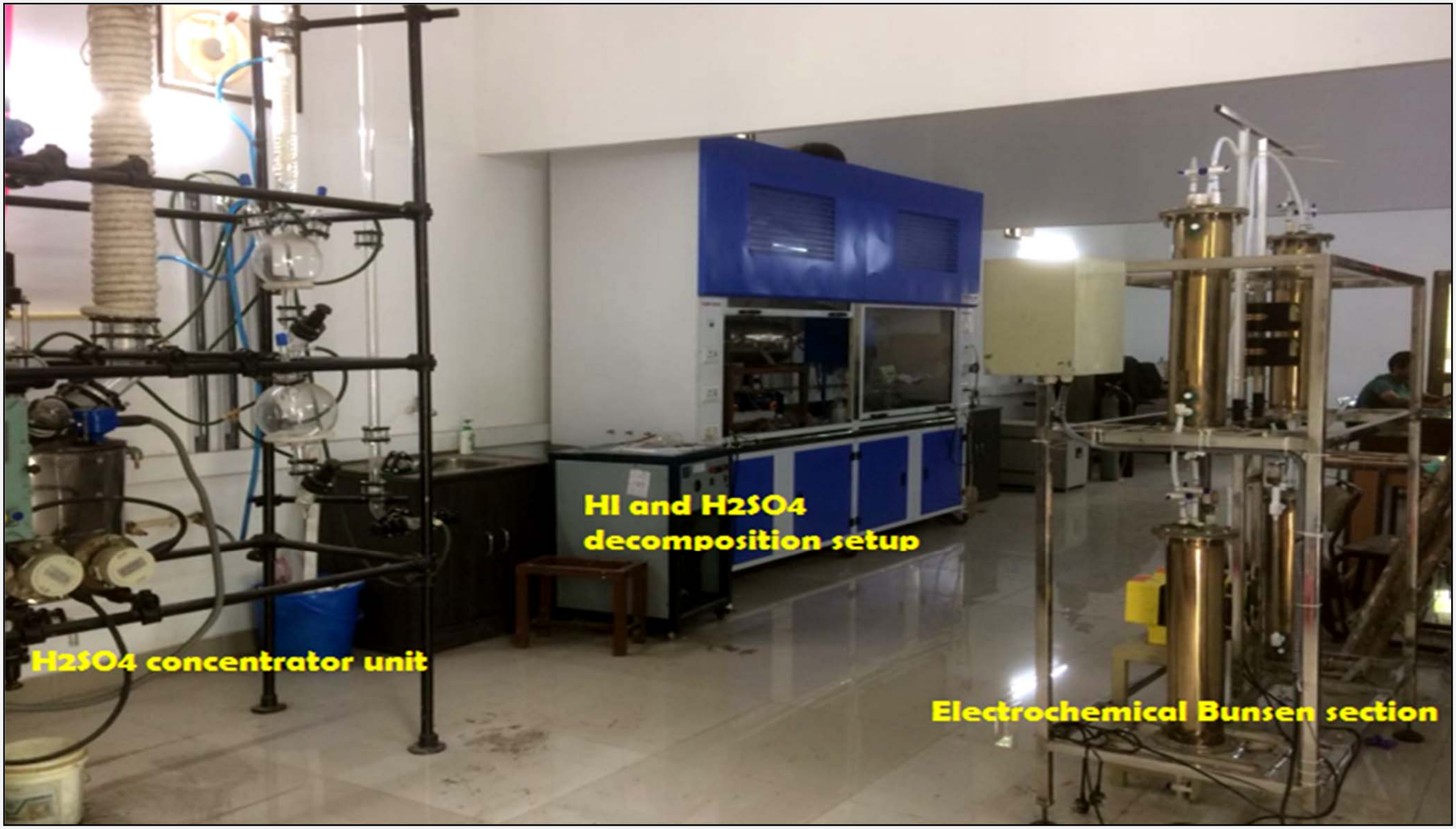
# Schematic of I-S Cycle



# Global plans vs. Current status: I.S Cycle (Concept to Commercialization)

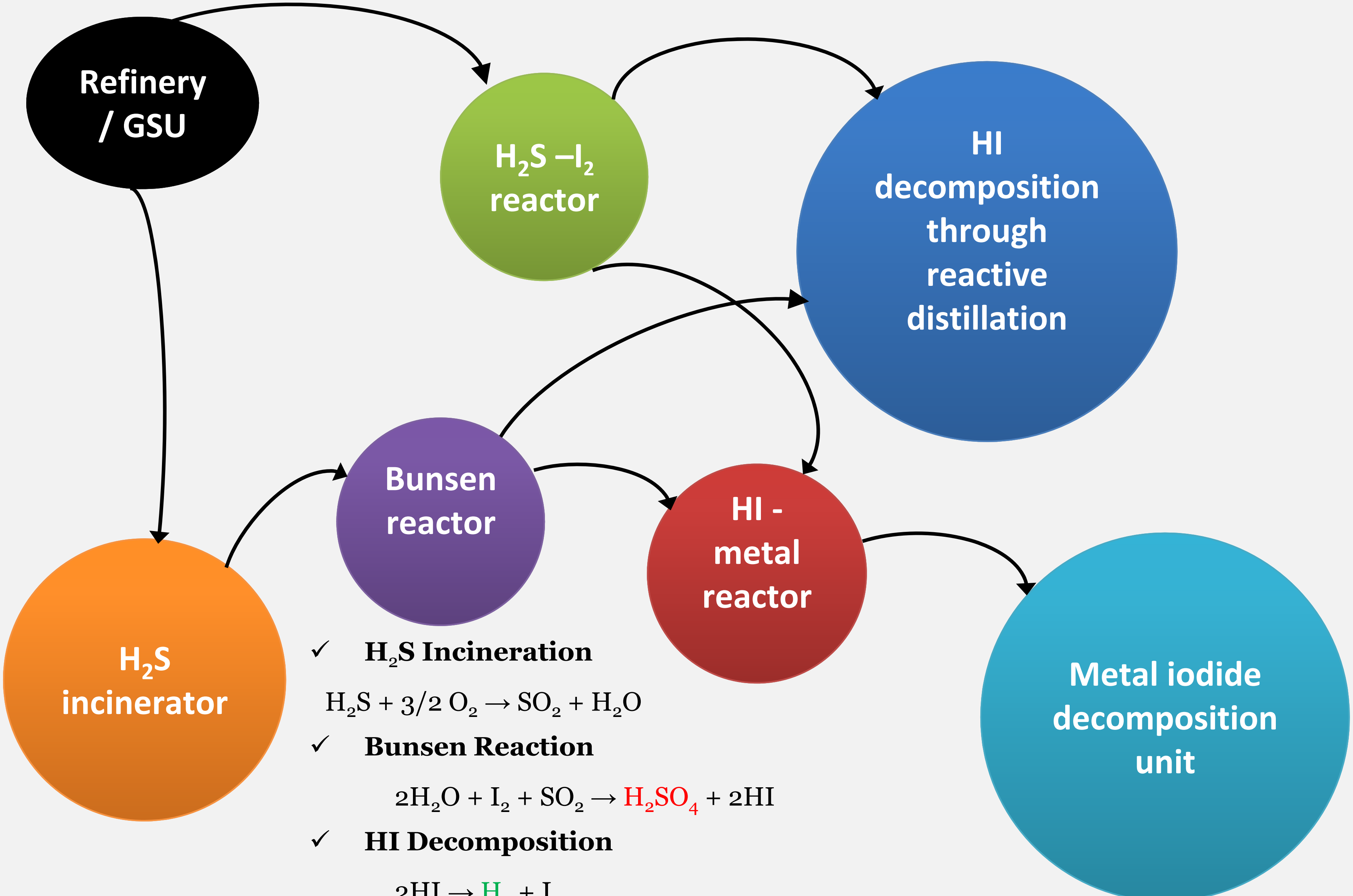
| S. No | Agency / Country | Year started | Year end | Stages with scales and time lines | | | | Reference / Status |
|---|---|---|---|---|---|---|---|---|
| | | | | Lab | Lab Engg. | Pilot | Commercial | |
| 1 | G.A, SRL-USA, CEA-France, | 1970 | 2017 | - 1980 | 75-150 L /h 2008 (2009) | 50 $M^3/h$ 2012 | 80,000 $M^3/h$ 2017 | NHI 10 yr prog plan 2005 Capriaglio *et al*., GA.ACS symp series, 1980 DOI: 10.1021/bk-1980-0116.ch016 Benjamin Russ GA. INL report 2010 |
| 2 | JAERI, Japan | 1997 | 2017 | 1 L/h 32 L/h glass 2004 | 150 L/H Metallic 2016 | 30 $M^3/h$ 2004 | 1000 $M^3/h$ (connected to VHTR) 2017 | Sadhankar, R AECL, 2008 Kasahara *et al*. IJHE 42(2017),13477-13485 |
| 3 | KAERI, Korea | 2004 | 2020 | 10 L/day 2009 | 100 L/H (50 l/h 2017 | 30-100 $M^3$/day | 7821 M.T/day 2020 | Shin *et al*, 3rd NIE, 2009 Kim *et al.* KAERI online publication March 2017 |
| 4 | INETA, China | 2005 | 2020 | 10 L/day 2010 | 100 L/h 2013 ( 60 l/h 2014) | 100 $M^3/h$ 2019 | 2020 | Mao *et al* IJHE 35(2010) 2727 Ping *et al* Renewable and Sustainable Energy Rev May 2017 |
| 5 | India | BARC 2006 OEC 2008 | 2020 | 1-25 L/day 2010 (2015 2018) | 150-300 L/day 2018-19 | 1MT/day | 80,000 $M^3/h$ 2022 | Latest BARC /OEC / MNRE Reports |

# Closed-loop experimental facilities at IIT-D




$H_2$ generation @5lph: Closed-loop operation in quartz / glass set operational since 2018; planning for scale up in metallic facility

# I-S open-loop cycle: Proposed routes of $H_2$ production




- ✓ **$H_2S$ Incineration**

  $H_2S + 3/2\ O_2 \rightarrow SO_2 + H_2O$

- ✓ **Bunsen Reaction**

  $2H_2O + I_2 + SO_2 \rightarrow H_2SO_4 + 2HI$

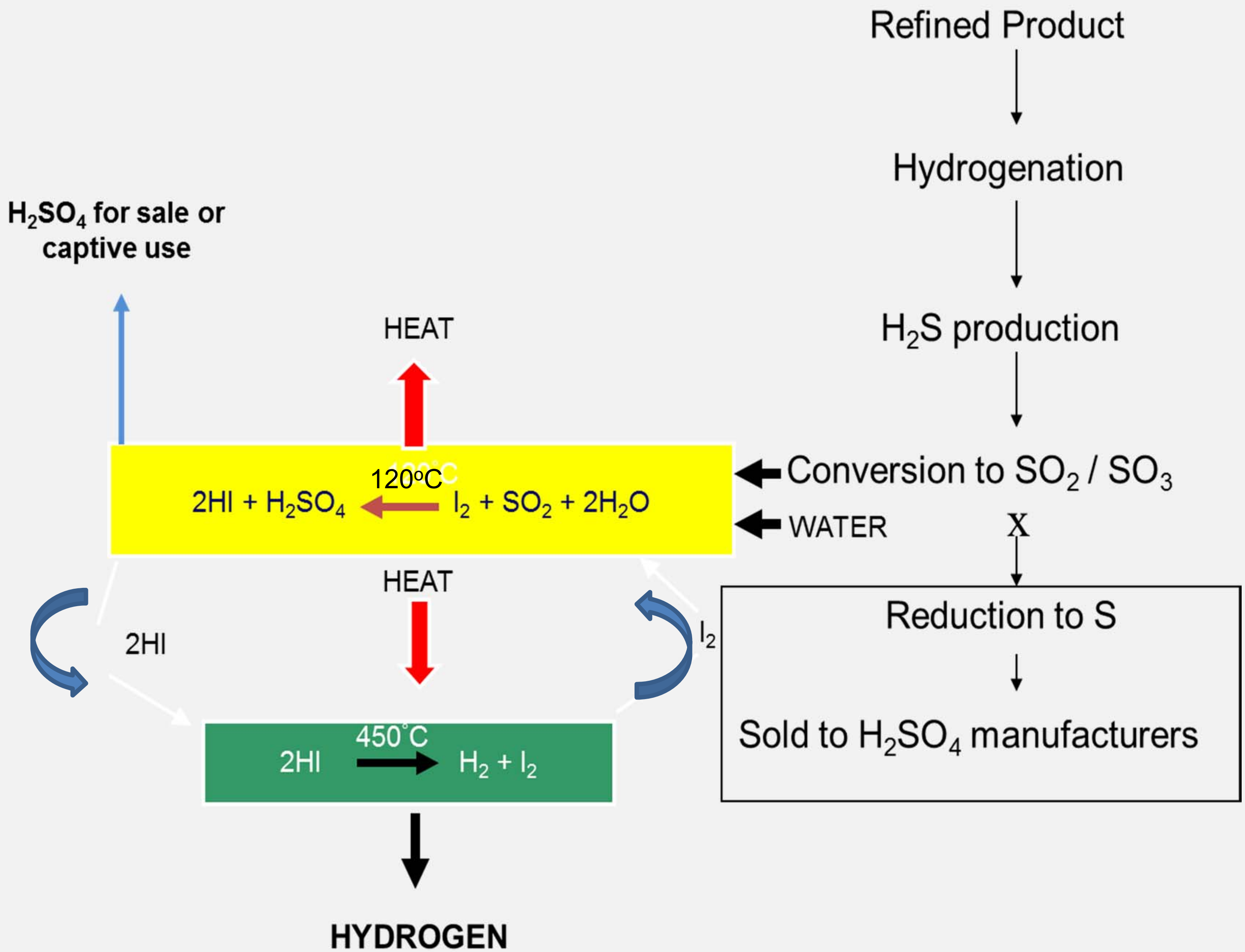
- ✓ **HI Decomposition**

  $2HI \rightarrow H_2 + I_2$

# OEC-IIP Open-loop Experimental facility: IIP, Dehradun


**Proof of concept in quartz / glass set up is nearing completion; planning for scale up in metallic facility to produce 10-12MT/day at MRPL**

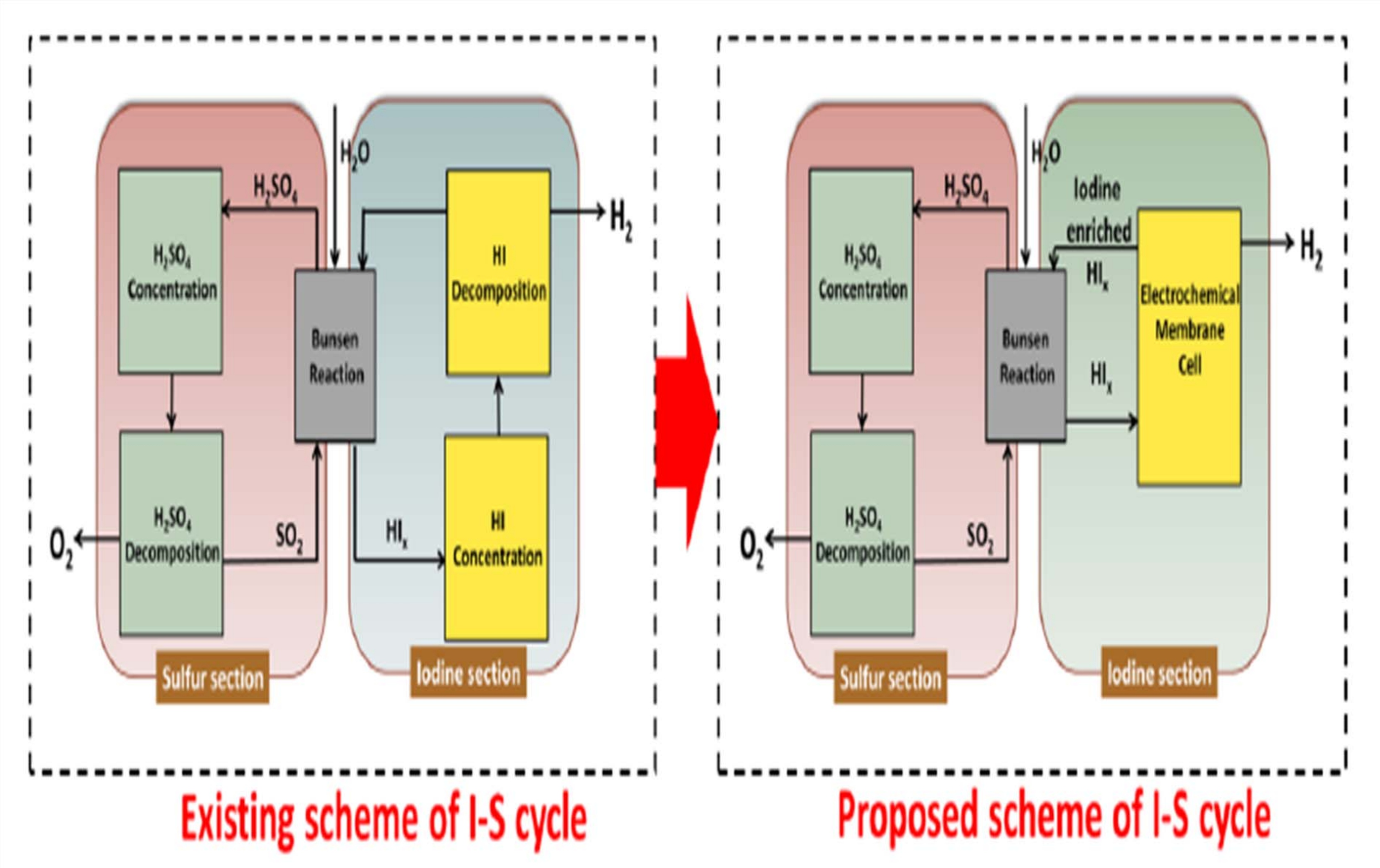
# New generation Sulfur recovery process is a value addition to Refinery



# New Initiatives

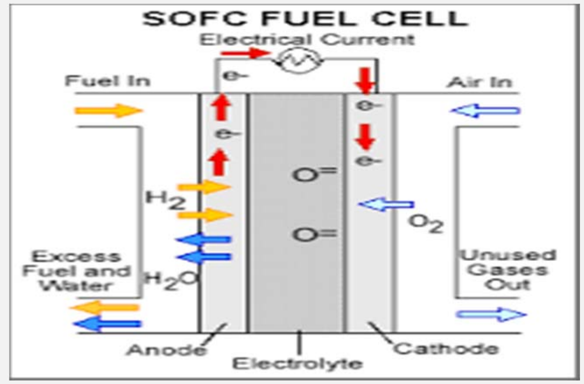
# New Initiatives: Alternate Approach in HI section

**OEC and BITS-Goa have initiated work on** Electrochemical decomposition of HI, an alternate route to HI section in I-S cycle

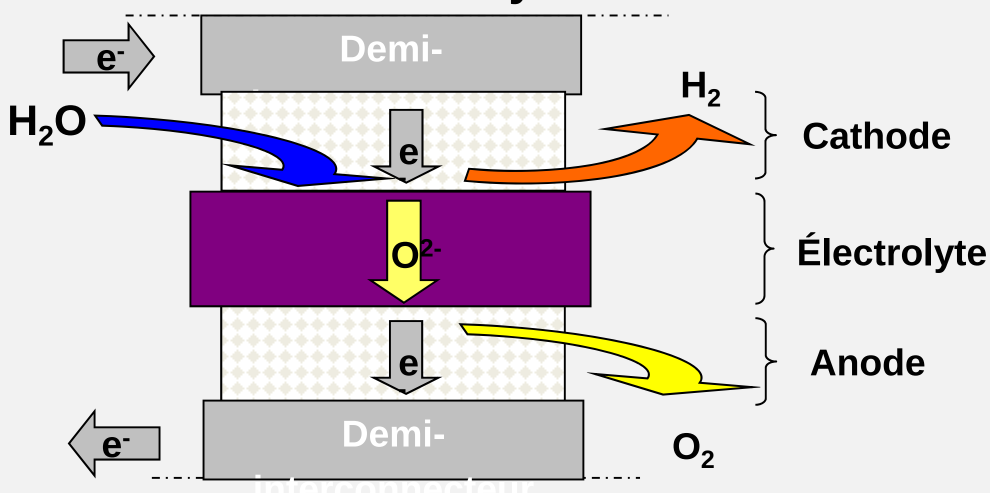


# New Initiatives: Development of SOFC

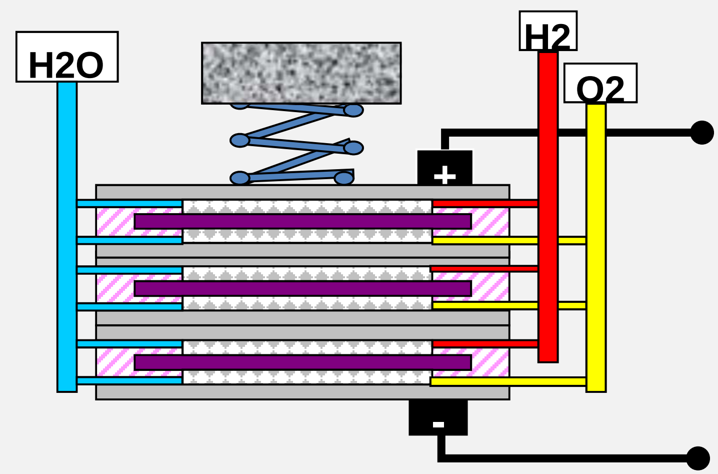
OEC and CGCRI have initiated work on "LSCF-based novel composite cathode, Fabrication of SOFC short stack using single cells to try on 3kV cell"




**From elementary cell …**




**to a stack**




**Cell : tri layer ceramic 200-300µm, where electrochemical reactions occur**

**Interconnector : metal distributing electrons and mechanical support**

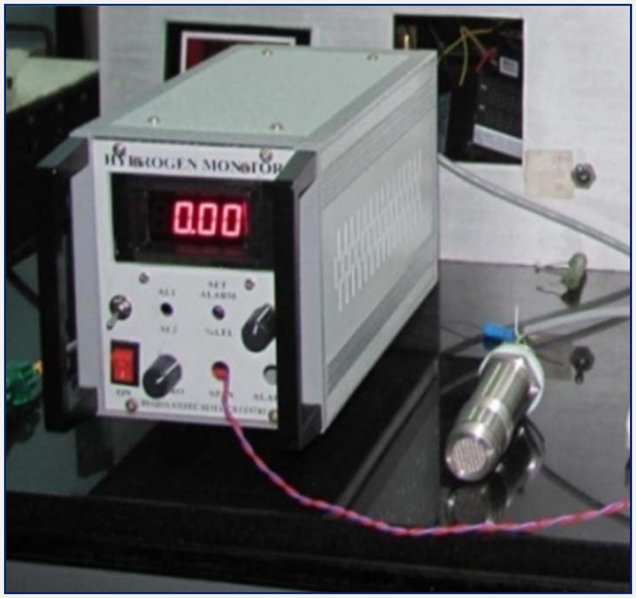
**2 main difficulties : Ceramic metal assembly**

**Leak tightness**

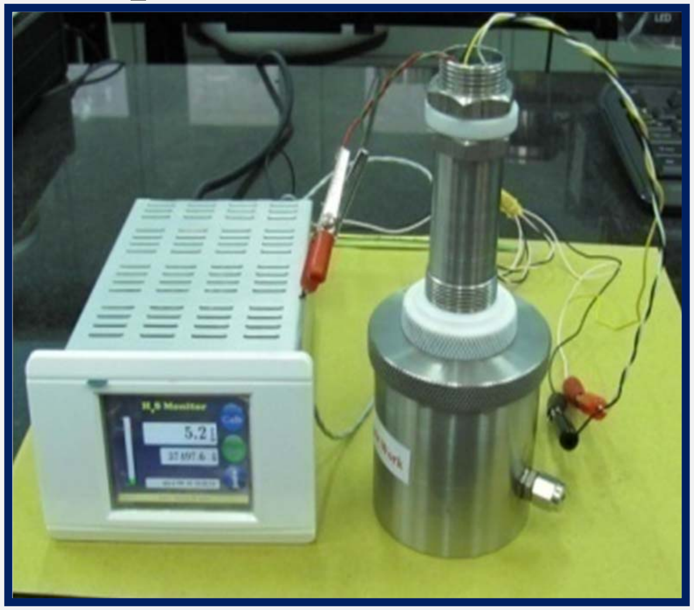
# New Initiatives: Development of Sensors

**Sensors Development:**

- **OEC in association with BARC has initiated development of sensors for $H_2S$, $SO_2$ for application in various ONGC Assets.**
- **At ONGC-Uran plant, preliminary studies on sensor testing are encouraging.**
- **OEC is in the process to develop $H_2$ and $Cl_2$ sensors with IGCAR.**

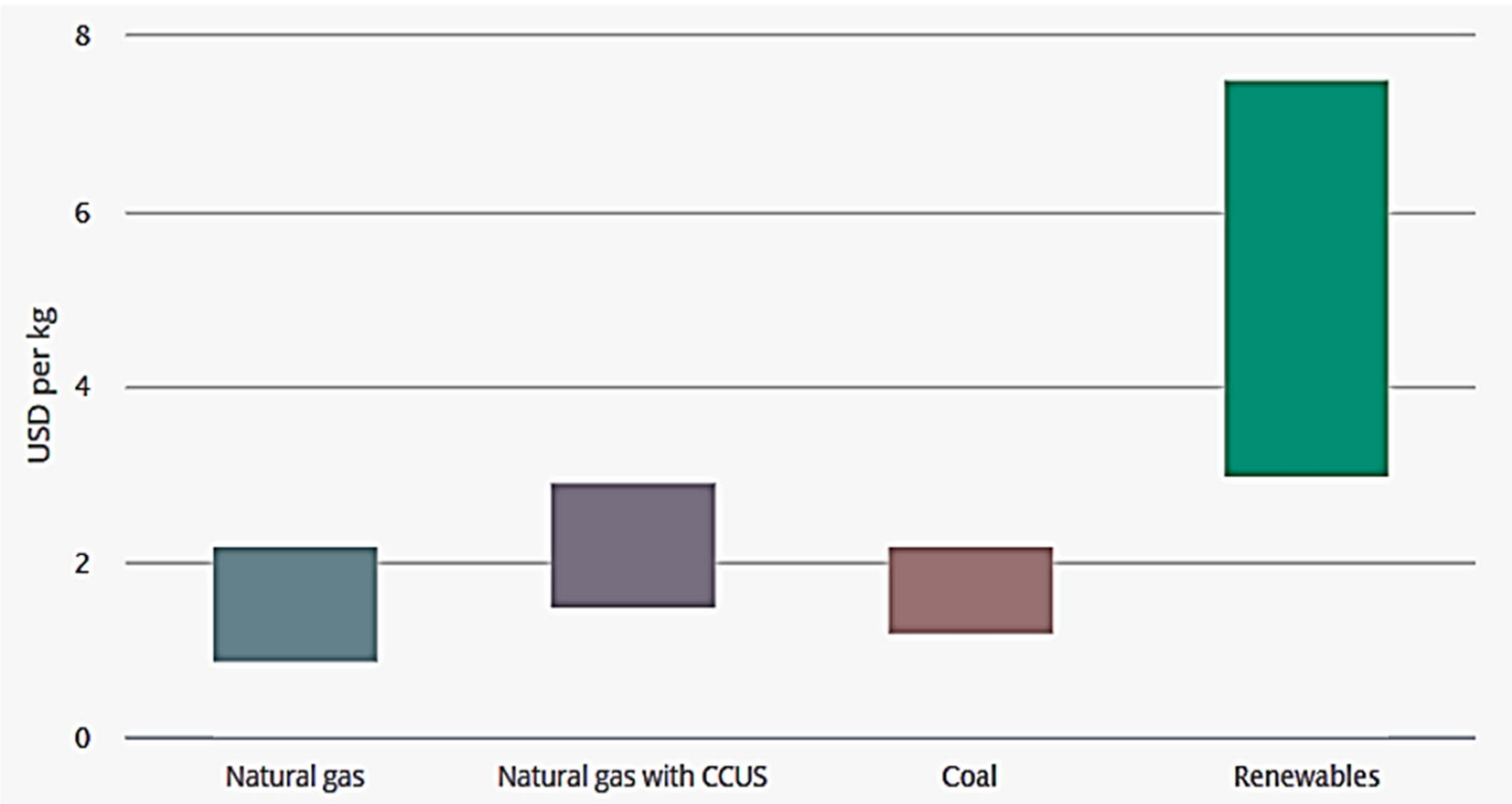



**$H_2$ sensor based on Pd films on Pt-100**



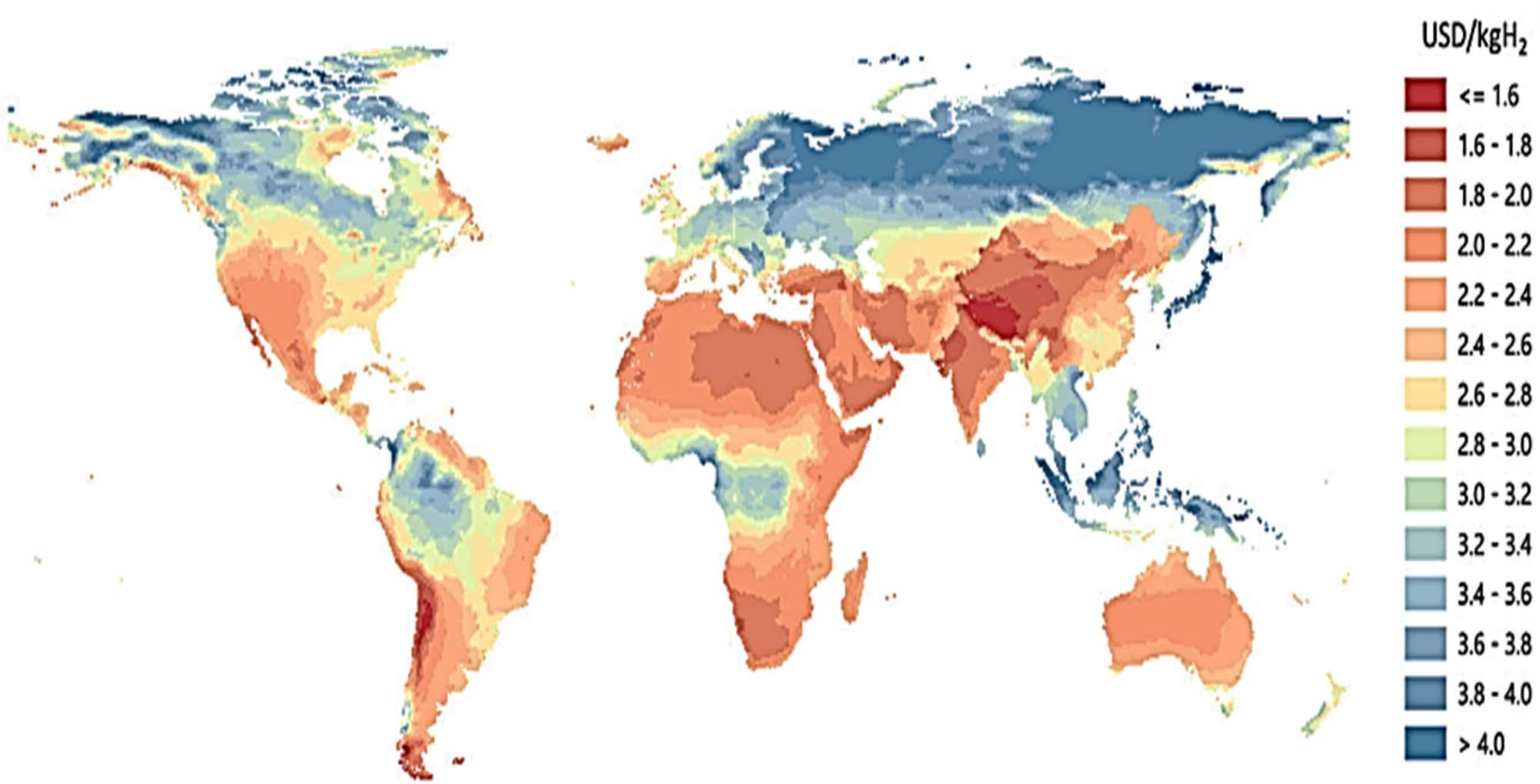

**$H_2S$ sensor based on $SnO_2$: CuO thin films**

# Hydrogen Production Costs, 2018




*Ref: IEA*

# Hydrogen costs from hybrid solar PV and onshore wind systems in the long term




Pic: IEA

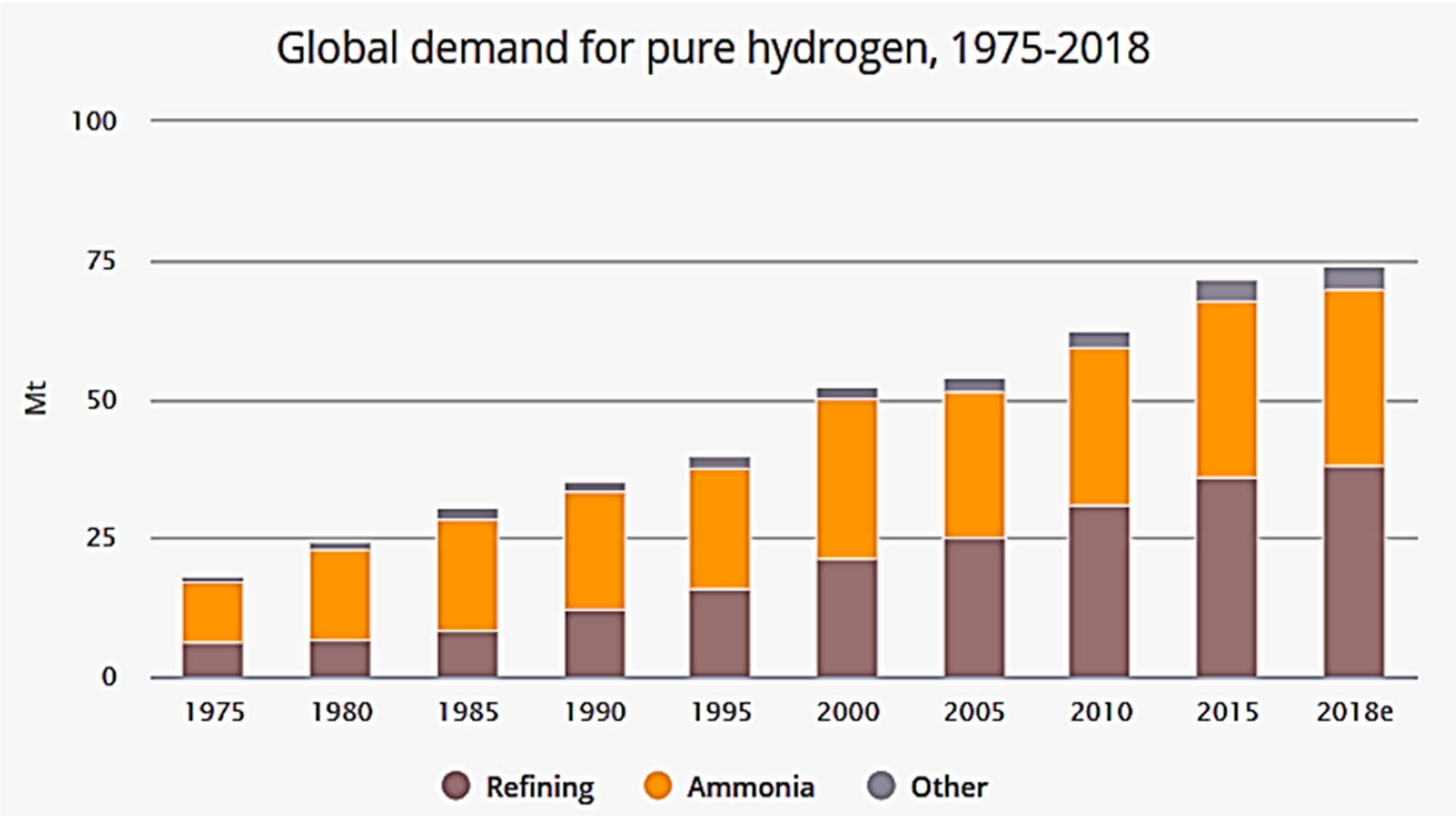
# Conclusion

- World is gearing up for meeting imminent energy transition in middle of this century with the help of renewables where water and hydrogen are the lead players.
- Hybrid Thermochemical water splitting processes are attractive green technology options for large scale production of Hydrogen.
- Electrochemical applications play vital role in reduction of energy consumption in the Thermochemical cycles but issues related to integration and continuous operations need to be worked out.
- OEC in association with partner organizations have developed Internationally Patented Thermochemical water splitting process based on indigenous equipment and facilities, membranes, catalysts, etc., working on further scale up.
- Possibility for reduction in operating temperature of I-S process with alternate approaches using electrochemical routes in processes, material challenges are addressed at present.
- Demonstration of Integrated Hydrogen Production facility comprising of Concentrated Solar Thermal Power Plant, Molten Salt Storage and Closed Loop Cycle for Thermochemical Splitting of Water, at a pre-pilot level capacity of about 12 MT/day at ONGC-OEC premises in planning.

# What is the long term future?

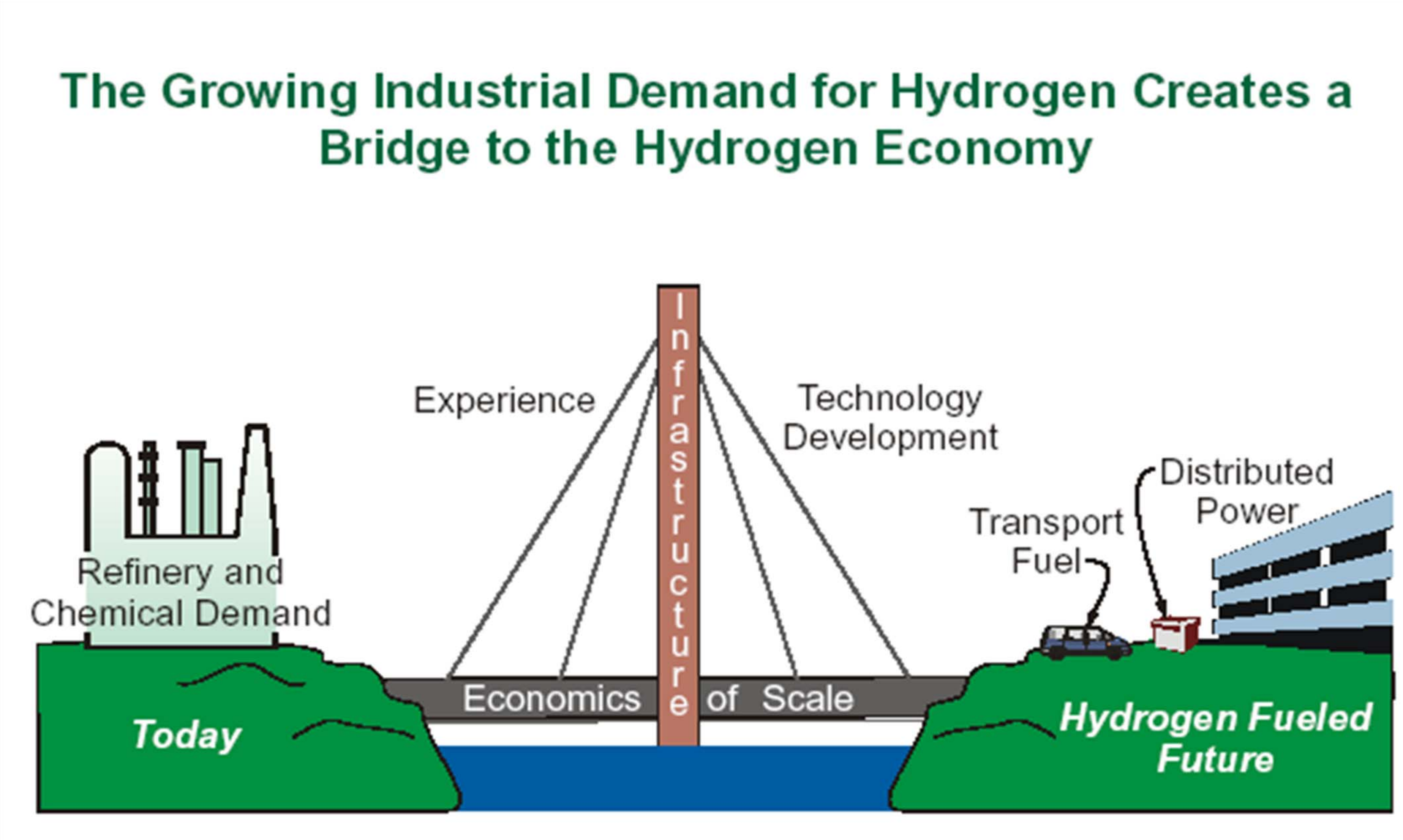

# Thank You !

# Demand for Hydrogen




*Ref: IEA*

# Hydrogen


The Growing Industrial Demand for Hydrogen Creates a Bridge to the Hydrogen Economy
Experience
Technology Development
Infrastructure
Distributed Power
Transport Fuel
Refinery and Chemical Demand
Economics of Scale
Today
Hydrogen Fueled Future