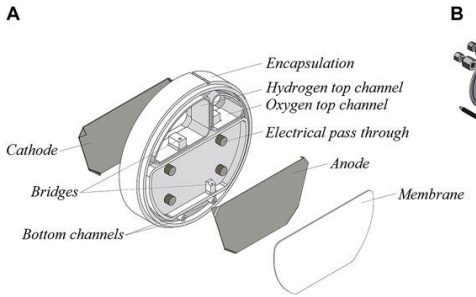
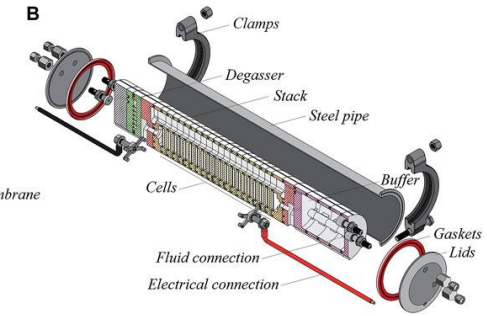
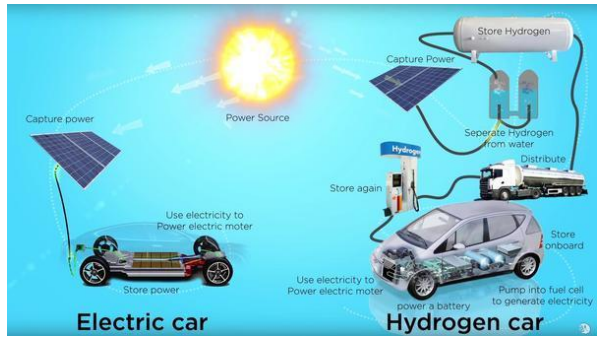
Energy Transition and Green Hydrogen Economy for India

This will demand unprecedented speed and funding







Any transition is toughest, but energy transition is the most difficult one as it touches every aspects of human activity. And when new transition is technology centric, then getting it "Right The First Time" is always questionable. Needs enormous wisdom and public acceptance.

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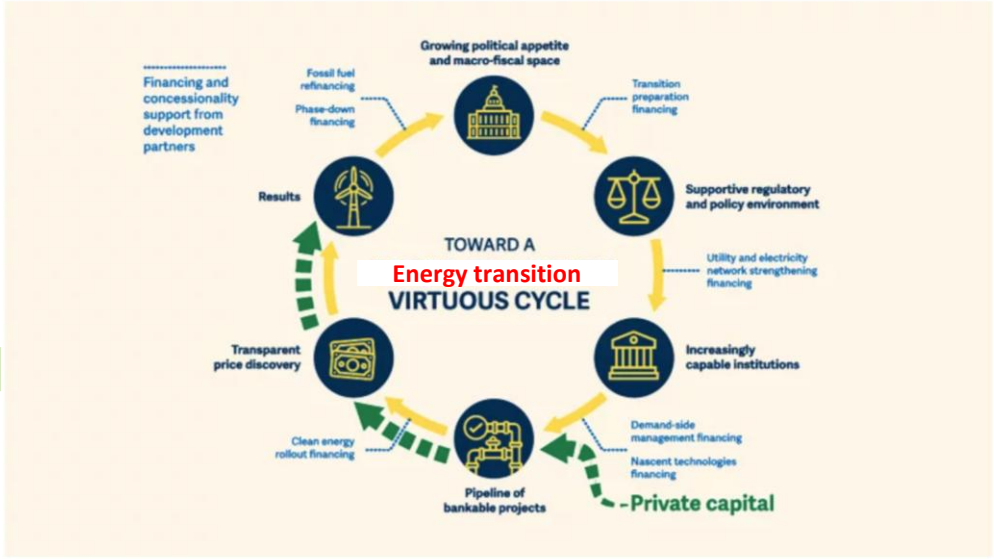
Invited talk on 14 September 23 , N. Delhi

Energy transition means different things to different nations. This is critical in the mult-lateral dialogs

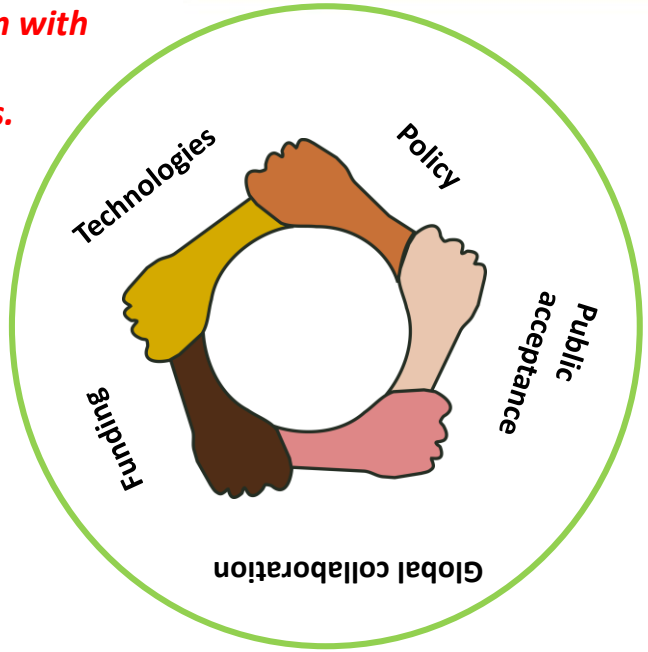
India grows say at 8% the economy will be 30 Trillion $ *(and this no one can deny)* managing energy transition needs multiple strategies.



Less developed nations: can start with new zero emission / clean technologies

Developing nations and the ones at high growth phase, need to manage the existing mid aged assets while building new assets with zero emission technologies

Developed nations and with their assets nearly aged, replace them with modern technologies.

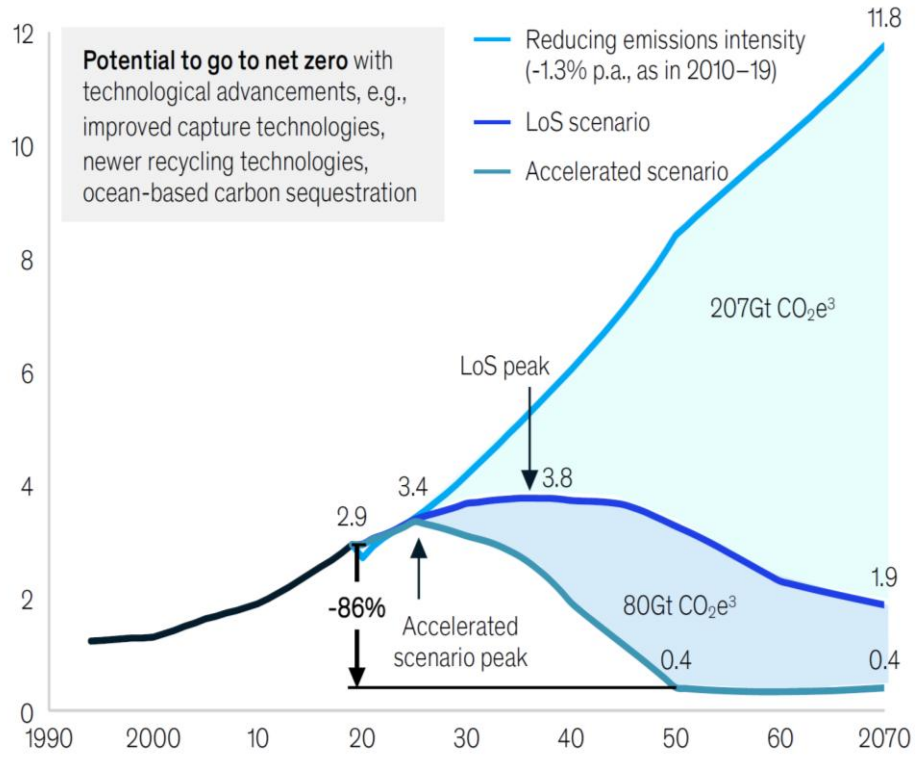


Common but Differentiated: Hence no single solution fits all proposed by many pundits

Energy transition and Net Zero: The eight-plus one-pillars for India, the fastest growing economy

India's GHG emissions[1]

$GtCO_2e$ per annum[2]



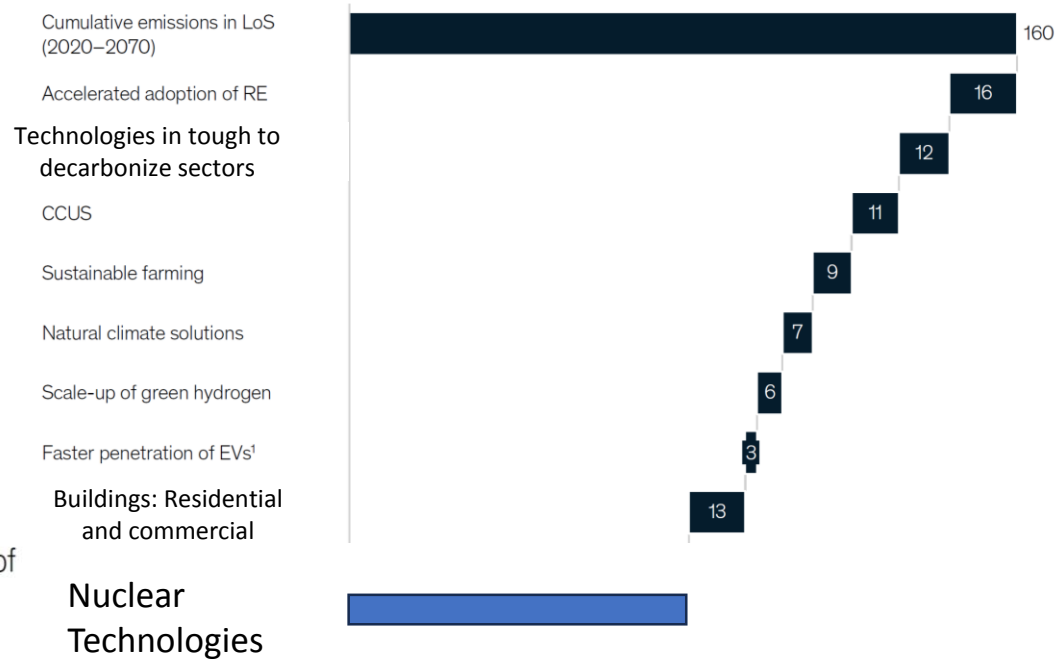
LoS scenario

- **Implementation** of India's NDC, existing and currently announced policies
- Technology advancement as current trajectory
- Shift in demand to sustainable alternatives in selected areas, e.g.

Accelerated scenario

- Adoption of **new policies** such as carbon pricing
- **Technology breakthroughs,** e.g., CCUS and faster implementation of existing levers
- **Accelerated shift** to sustainable consumption, e.g., EV, alternative materials, coarse cereals, green steel

Cumulative emissions reduction between LoS and Accelerated scenarios, 2020–70, $GtCO_2e$



If we get the above right – the eight plus one -pillars- I think India can be leading light to Globe

Hydrogen is capable of meeting energy access challenge in India. Both central and distributed hydrogen for India will enable energy access to all. India way!

Million TPA to Thousand TPA hydrogen plants

- Solar
- Wind
- Fossil (coal)
- Water (source of hydrogen)

Electricity from Renewable with storage

Hydrogen from renewable energy

Hydrogen from fossil (coal) / nuclear / hydro

CCUS block

3125 TWH RE
9375 TWH others

Electricity (T&D)

3125 TWH (62.5 MTHA)

9375 TWH (187.5 MTHA)

Hydrogen / Hydrogen carriers (storage +transport)

- Industry
- Transport
- Agriculture
- Buildings
- Water and Wastewater

3000 TWH (60 MTHA)

Biomass and distributed renew electricity and hydrogen

Transforming the five pillars: The Current Devices and Technologies

Industry
Electricity
Heating & Cooling
Input raw materials

Transport
ICE/
Jet
engine

Buildings
Electricity
Heating & Cooling
Cooking

Fossil as RM
Steel
Cement
Fertiliser & Petrochem ical

Agriculture
Electricity
Heating & Cooling

Fossil Power Plant

Fossil Boilers for Industry

Fossil Transport

Fossil Steel Chemical Complex

Fossil and inorganic cropping

Transforming the five pillars: The Future Devices and Technologies

Industry
Electricity
Heating & Cooling
Input raw materials

Renew & clean fossil Power Plant

Transport

ICE/
Jet
engine

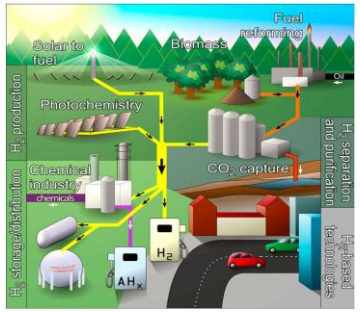
Hydrogen boilers

Buildings
Electricity
Heating & Cooling
Cooking

Hydrogen / battery Transport

Fossil as RM
Steel
Cement
Fertiliser & Petrochemical

Decarbonised steel / cement

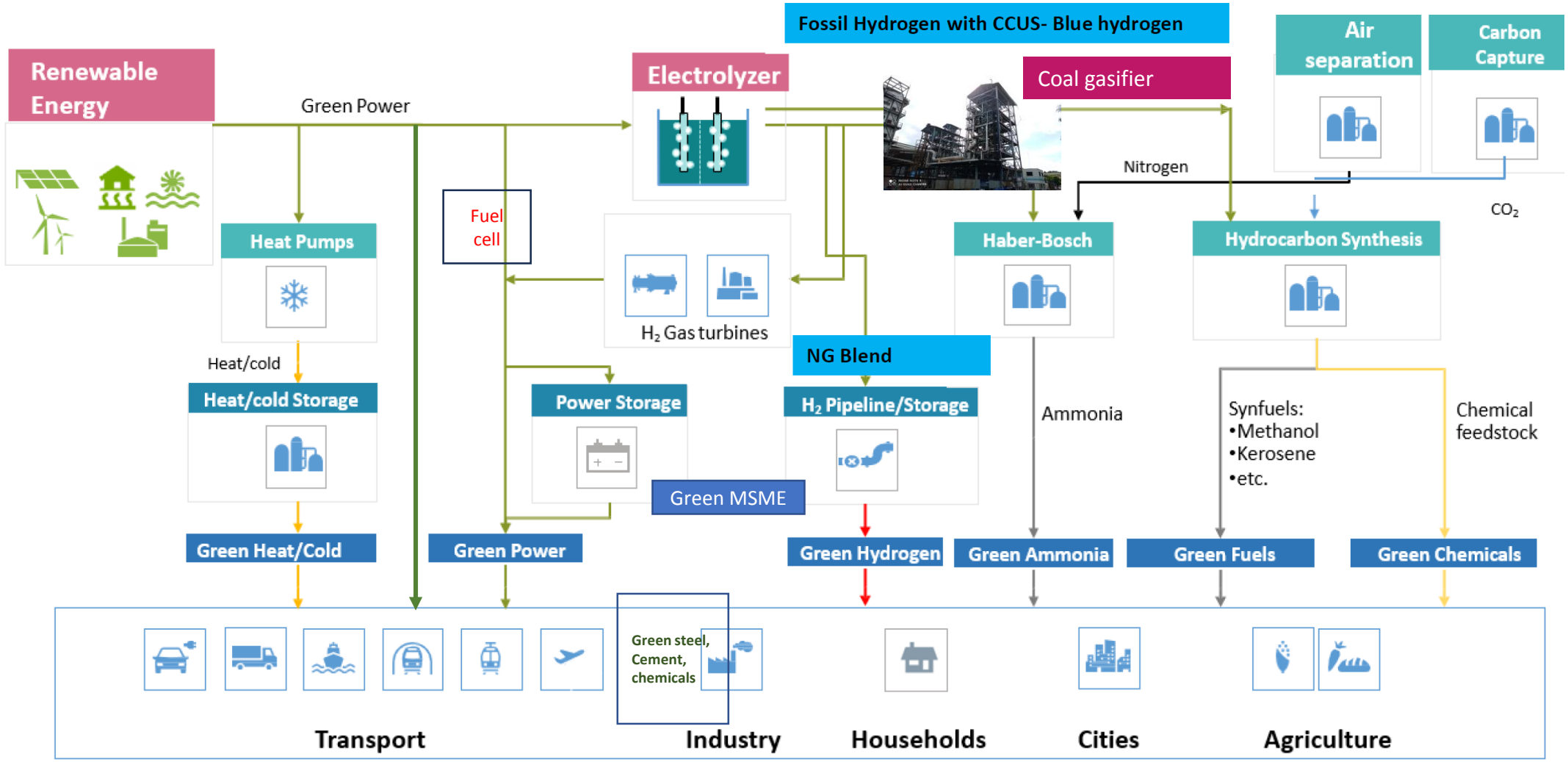


Agriculture
Electricity
Heating & Cooling

Green Aggriculture

This is Hydrogen Map for India: It touches every sector!

Hydrogen map:



Green hydrogen economy: What should be the correct cost of hydrogen and how do we get it?

As hydrogen is an energy carrier and not a primary source, cost of hydrogen is the most critical aspect

A kg of Hydrogen carries 33.2 kWh of energy

At 1 kWh energy level,

Coal energy costs 0.6 ₹/kWh, Natural gas costs 3.0 ₹/kWh, Nuclear fuel costs < 0.1 ₹ / kWh at fuel cost level.

And if we produce hydrogen from water via renewable energy the current cost of hydrogen converted to energy is 25 ₹/kWh.

Strictly this comparison is not OK. We need to build CO2 into this analysis. Assume we account say 100 $/ton of CO2 or 8.2 ₹ / kg of CO2, then the coal cost will be 9₹/ kWh, NG 8₹ / kWh.

The green hydrogen economy is not 1-1-1 slogan of one $ in one decade for one kilogram or such similar lofty statements.

Hydrogen to be examined from energy conversion angle. Often ignored in analysis!

Example: Coal delivering transport electricity vs. the same coal delivering similar energy via hydrogen.

Coal combustion to power	Power transmission and distribution	Battery driven EV
35%	90 %	85%

For a 1 kWh transmission needed at the vehicle end, the generation end power and coal energy will be 3.57 kWh. (35% power plant and 80% other losses)

Coal gasification to hydrogen	Hydrogen transport	HFC based e-mobility
80%	95%	70%

For a 1 kWh transmission needed at the vehicle end, for HFC the coal needed for gasification is just about 1.78 kWh. (95% gasification and 60% HFC)

This needs to be understood why coal – hydrogen becomes a low CO2 emission system. And we can then make it zero emission by CCUS.

So, my submission is that while green hydrogen is a good plank to focus on, but the policy should not exclude other hydrogen generators.

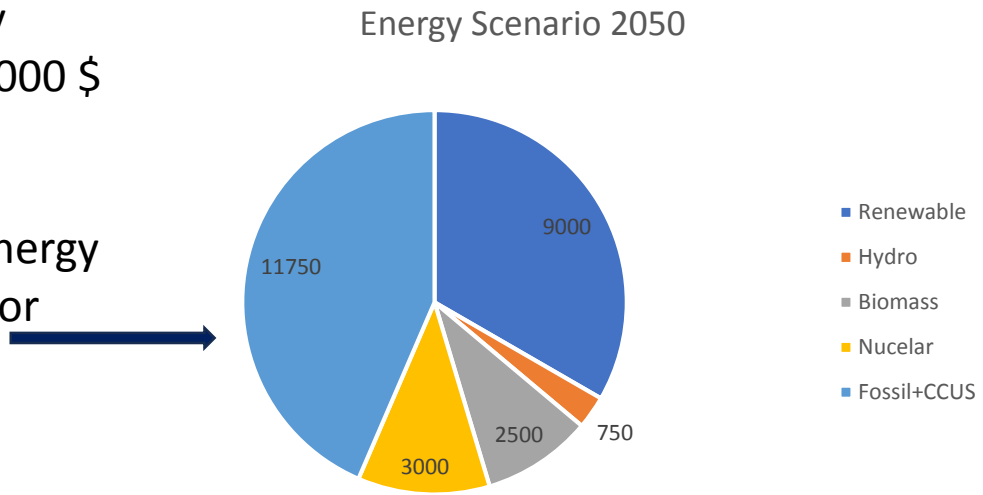
- Coal gasification to hydrogen or low carbon fuels and materials
- SMR - steam methane reformation
- Nuclear hydrogen

And this can bring scale and hydrogen use quickly in the eco system.

What & how on hydrogen value chain? Setting the scene..

1. India today consumes 10,000 TWR primary energy mainly fossil supporting a 3.5 Trillion $ economy. This will grow to 28,000 TWH by 2050 when economy grows to a 27 Trillion (per capita income at 18,000 $ will mean a decent HDI) Nearly 9-fold growth!

2. 28,000 TWH energy (which includes energy in material) for India's energy independence and net zero pathway, would mean count on five major sources of energy. The adjacent chart shows the sources and their magnitude.



3. Ultimately, the clean energy carriers will be electricity (wired energy) and hydrogen (road, train and ship) or its carriers – discussed later.

4. Even at 50:50 ratio, the need of hydrogen per year will be 250 Million Tons! And that is the magnitude of hydrogen economy. So, a 5 MT by 2030 as per our current mission program, hydrogen will grow at 20 percent YOY basis to meet the above demand

India has four commitments:

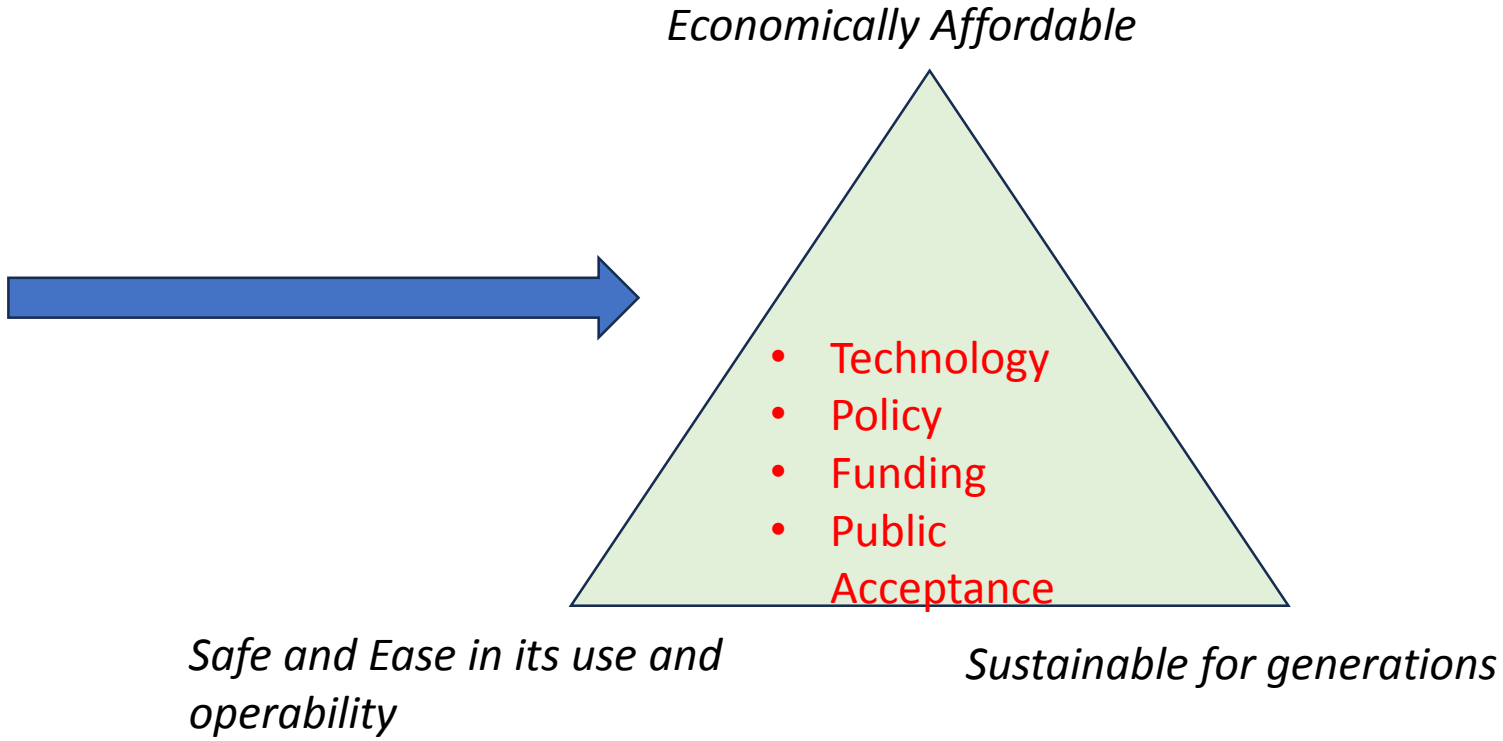
- *Energy Independence*
- *Economic Development*
- *Climate change and Clean Air*
- *Energy Access*

Two major criteria for this to succeed: One cost of hydrogen and second is safety!

We need quick demonstration of entire value chain in hydrogen:

In any transition, the society demands that such a transition is sustainable for generations, economically affordable, and is entirely safe in its usage.

The HVIC- hydrogen valley innovation centre in a particular geography attempts precisely to meet these three objectives. This gives enormous confidence to the common people that hydrogen is a dependable carbon free energy and material.



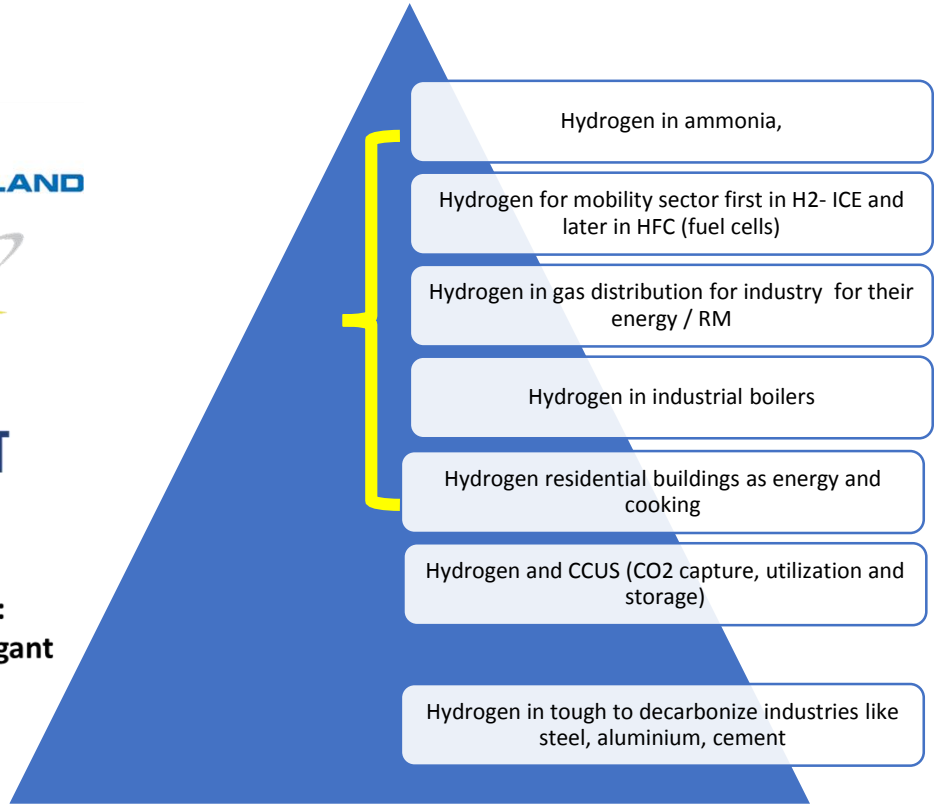
Demonstrating this at some scale – the complete value chain – is the main purpose behind the hydrogen valley innovation centre – HVIC for India explained later.

The glimpse of HVIC – Jodhpur

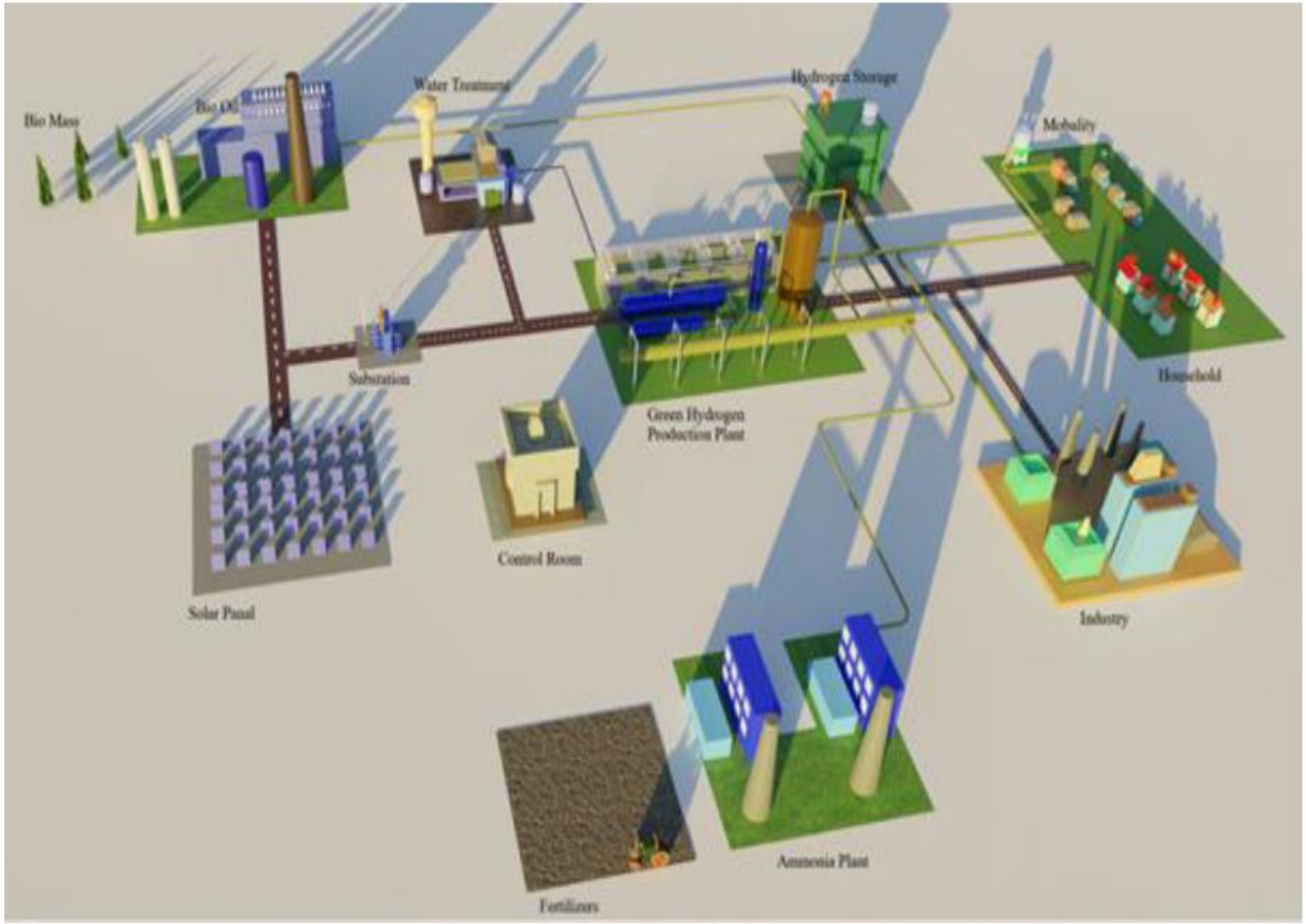
- **300 TPA H_2 production**
- **~10 MW RE requirement (without storage)**
- **~3 MW Alkaline Electrolyser (~80%CUF)**
- **1500 TPS ammonia**
- **15 TPA Bio hydrogen**
- **H2-ICE**
- **H2-CNG**
- **H2-Boilers**

The network: Unique in its creation

Hydrogen usage pattern at Jodhpur: A complete value chain



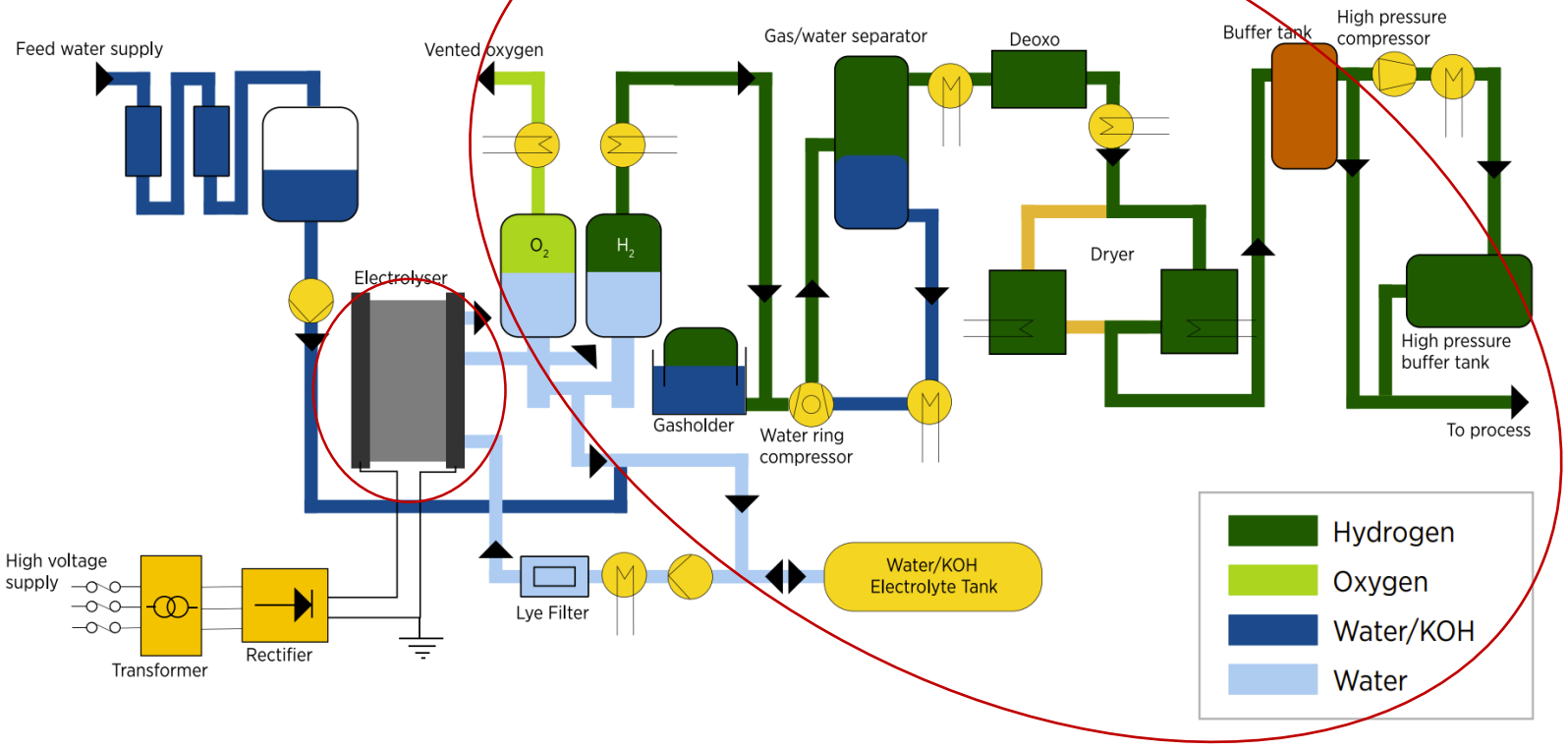
A Unique Concept: HVIC Jodhpur



All elements in hydrogen valley system being integrated in a first-of-a-kind scenario.

Water Electrolysis: Great rush globally. Need to begin at SYSTEM level and then go down to cellular level : BOS balance of system is the cost determining step.

Typical system design and balance of plant for an alkaline electrolyser.



Note: This configuration is for a generic system and might not be representative of all existing manufacturers.

Based on IRENA analysis.

The 40:30:30 paradigm from System: Stack: cell cost reduction strategy.

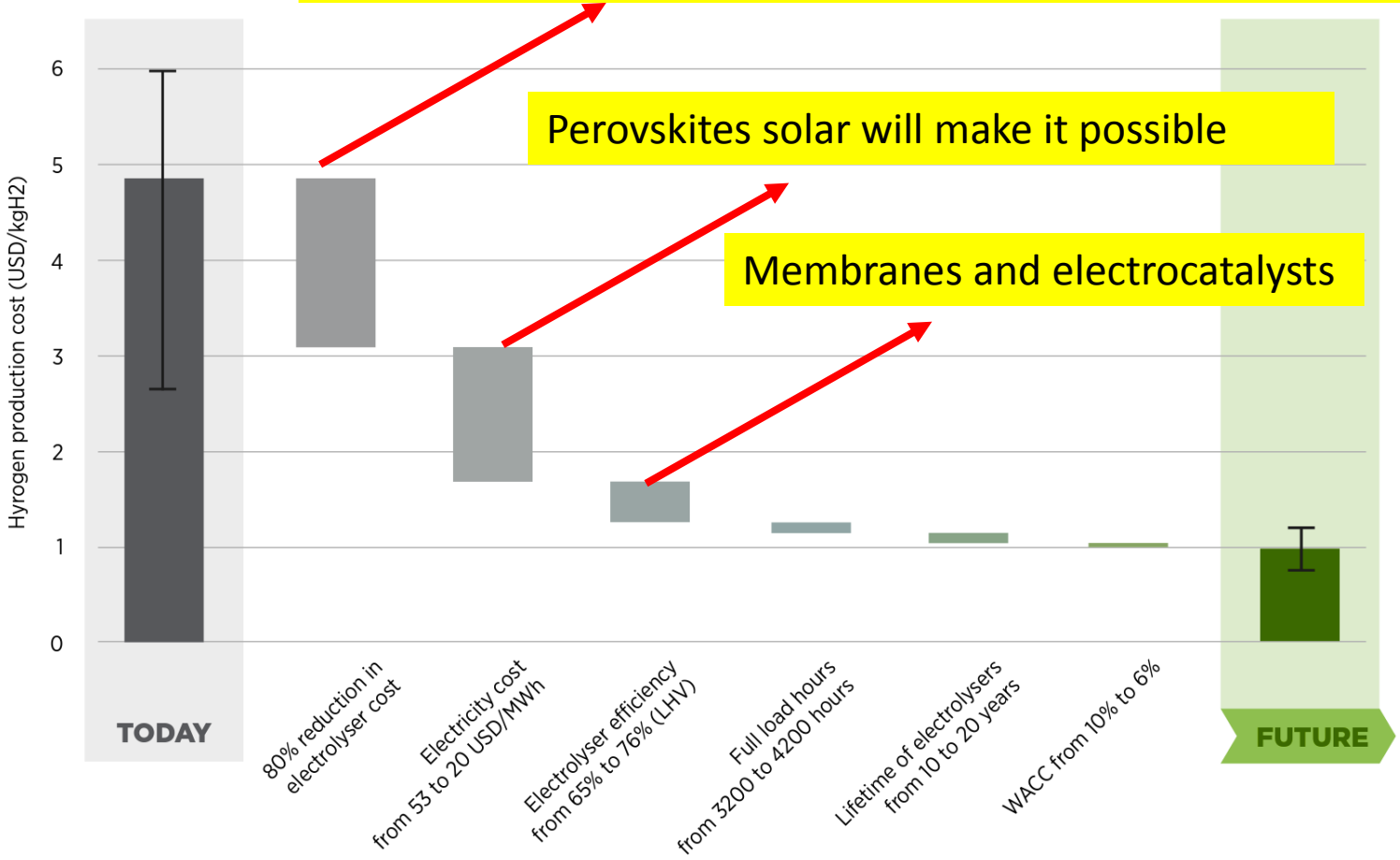
This kind of works so well in all this.

So, reduce from current cost of 2000 $/kW to 200 $ / kW requires 40:30:30 strategy.

Applied R&D and Industry has to invest in this.

R&D at all levels

Attempting to push ASM (ampere per square meter say at 12000 level. Eminently possible!



Note: 'Today' captures best and average conditions. 'Average' signifies an investment of USD 770/kilowatt (kW), efficiency of 65% (lower heating value – LHV), an electricity price of USD 53/MWh, full load hours of 3200 (onshore wind), and a weighted average cost of capital (WACC) of 10% (relatively high risk). 'Best' signifies investment of USD 130/kW, efficiency of 76% (LHV), electricity price of USD 20/MWh, full load hours of 4200 (onshore wind), and a WACC of 6% (similar to renewable electricity today).

Based on IRENA analysis

Need to prioritize the focus of our development with cost as main target

Tradeoff between efficiency and capital cost. Definitely reduction in capital cost is more dominant.

Salient features of HVIC at Jodhpur

1. Cheapest hydrogen due to its location in Jodhpur and design of the system to use the on-site soalr power 24*7 and a innovative power electronics to maximize the generated solar energy. Cost is under 272 Rs/kg.

2. Indian technology for manufacturing ammonia at skid scale based on in-house design. The cost of ammonia will also be the cheapest

3. Hydrogen storage, compression (at different levels) and dispensation system design

4. H2 ICE bus for full scale demonstration in mobility sector

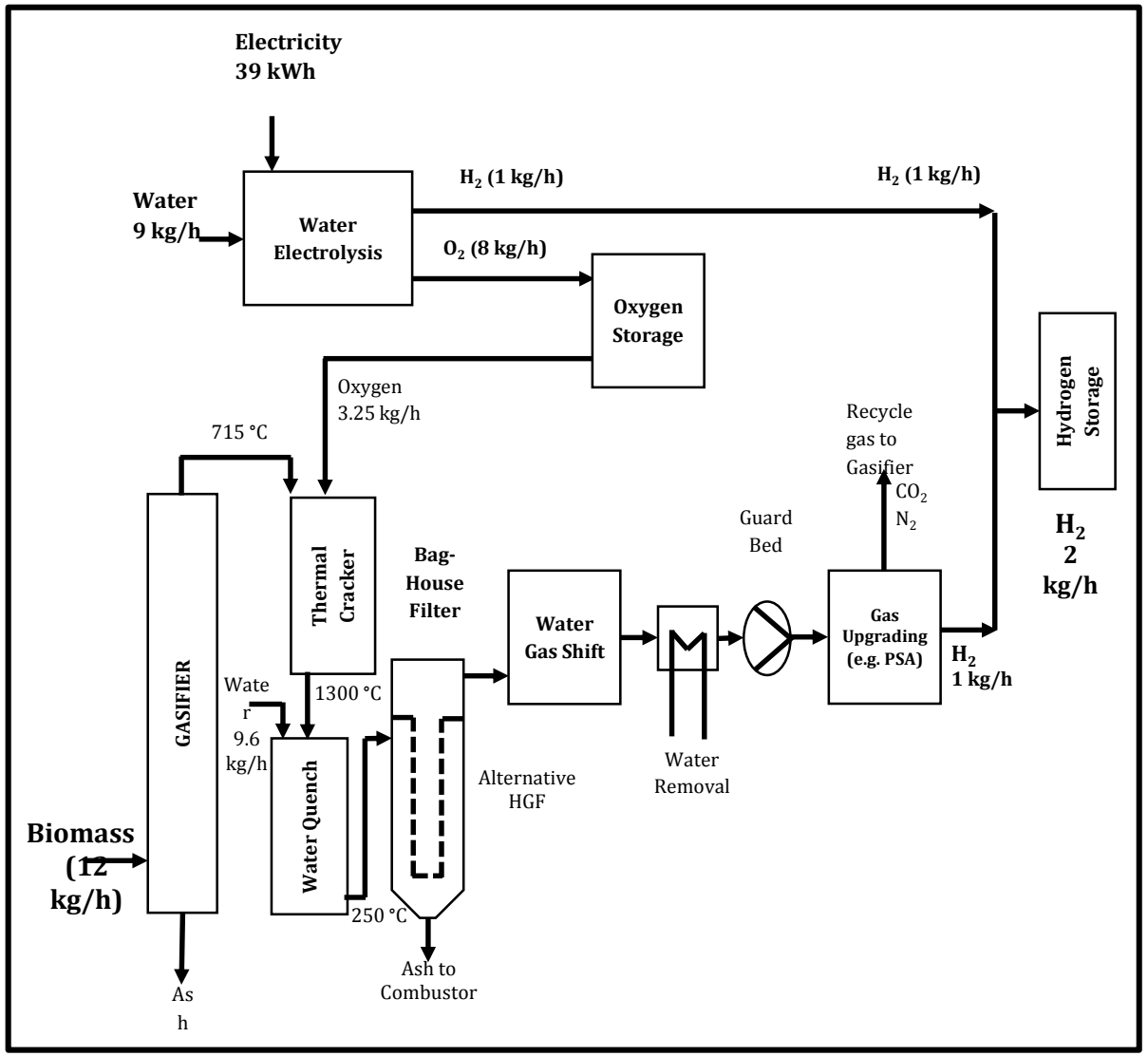
5. H2 as CNG blend for industrial use of hydrogen as energy

6. Ammonia to hydrogen for industries as energy and raw material

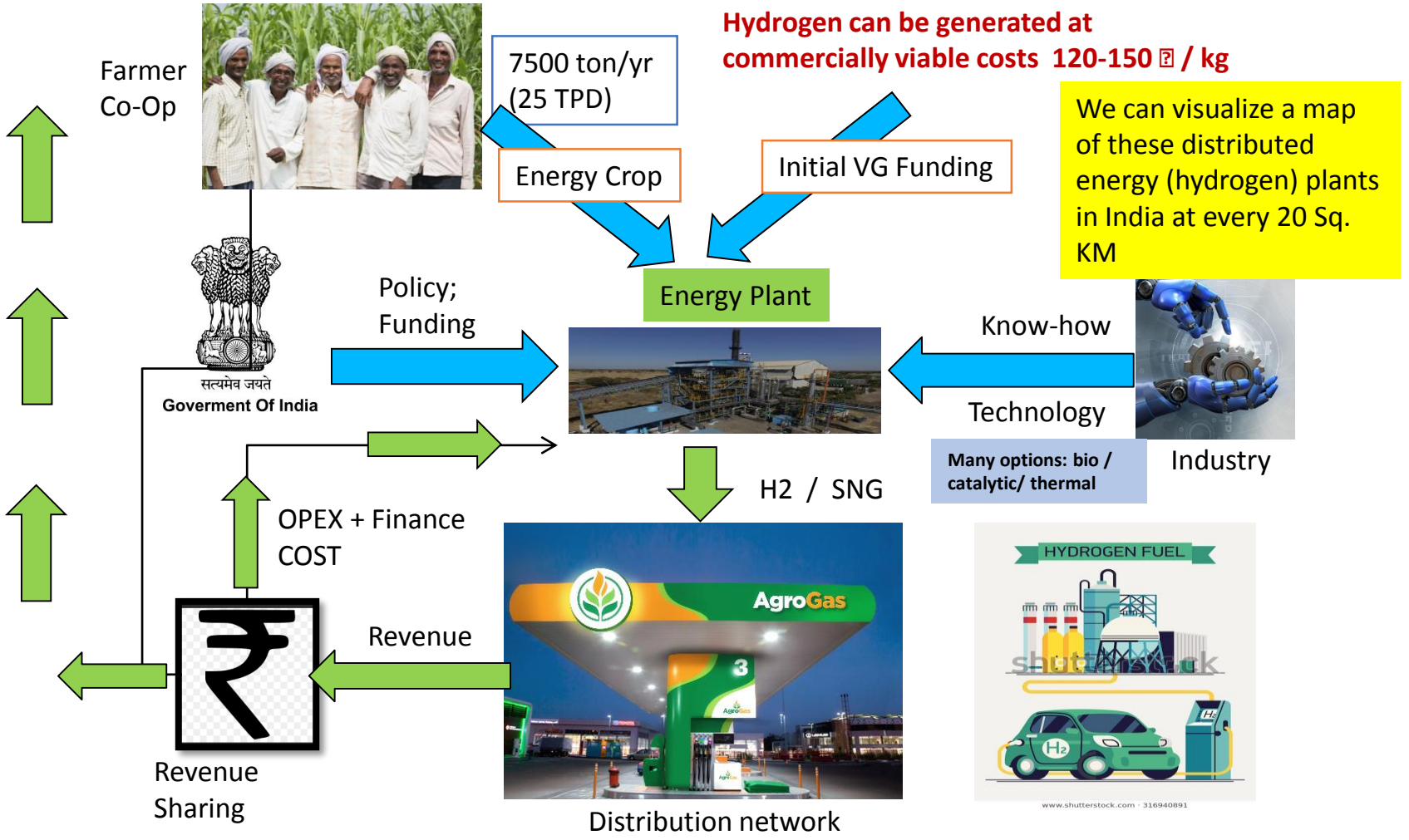
7. Ammonia-Hydrogen-Fuel cell combination to replace diesel and DG sets

Another innovation. Biomass to Hydrogen another potential for India. Distributed Hydrogen. We need to give a big push on this for India.

Several such small plants will be built based on this technology



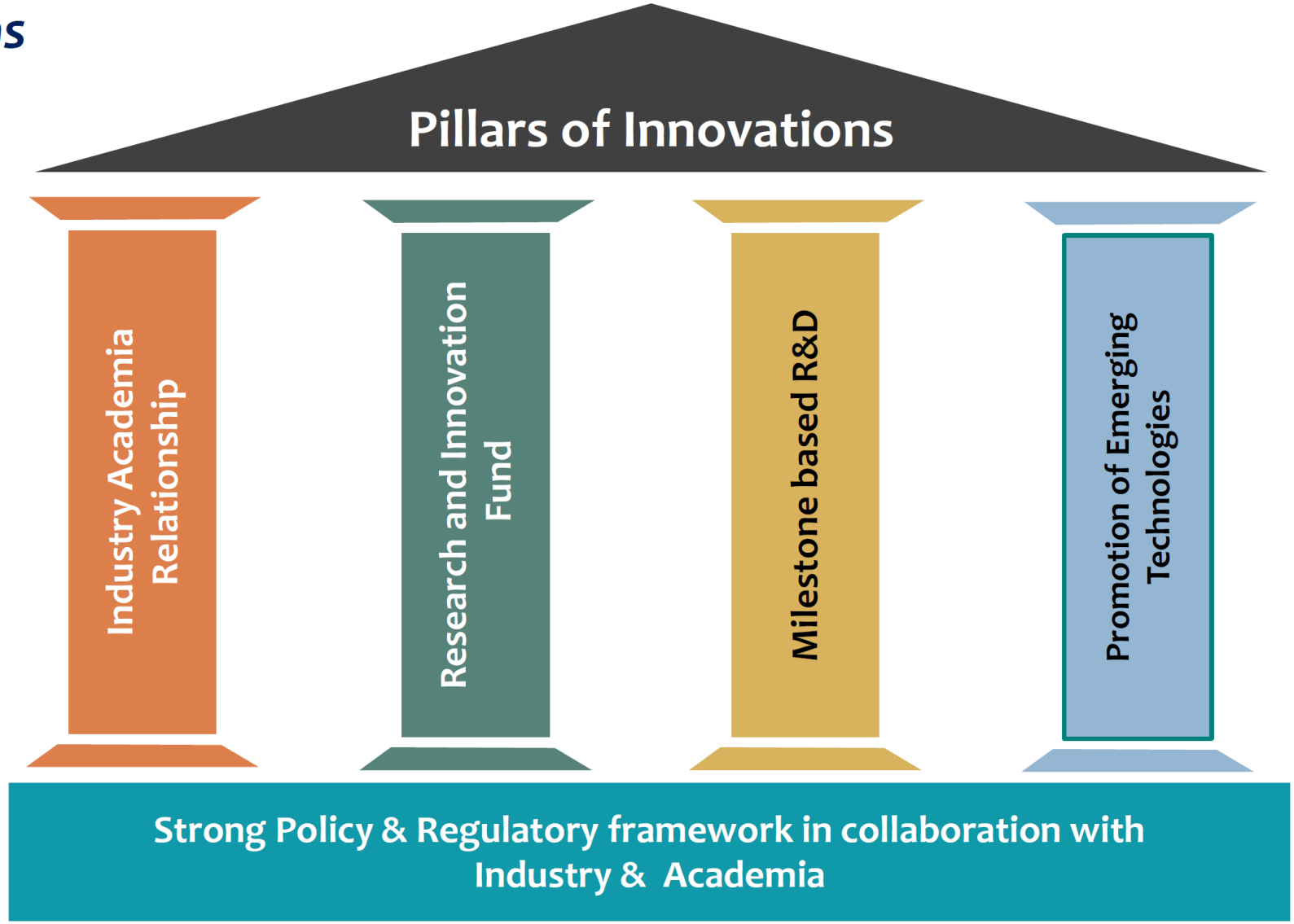
Distributed Hydrogen Plants with Local Energy Network: Hydrogen to bring prosperity to the lowest common denominator



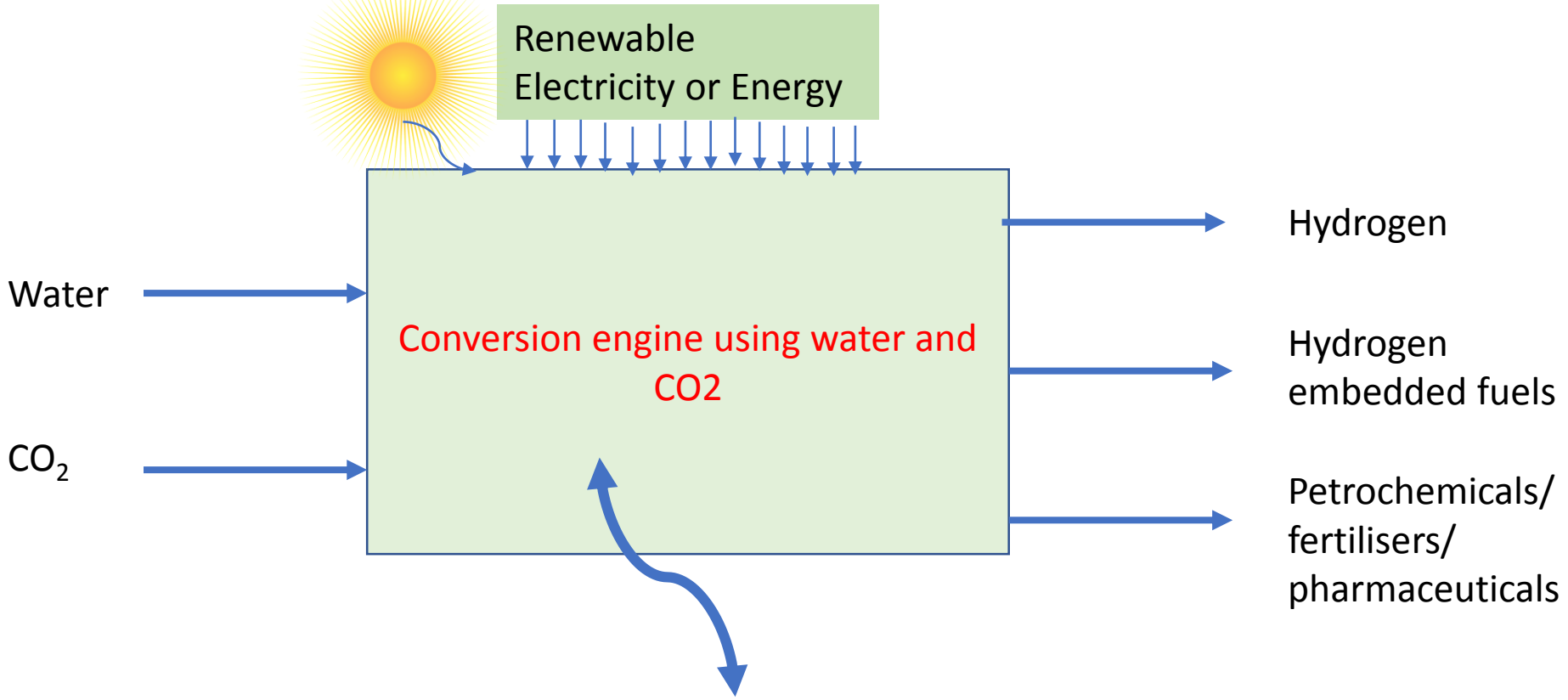
Agricultural residue as a valuable source of energy and technologies to convert them to demand side needs

Energy transition and Hydrogen economy is transformational and need innovations all the way!

Pillars of Innovations



Big Ideas in R&D, Have a think: Hydrogen has been a primordial element and if we can only mimic nature with accelerated process! Bio-Nano-Photonics are the triumvirate in this.



Many devices for this conversion from water electrolysis (WE) to SOEC to non faradic electron assisted conversion pathways

There are many intermediate milestones to be reached…

LET THE WISDOM PREVAIL ……..