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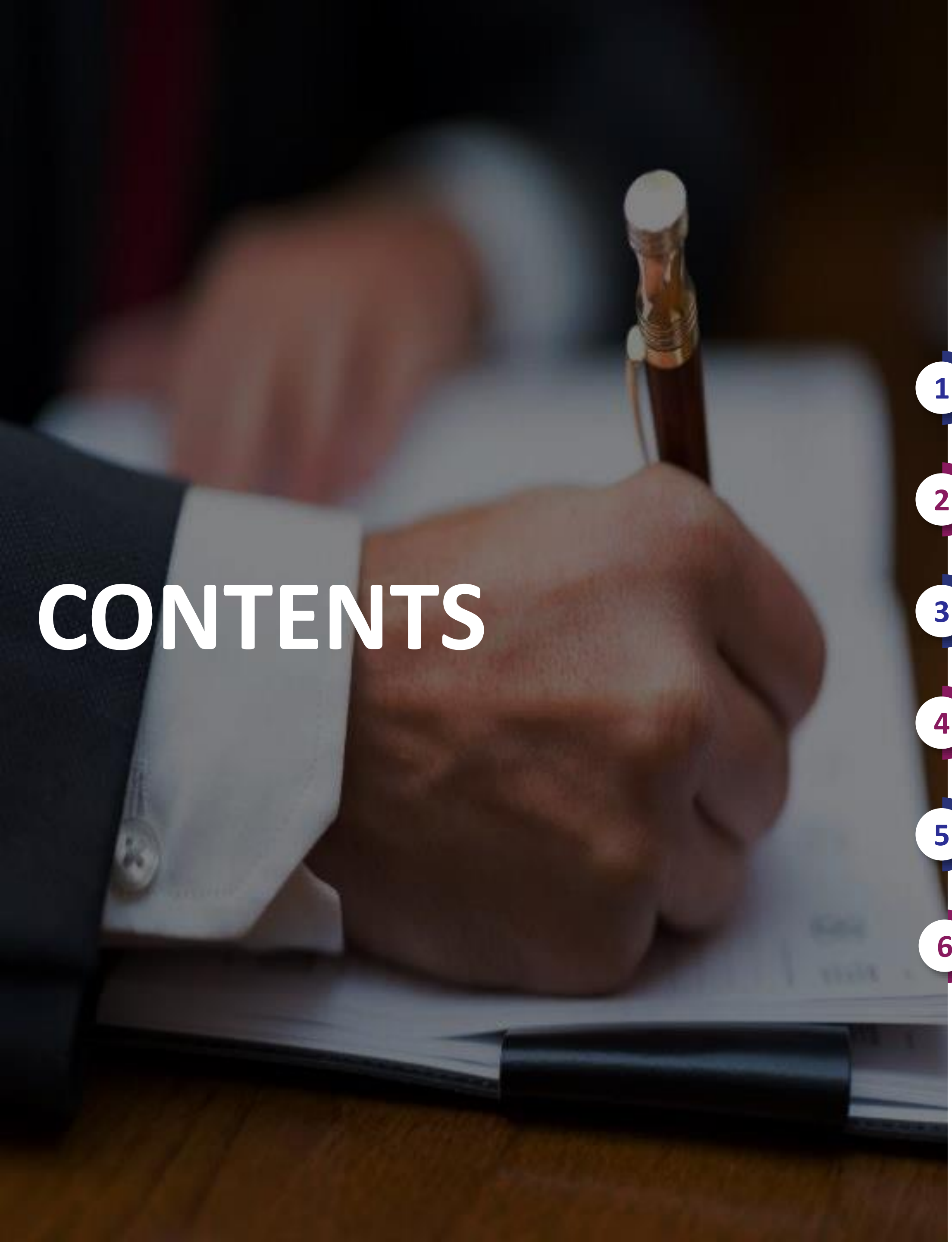
REPORT ON GREEN HYDROGEN

THE H_2ERO OF NET ZERO?

16 DECEMBER 2024



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EXECUTIVE SUMMARY

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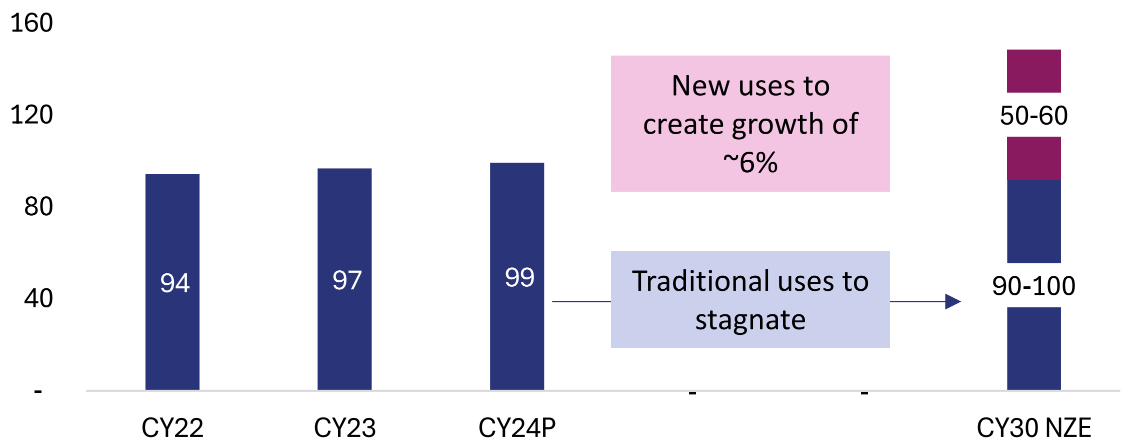
Increased usage of hydrogen essential for deep decarbonisation in hard to abate sectors
A typical method of greening a sector is to replace the energy source with electricity and then sourcing that from renewables. However, this technique fails in cases where greenhouse (GHG) emissions are released as part of the use of a material as feedstock. Some examples include the use of coke as a reducing agent for iron which releases CO_2 and the use of H_2 in NH_3 production via Haber process (H_2 so used is produced using fossil fuels as of now)]. In these processes, usage of H_2 becomes essential to alleviate GHG emissions. It is estimated that the annual use of H_2 in India will go up from 5-7 mn tonnes currently to 15-20 mn tonnes by 2030
Growth in H_2 consumption depends on changing its colour from grey to green
Given the imperative for increasing the usage of H2 lies squarely on its credentials in reducing GHG emissions, a corollary is that the H_2 so used must be produced sustainably. Traditional processes to produce H_2 use fossil fuels and thus unsuitable. Green H2, which uses the electrolysis path and renewables, emerges as the solution. It must be remembered that the source of growth in H_2 consumption will be this greening – as traditional demand sources such as fertilisers and petroleum industry stagnate, a third of the demand by CY30 globally (total 150 mn tonnes) will come from new uses. Accordingly, 13% of the hydrogen use in India by 2030 will be from new sources (power, transport, residential and buildings)
High cost of green H2 the key constraint in increasing usage, more incentives needed to bring costs in line with grey H2
The cost of production of green H_2, at USD 3.4-12/kg is multiple times that of grey H_2 which costs USD 1-3/kg. The increased costs are attributable to the prohibitive cost of electrolysers (due to miniscule scale of production) and expensive electricity. While in India, green H_2 costs are expected to be at the lower end of the this range, additional reductions to the USD 2/kg mark will be contingent on waiver of power banking charges across states, more affordable storage, and reduction in GST for electrolysers from 18% to 5% to complement natural dips in their cost of production as scale picks up. Finally, access to cheap green finance will be pivotal in bringing parity between the colours of H_2
India has inherent advantages in green H_2 production, Green H_2 hubs and SIGHT schemes to crown this kingly position
Given its ample renewable potential and generous demand for fertilisers and petroleum (key end user industries), India is well positioned to be a leader in green molecule production – with possibility of even exports to Japan etc. Recognising this and keeping in mind net zero goals, the Government has announced the ambitious National Green Hydrogen Mission (NGHM) which seeks to achieve 5 mn tonnes per annum production of green H_2 by 2030. As part of this, multiple components of the SIGHT programme with a cumulative outlay of Rs. 175 bn have been launched. The schemes involve a clever mix of not only supply side subsidies, but also guaranteed demand incentives, to reduce the offtake risk.
Investments of Rs. 8-10 trn needed by 2030 to develop Green H_2 ecosystem; financing ecosystem must evolve to accommodate this opportunity
Given much of the capacity for green H2 has to be set up from scratch, a massive Rs. 8-10 trn would be needed by 2030. Of this, ~Rs. 1.6 trn will go towards building sufficient electrolyser capacity, while Rs. ~4.2 trn will be for setting up facilities for manufacturing green molecules. Importantly, an additional Rs. 4.5 trn would be needed in setting up associated renewables capacity to fuel these new factories. To achieve these aims, it is important to solve issues plaguing projects right now, which include uncertain demand offtake and a vicious loop of low scale and high costs of capex. Achieving these milestones can not only ensure deep-decarbonisation in hard to abate sectors, but also open up new applications for green H_2.

01

HYDROGEN AND ITS COLOURS: AN INTRODUCTION

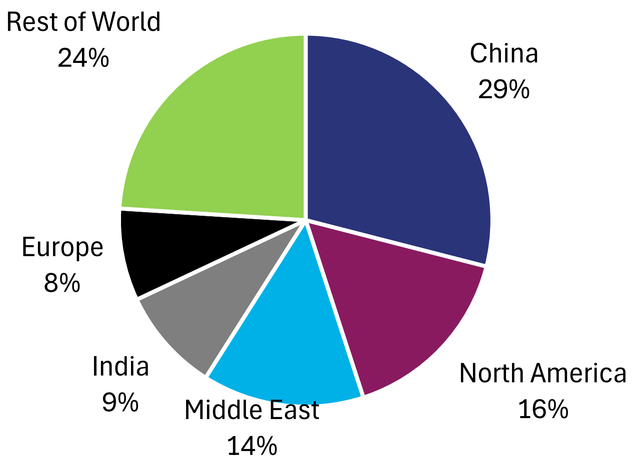
GLOBAL HYDROGEN USE TO INCREASE BASED ON NEW USES

TOTAL GLOBAL HYDROGEN USE (mn tonnes)



Note: NZE = Net Zero Emissions by 2050 Scenario in 2030

REGION-WISE HYDROGEN USE (CY23)



USES OF HYDROGEN

FEEDSTOCK

Traditional Uses

- Ammonia production using Haber process
- Desulphurization of fossil fuels to reduce pollution
- Methanol production

New Uses

- Reducing agent in steel production
- Caustic soda production

FUEL USE

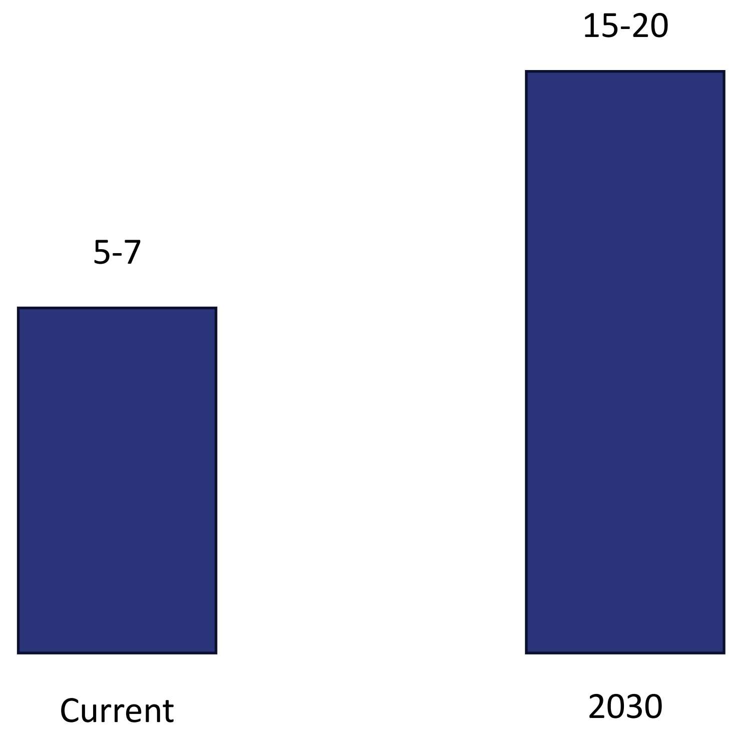
- Blending with conventional fossil fuels
- Electric arc furnaces in steel & iron making
- Fuel cells or in heavy-duty and long-distance transport

- Hydrogen use could reach ~140-160 mn tonnes by 2030. India is one of the largest users of H_2 in the world
- Hydrogen is an important industrial chemical. The current uses of H_2 are as feedstock in fertiliser production and cleaning of fossil fuels
- New feedstock uses for H_2 will be contingent on solving challenges associated with its production. Fuel use is likely to remain minor even in the future

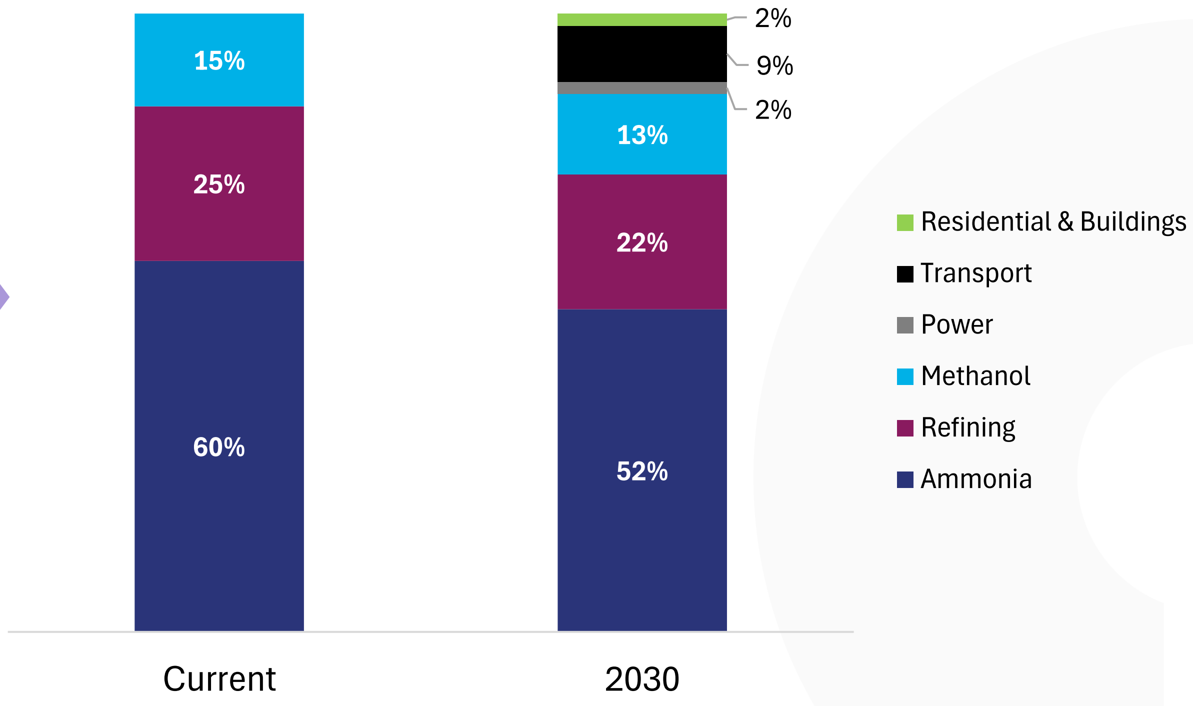
Source: IEA, BofA, BNEF, SBICAPS

INDIA'S HYDROGEN USE TO BE FASTER THAN THE GLOBE

INDIAN HYDROGEN USE (mn tonnes)



INDIAN HYDROGEN USAGE BY SECTOR



- Hydrogen use will triple in the next few years in India – much faster than the global growth rate. Besides domestic use, India has export potential as well
- Industrial uses shall dominate in India just like the world, with limited use for transport – especially heavy-duty long-distance shipping and trucking

Source: TERI, NITI Aayog, SBICAPS

CHALLENGES CONSTRAINING HYGROGEN ADOPTION

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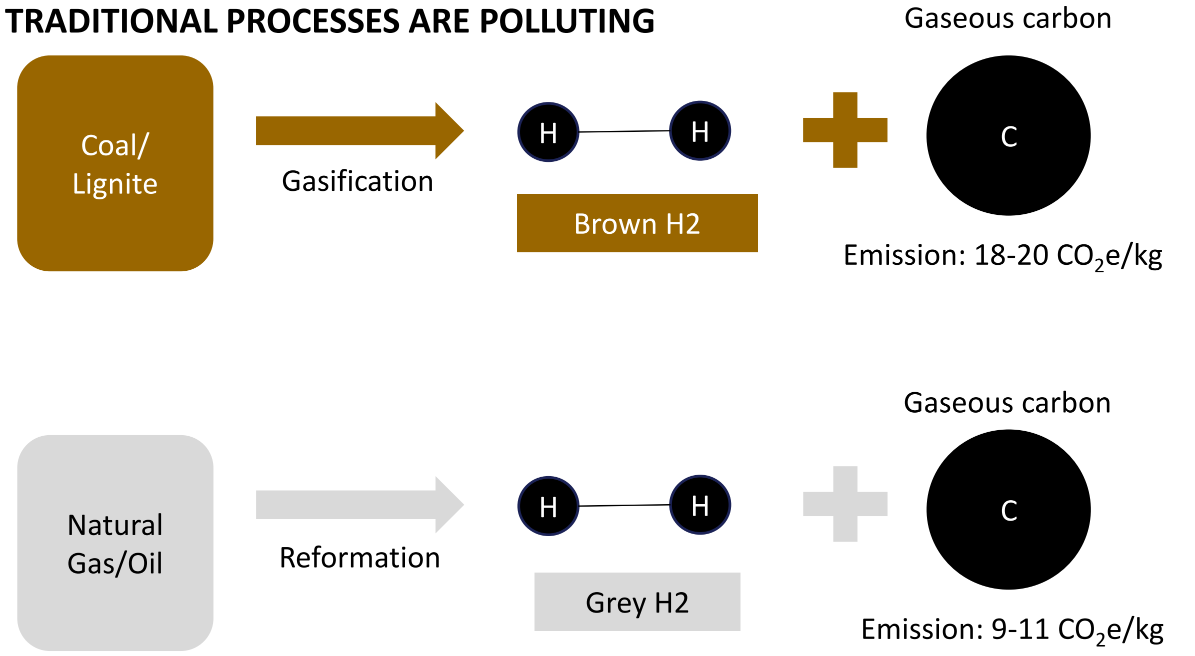
Challenge 1: Polluting Production Pathway

Challenges in increasing H_2 use

Challenge 2: Difficult to Store & Transport

TRADITIONAL PROCESSES ARE POLLUTING



HARD TO STORE AND TRANSPORT

STORAGE OPTIONS: UNATTRACTIVE COST-SCALE-LOCATION TRADEOFF

GASEOUS STATE STORAGE
- Typically have lower cost
- Availability is restricted geographically, especially for large volumes

LIQUID STATE STORAGE
- Typically have higher cost
- Large volume storage is possible without geographic issues

TRANSPORTATION INFRASTRUCTURE INFEASIBLE AT SCALE

ROAD TRANSPORT
- Suitable only for low range (<500 km)
- Limited carrying capacity

PIPELINE
- Cheapest upto 5,000 km
- Retrofitting gas pipelines is expensive

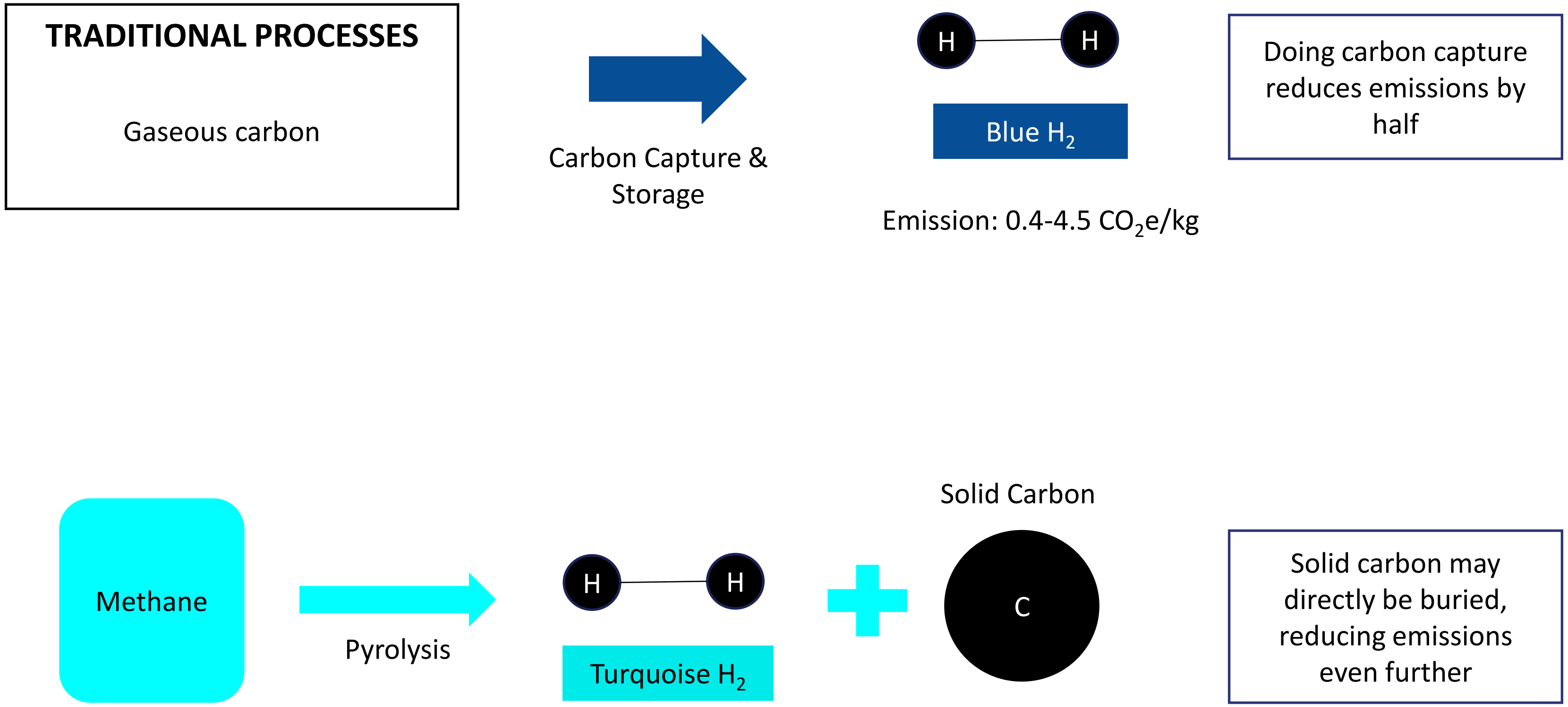
SHIPPING
- Suitable only for offshore and > 500 km
- Most expensive, but large volumes possible

>95% of the world's H_2 production is using dirty traditional processes. H_2 production is responsible for ~2% of all GHG emissions

Its light and explosive nature makes large-volume, low-cost universal storage and transport tough, restricting it to mostly on-site uses

Source: US Department of Energy, BNEF, EY, SBICAPS

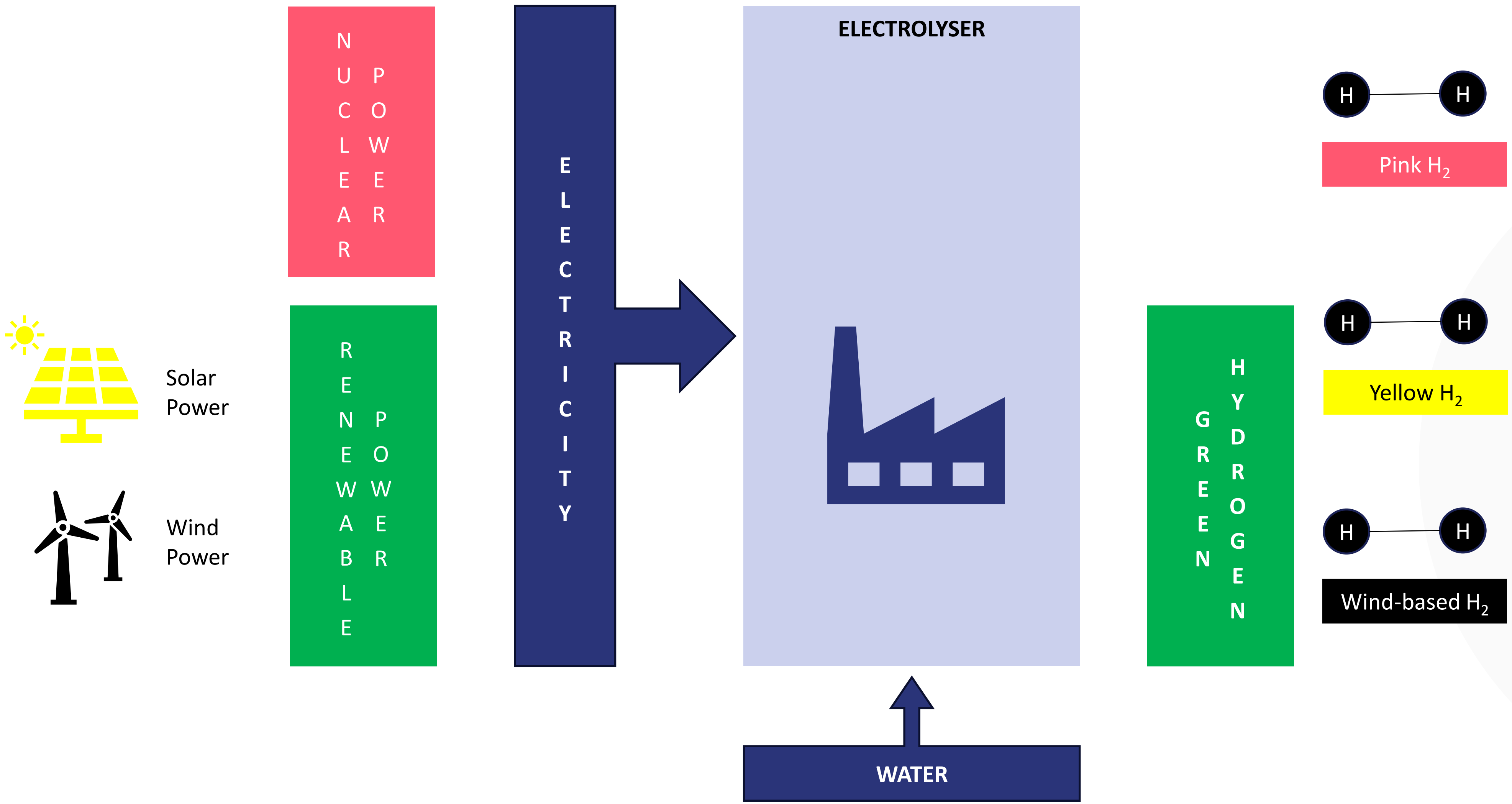
CUTTING GHG EMISSIONS BY MODIFIED FOSSIL-FUEL PATHWAYS IS ONE SOLUTION…



Blue H2 pathway is marginal, and methane pyrolysis remains in early stages

Source: US Department of Energy, Greentech, WEF, National Grid, Forbes, SBICAPS

… GREENING PRODUCTION BY SUSTANAIBLE ELECTROLYSIS IS THE ULTIMATE ANSWER



Currently, only ~1% of the world's H2 production is currently green, as it remains costly compared to dirty variants

WHY NOT USE RENEWABLES DIRECTLY INSTEAD OF GREEN HYDROGEN?

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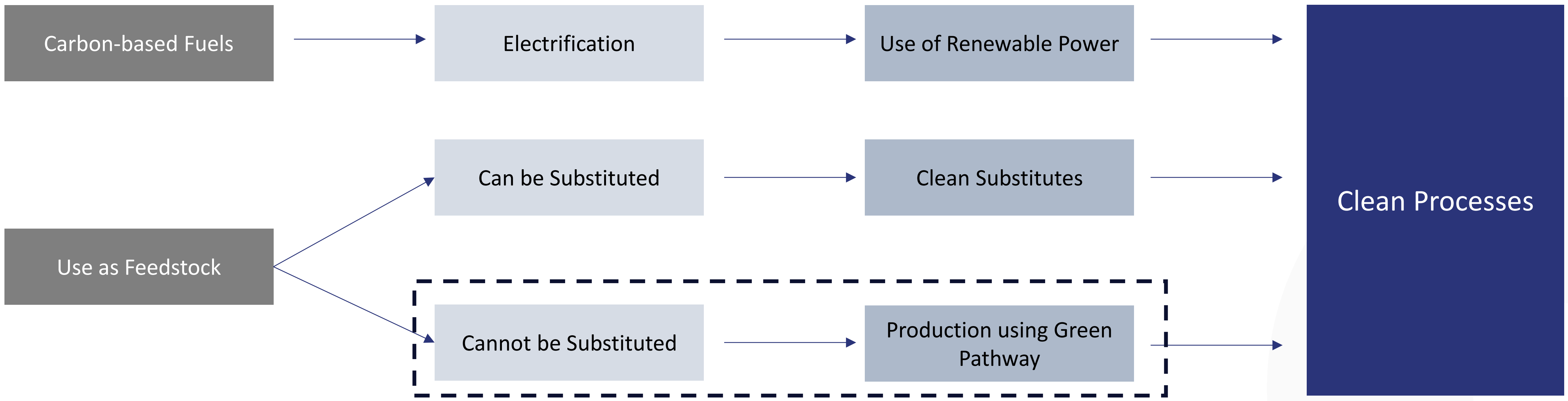

Green Hydrogen is useful in these “Hard to Abate” sectors where H2 is used as a feedstock, and not a fuel.

Examples:

- In production of ammonia, methanol, and caustic soda, H_2 is a raw material and not a fuel, hence it cannot be replaced
- In steel industry, the traditional reducing agent is coke – here H_2 helps replace carbon

~12% of the of the abatement in CO_2 emissions to be done between now and 2050, to achieve 1.5° C scenario will come from H_2 and its derivatives

Source: IEA, IRENA, SBICAPS

GREEN H_2: COMPRESSING COSTS VITAL TO MAKE AN IDEAL GAS

GREEN HYDROGEN CURRENTLY MUCH MORE EXPENSIVE THAN OTHER SOURCES

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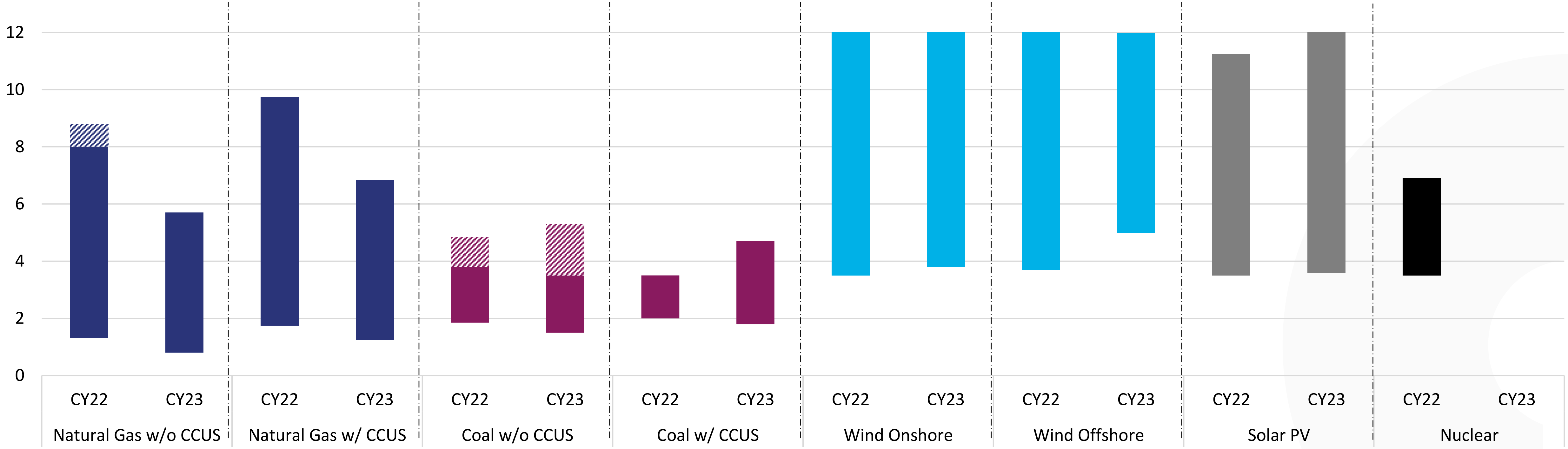
PRICE OF HYDROGEN BY COLOUR (USD/kgH_2)



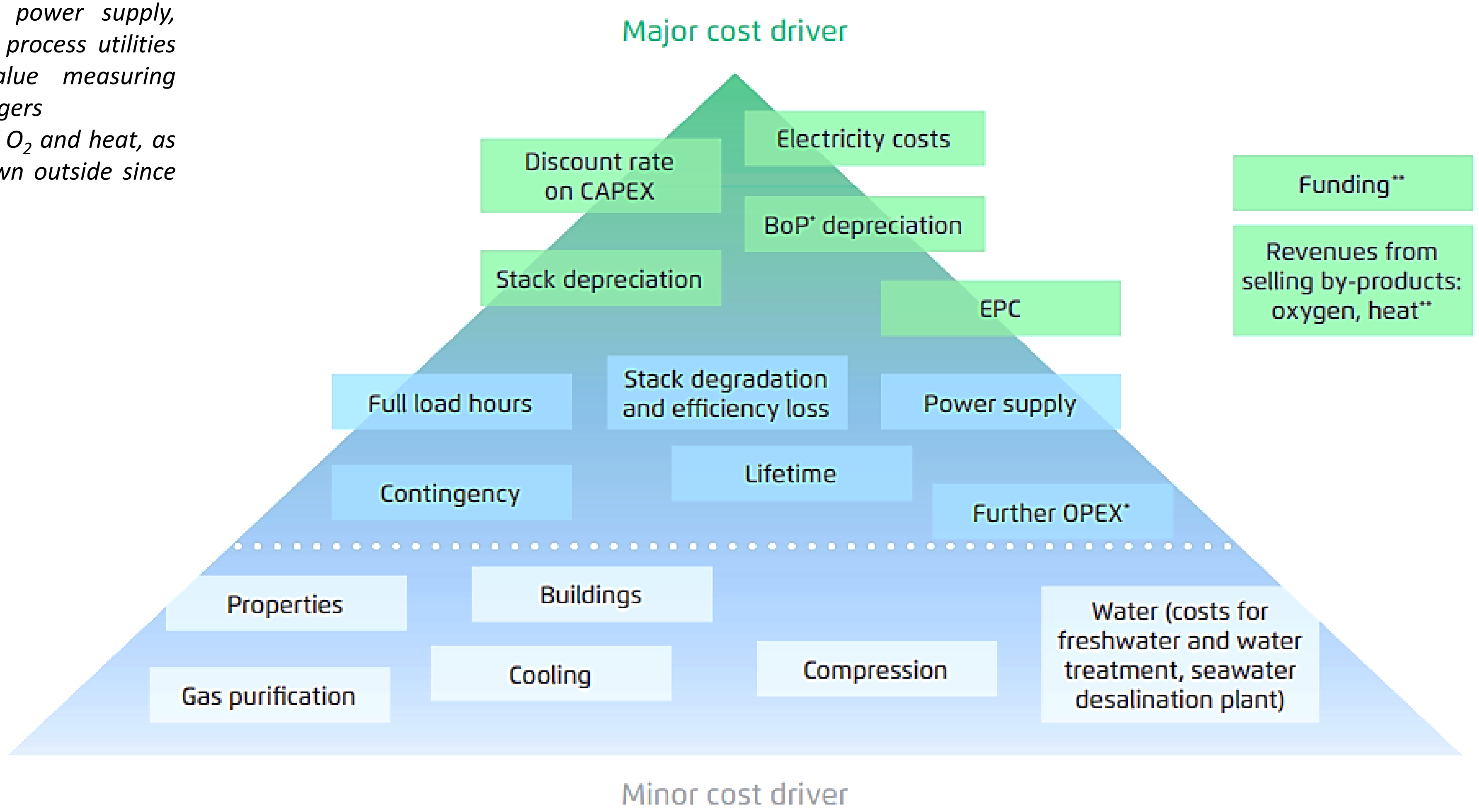
Notes: 1. NZE = Net Zero Emissions by 2050 Scenario in 2030 2. The dashed area represents the CO_2 price impact, based on USD 15-140/t CO_2 for the NZE Scenario.

- **Currently, green H_2 costs USD 3.4-12/kg vs. USD 1-3/kg when using unabated fossil fuels. Much of the incremental costs come from capex on electrolysers and electricity cost**
- **In the Indian context, cost of producing green H_2 is at the lower end ~USD 3.5-5/kg (for 2024) vis-à-vis <USD 2/kg for grey H_2. Some countries have bridged this differential using tax incentives – US provides USD 3/kg tax incentive for production, for instance**

Source: IEA, WEF, SBICAPS

ELECTROLYSER CAPEX AND POWER EXPENSES DRIVE GREEN HYDROGEN COST

Notes:
**BoP typically includes power supply, water conditioning, and process utilities like pumps, process-value measuring devices, and heat exchangers*
***Revenues from sale of O_2 and heat, as well as funding are shown outside since they are not costs*



This typical hierarchy of costs can vary greatly based on region, utilisation of electrolysers, and scale. For instance, a 10 MW electrolyser has only 63% of specific capex of 1 MW electrolyser, which for 100 MW it further reduces to 40%

Source: Agora Energy, SBICAPS

COST VS. EFFICIENCY TRADEOFF CRITICAL IN CHOOSING ELECTROLYSER TECHNOLOGY

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	Alkaline	Proton Exchange Membrane (PEM)	
	Uses thick membranes with Ni-based electrodes. Simple system design, widely used in fertilisers, NH_3 production	*Uses thin perfluorosulfonic acid (PFSA) membranes, which necessitates use of precious metal electrodes*	
Operating Pressure	Moderate (30 bar)	High (70 bar)	Higher pressure requirement increases cost
Efficiency	Moderate (70-80%)	High (80-90%)	Higher pressure increases efficiency
Capex	USD 300-350/kW (lowest from China), USD 750-1,000 (standard)	USD 600-1,250/kW	Installation/indirect costs are typically equal to uninstalled system costs (total is ~2x)
Technology readiness	Matured and Commercialised. 2/3 of global capacity	Young and Commercialised. 1/5 of global capacity	Remaining capacity is from marginal SOEC/AEM technology
Life	60,000 hours	80,000 hours	Post life, stack replacement, which costs 60-80% of upfront capex, is needed

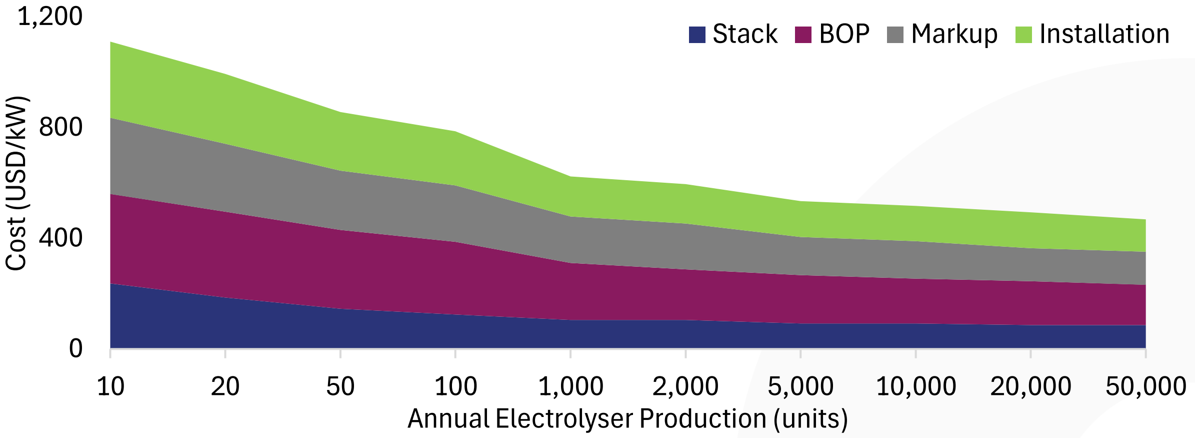
- **Cost trade-off between alkaline and PEM is not direct as the latter operates better under varying power conditions, reducing battery storage cost in the system. This could make capex for PEM lower than alkaline in certain cases, especially since alkaline requires higher space as well**
- **SOEC is an upcoming technology in large prototype phase, which has lower power consumption than other technologies. Its cost is typically above USD 2000/kW**

Source: CEEW, IEA, IRENA, Industry, SBICAPS

COST OF SETTING UP ELECTROLYSERS TO COME DOWN SIGNIFICANTLY

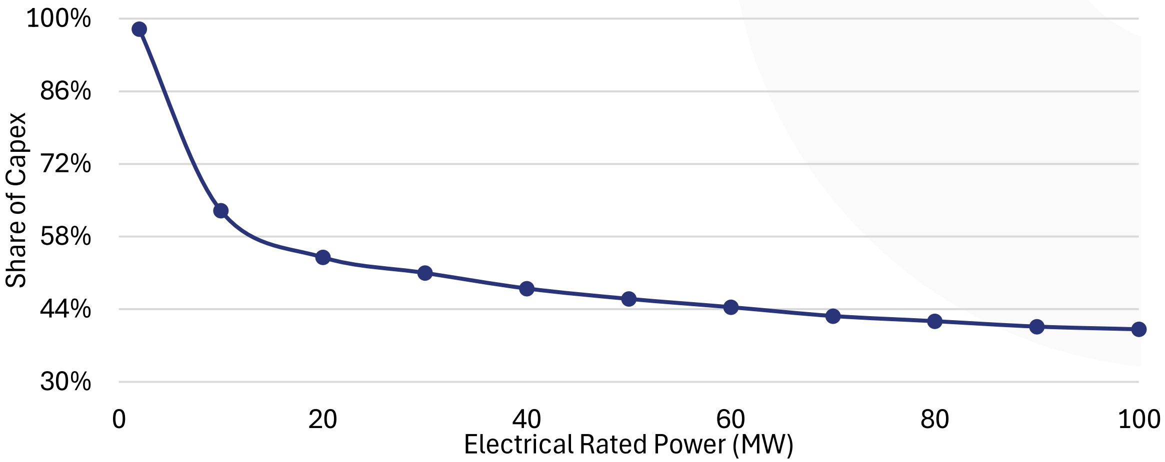
PROJECTED COST OF ELECTROLYSERS (USD/kW_e)

PRODUCING MORE ELECTROLYSERS IS CHEAPER*



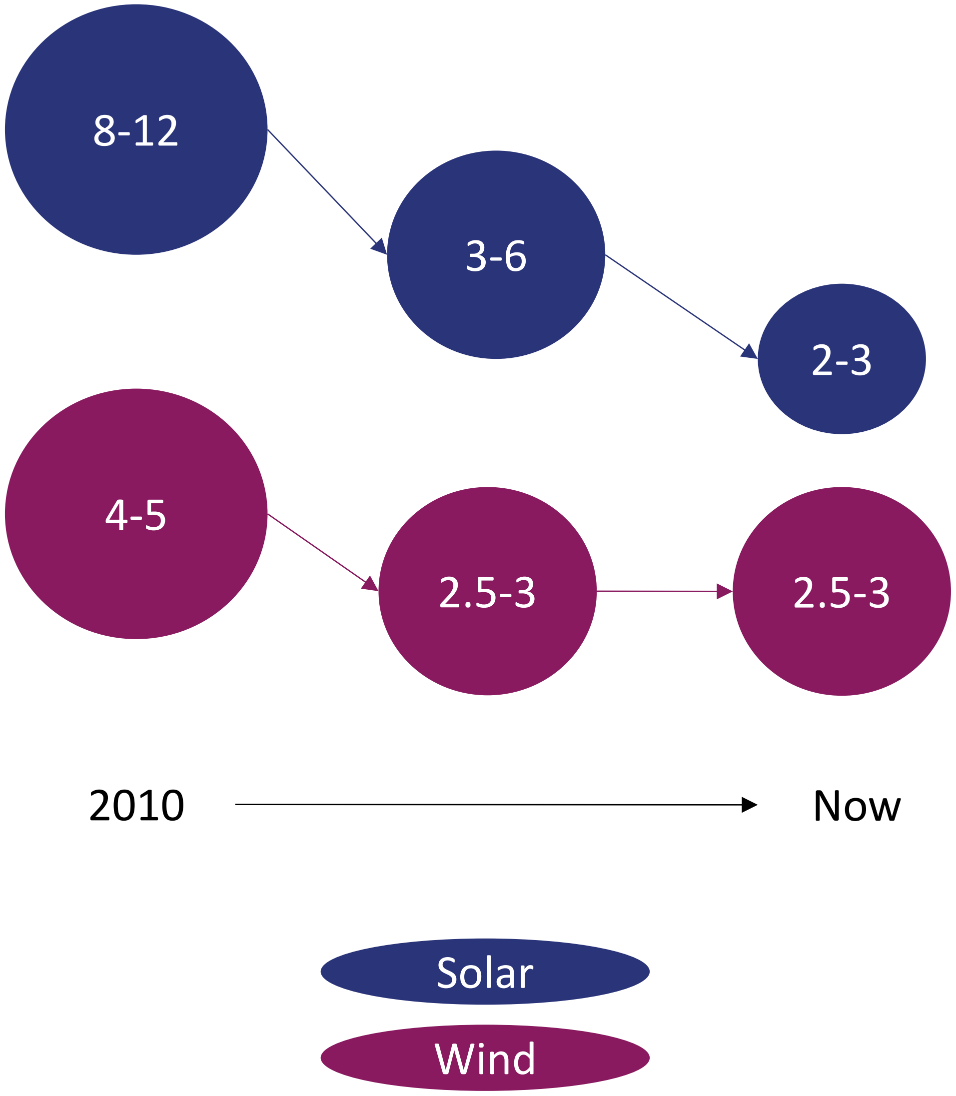
Note: Analysis for 1 MW PEM electrolyser

LARGER ELECTROLYSERS ARE MORE CAPEX EFFICIENT



Source: IEA, NREL, SBICAPS

AFFORDABLE & DIVERSE RENEWABLE SOURCES ARE KEY FOR HIGHER UTILISATION



~125 GW of renewables are expected to be needed just for NGHM by 2030

Solar tariffs have dropped rapidly owing to declining module prices and improved technology

Wind tariffs started out lower, then dipped sharply due to reverse bidding. They have since stagnated due to low returns at these tariffs

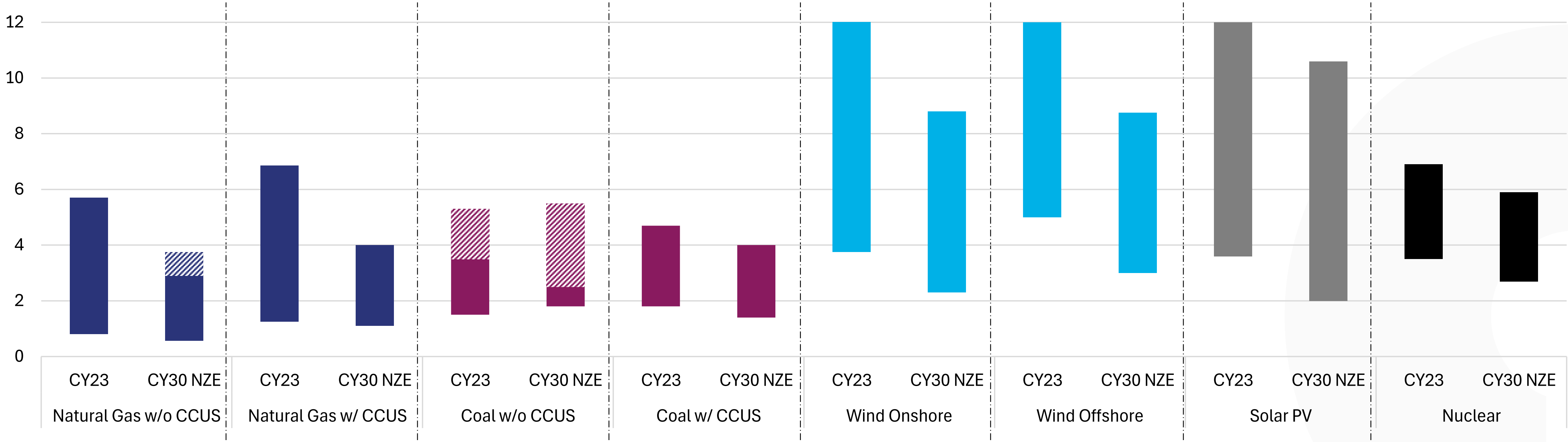
Given the requirement for constant renewable power, the role of wind and storage will go up when Green H_2 ecosystem develops – the exact mix various from project to project

Recent FDRE tariffs discovered of <Rs. 5/unit augur well for reducing the levelised cost of Green H_2 production

Source: ADB, Parliament, EY, SBICAPS

TECHNOLOGY EVOLUTION TO BRING DOWN GREEN H2 COSTS GLOBALLY

PROJECTED PRICE OF HYDROGEN BY COLOUR (USD/kgH_2)



Notes: 1. NZE = Net Zero Emissions by 2050 Scenario in 2030 2. The dashed area represents the CO_2 price impact, based on USD 15-140/t CO_2 for the NZE Scenario.

- **Factoring in carbon costs, the cost of producing green H_2 from solar will start becoming competitive with fossil fuel-based sources by 2030**
- **This will foster not only create new avenues of demand such as steel, transport etc., but also gradually replace existing places where H2 is used, such as fertiliser and refining industries**

FORE'SIGHT'ED INCENTIVES: GREENLIGHTING VIABILITY

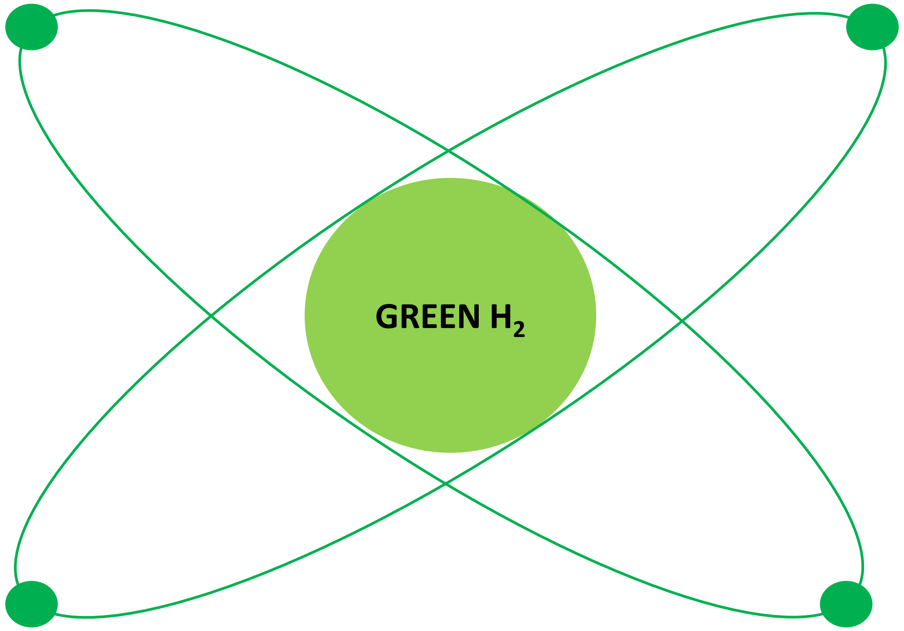
INDIA WELL POISED TO MAKE THE GREEN HYDROGEN LEAP

High Renewable Potential

- Total RE potential of 2.1 TW, amongst highest in the world
- Fair mix of wind (55%) and solar (36%), aiding 24x7 power
- Suitable storage potential for PSP, and upcoming BESS

Robust Domestic Demand

- India is a major consumer of fertilisers, petroleum, and steel: key end users
- These sectors are set to grow in India unlike other countries



Low Energy Cost

- RE cost at ~Rs. 2.5-3.5/unit is near lowest in the world
- FDRE tariffs (incl. storage) are also very cheap

Trade advantage

- 5 mn tonnes per annum of Green H2 by 2030 will lead to cumulative reduction in fossil fuel imports of over Rs. 1 trn
- Ample export potential to Europe, Japan

Adding strategic incentives to these inherent benefits could make green H_2 more viable

Source: CEA, WEF, PIB, SBICAPS

GREEN HYDROGEN TIMELINE: 'GREEN' SHOOTS

Feb 2021

NGHM announced by the Finance minister in the Union Budget

Feb 2022

Launch of Green hydrogen policy

Jan 2023

NGHM approved by the Cabinet

Jun 2023

SIGHT scheme incentives announced for electrolyzers manufacturing and green hydrogen/ ammonia

Aug 2023

Green hydrogen standards announced

Oct 2023

R&D Roadmap for Green Hydrogen Ecosystem in India

Jan 2024

SIGHT component-I: Incentives for electrolyzer manufacturing announced

Feb 2024

Scheme guidelines for pilot projects using hydrogen/green hydrogen in shipping. Steel and green transport

Mar 2024

Implementation of R&D scheme, setting up hydrogen hubs, scheme guidelines for skill development

Mar 2024

SIGHT component-II: Incentive for procurement of green hydrogen/ammonia production announced

Source: PIB, Ministry of Power, MNRE, Gazette of India, SBICAPS

SIGHT PROGRAMME COMPONENTS HAVE OVER'SIGHT' ACROSS THE VALUE CHAIN

Scheme	Component 1	Component 2 Mode 1	Component 2 Mode 2A	Component 2 Mode 2B
End Product	Electrolysers	Green Hydrogen or its derivatives	Green Ammonia	Green Hydrogen
Basis of Bid	Highest index based on specific energy consumption and local value addition. Some preference to small players	Least average incentive demanded over 3-year period	Least cost for production and supply, fixed incentive and firm demand	Least cost for production and supply to refineries, fixed incentive and firm demand
Outlay (Rs. bn.)	44.4	130.5		
Implementation Agency	SECI	SECI	SECI	Oil & Gas Companies, CHT
Incentive	I = Rs. 4,400/kW in Year 1, progressively decreasing till Year 5 (Fixed incentive) I*min (allotted capacity, net sales of electrolysers)	I = Rs. 50/kg in Year 1, Rs. 40/kg in Year 2, and Rs. 30/kg in Year 3 (These represent upper caps, and developers must bid lower) I*min (allotted capacity, actual production)	I = Rs. 8.82/kg in Year 1, Rs. 7.06/kg in Year 2, and Rs. 5.30/kg in Year 3 (Fixed Incentive) I*min (allotted capacity, actual production)	I = Rs. 50/kg in Year 1, Rs. 40/kg in Year 2, and Rs. 30/kg in Year 3 (Fixed Incentive) I*min (allotted capacity, actual production)
Other Details	First Tranche of 1,500 MW: • Bucket 1: 1,200 MW (any stack) • Bucket 2: 300 MW (indigenous stack technology) Second Tranche of 1,500 MW: • Bucket 1: 1,100 MW (any stack) • Bucket 2: 300 MW (indigenous stack technology) • Bucket 3: 100 MW (indigenous stack technology – smaller units)	Each Tranche of 450 ktpa: • Bucket 1: 410 ktpa (technology agnostic) • Bucket 2: 40 ktpa (biomass pathway) Two tranches launched till now	First Tranche of 550 ktpa, enhanced in Jun'24 to 750 ktpa Actual tender in Tranche 1 of 539 ktpa (live tender)	First Tranche of 200 ktpa

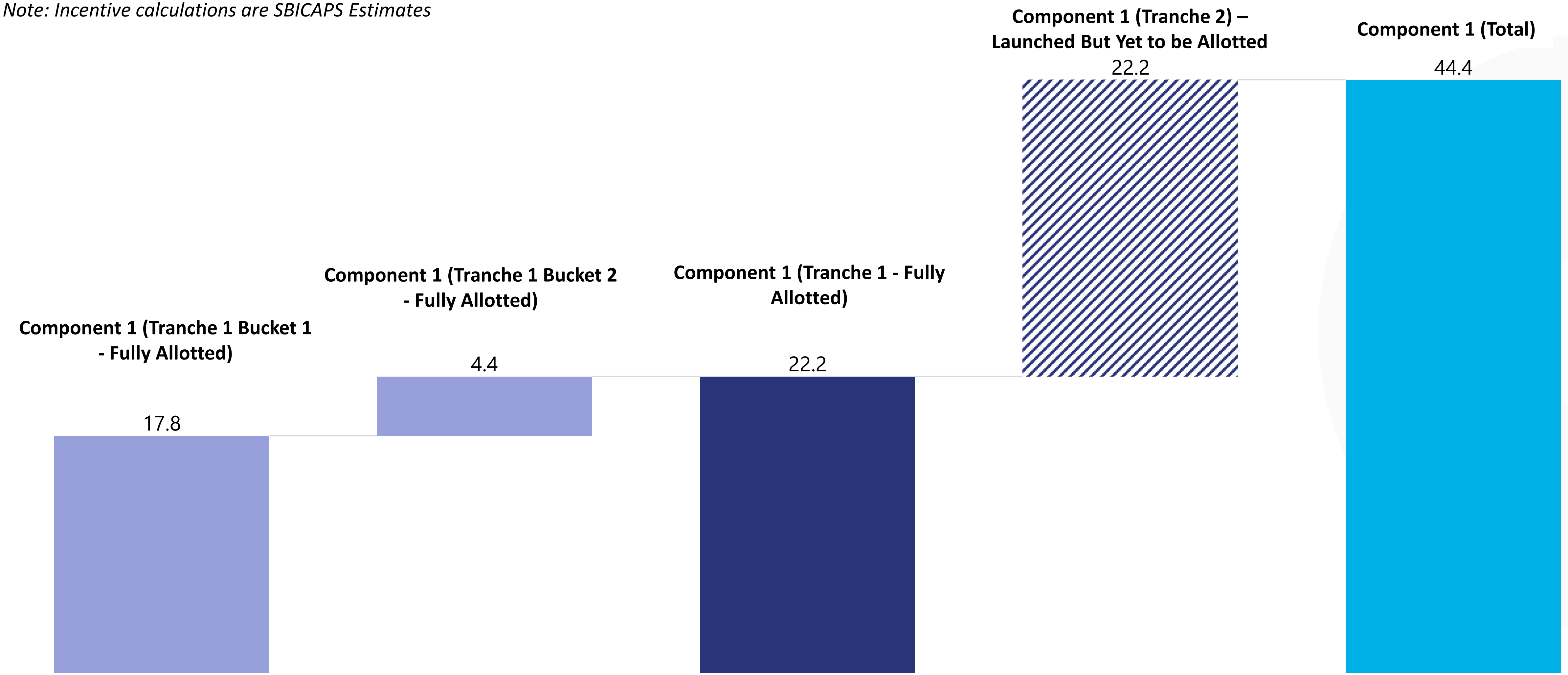
TOTAL OUTLAY
Rs. 175 bn

Source: MNRE, SBICAPS

ELECTROLYSER COMPONENT FULLY LAUNCHED

INCENTIVE ALLOCATION FOR SIGHT COMPONENT 1 (Rs. bn.)

Note: Incentive calculations are SBICAPS Estimates



Source: MNRE, MERCOM, News Sources, SBICAPS

>75% IN COMPONENT 2 YET TO BE COMMITTED

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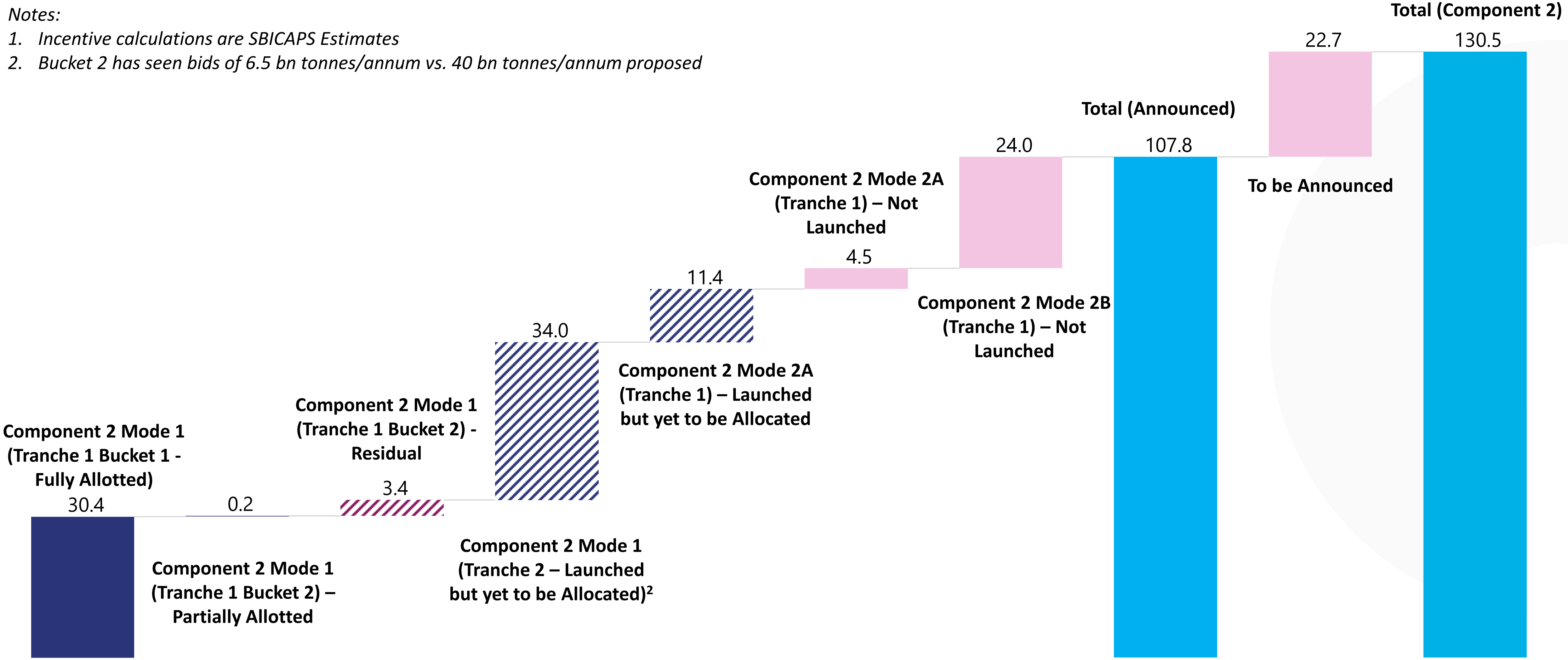
INCENTIVE ALLOCATION FOR SIGHT COMPONENT 2 (Rs. bn.)

Notes:

1. *Incentive calculations are SBICAPS Estimates*
2. *Bucket 2 has seen bids of 6.5 bn tonnes/annum vs. 40 bn tonnes/annum proposed*



CURRENT WINNERS: A MOTLEY MIX OF SPECIALISTS AND END USERS

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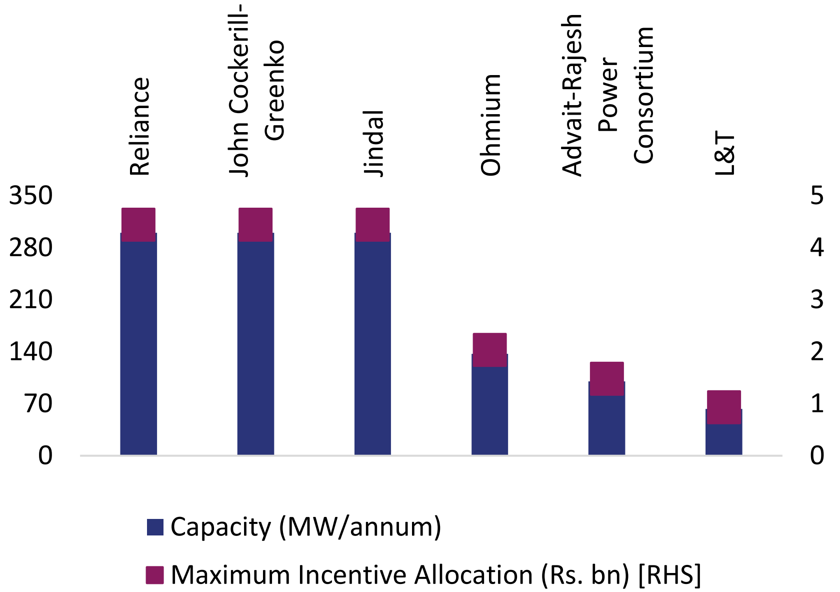
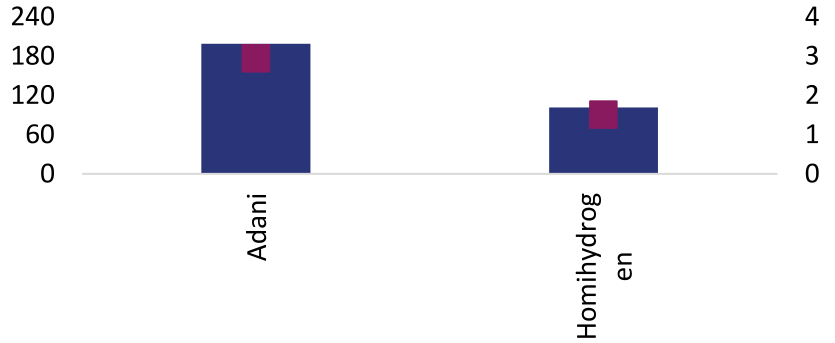
ELECTROLYSER | **GREEN H2** | **DERIVATIVES**

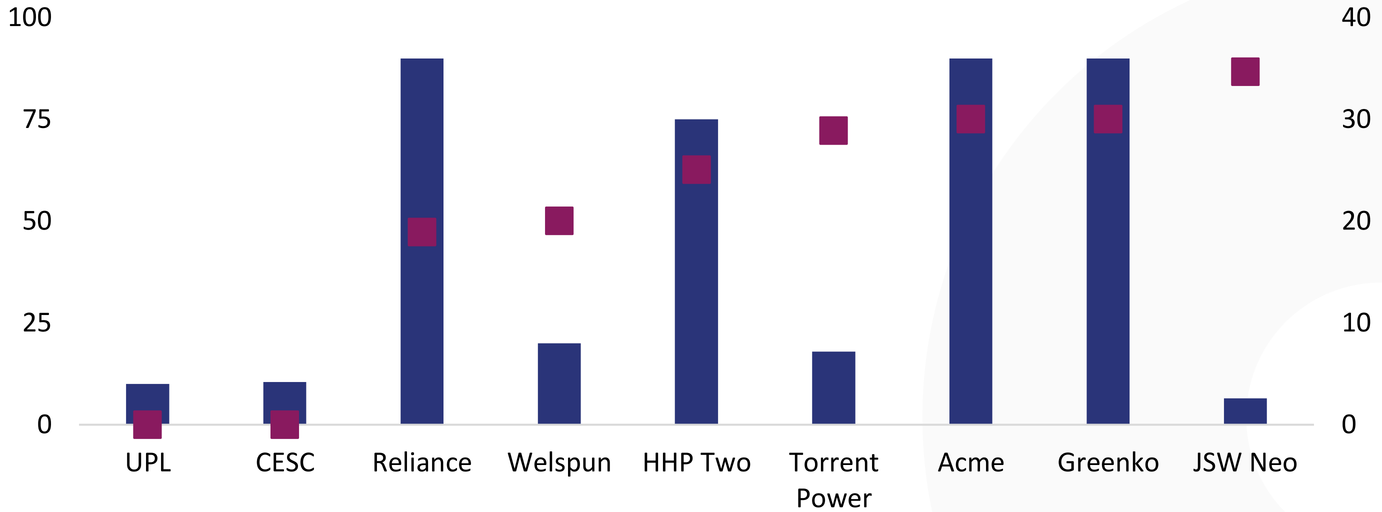
ANY STACK



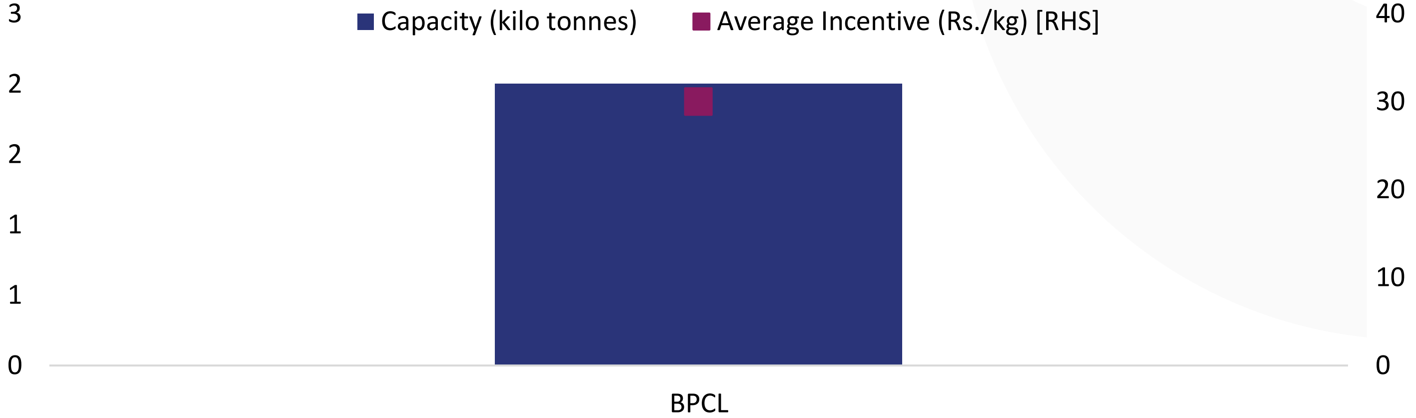
INDIGENOUS STACK



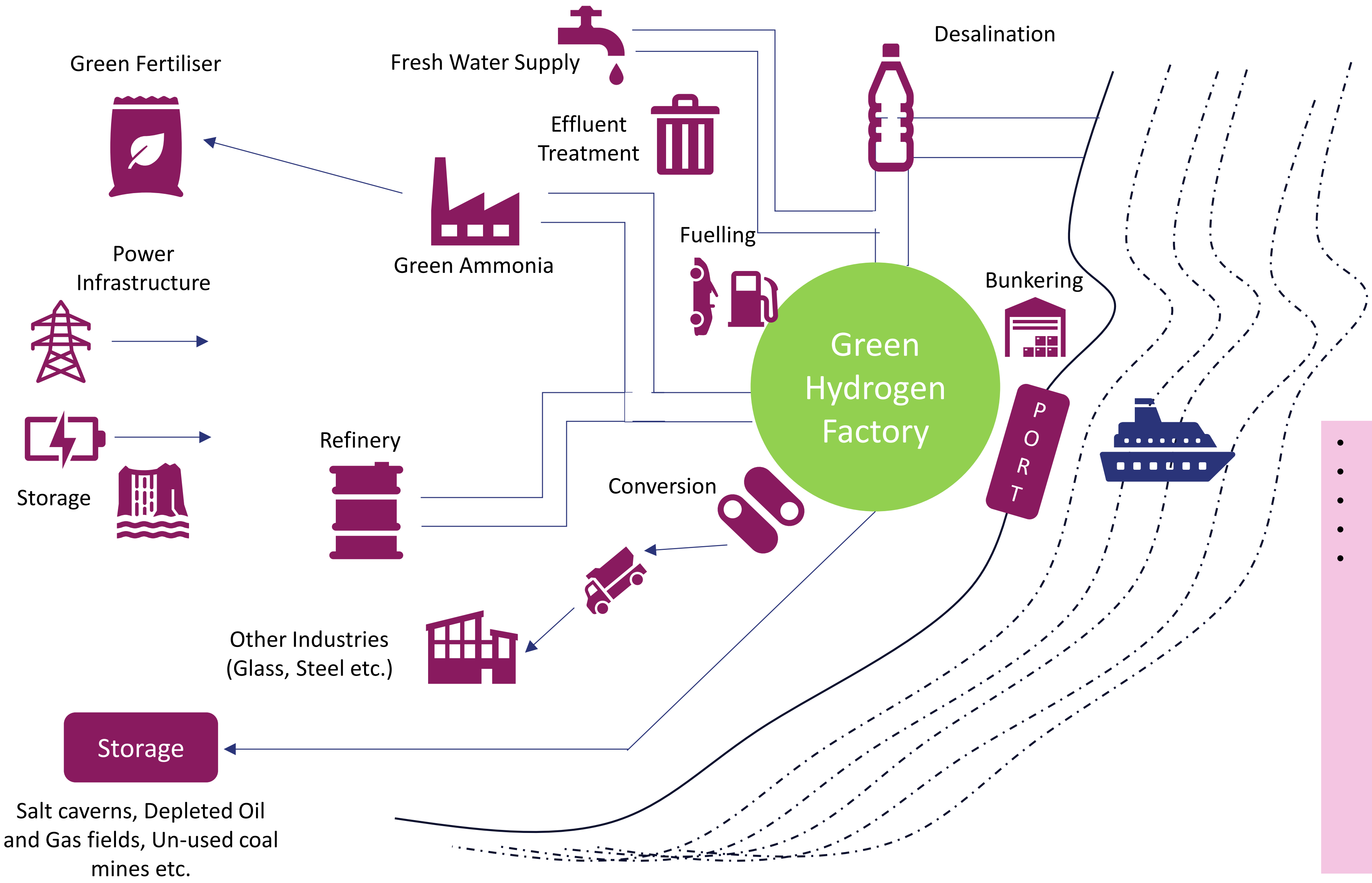
ANY PATHWAY



BIOMASS PATHWAY



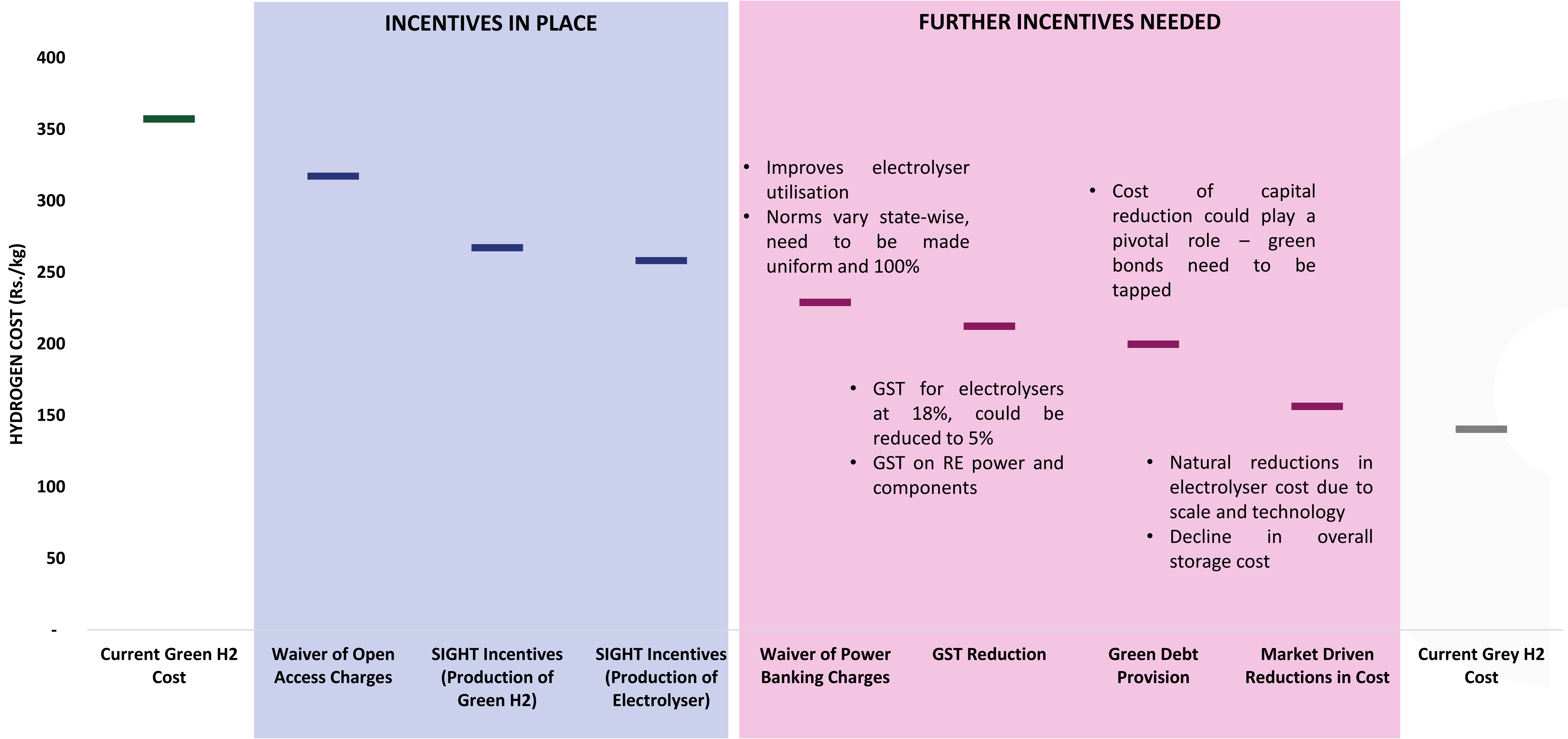
GREEN HYDROGEN HUBS TO SOLVE THE STORAGE AND TRANSPORT PROBLEM



- Two Green H2 Hubs to be made by FY26
- Capacity per hub of 100 ktpa
- Central Financial Assistance of Rs. 1 bn per hub
- Overseen by SECI
- Bidding based on:
  - Tpa of Green H_2 projects approved
  - DPR of infrastructure available or planned
  - Natural Resource Availability – water, power, land
  - Presence of demand centres
  - Proximity to export centre
  - Firm offtake agreements
  - Financial viability
  - Debt/Equity tied up

Source: MNRE, SBICAPS

INCENTIVES WILL BOOST VIABILITY, MORE IS NEEDED



Source: CEEW, SBICAPS

WIDER APPLICATIONS THAN NOW ENVISAGED POSSIBLE

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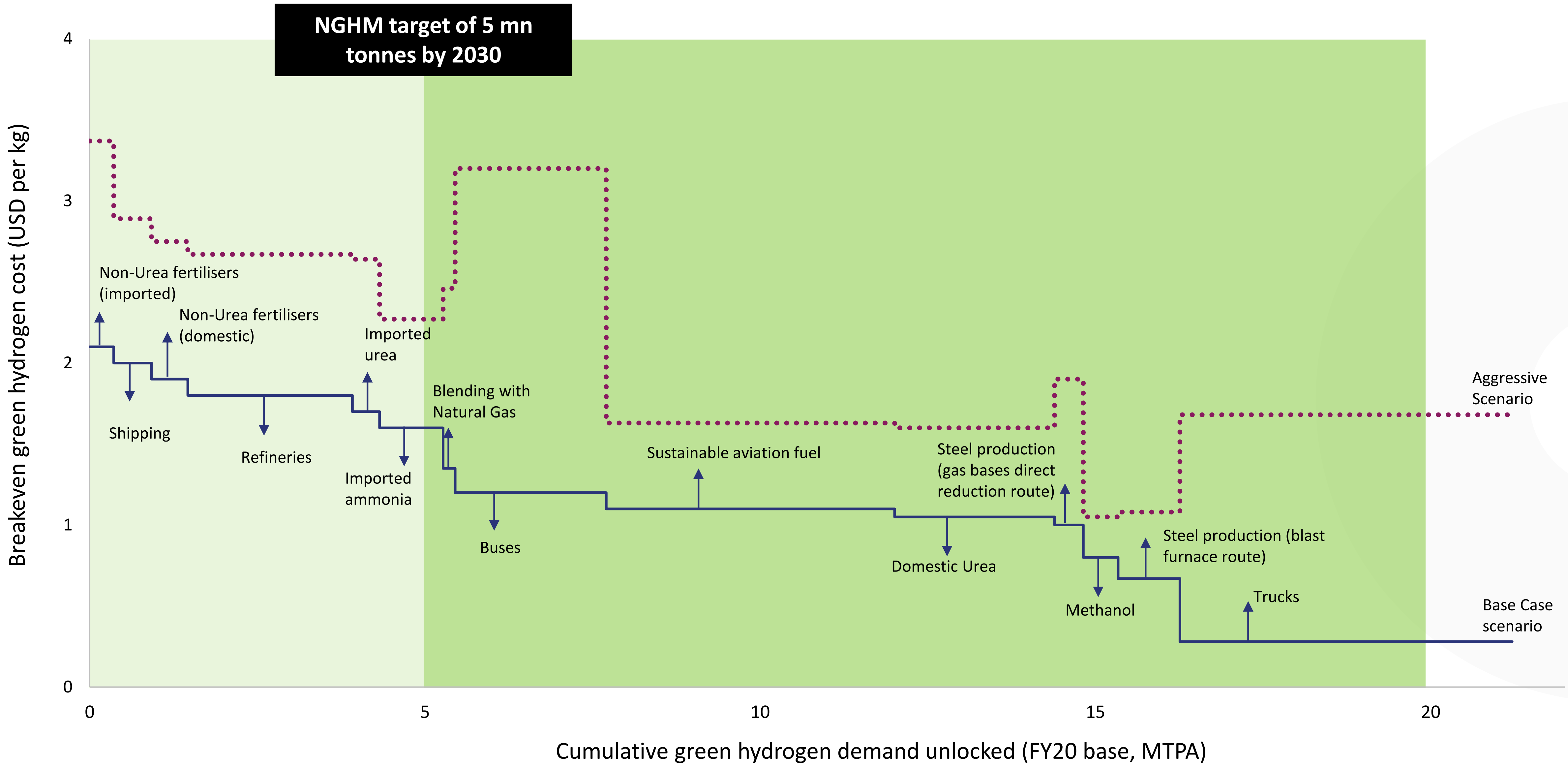
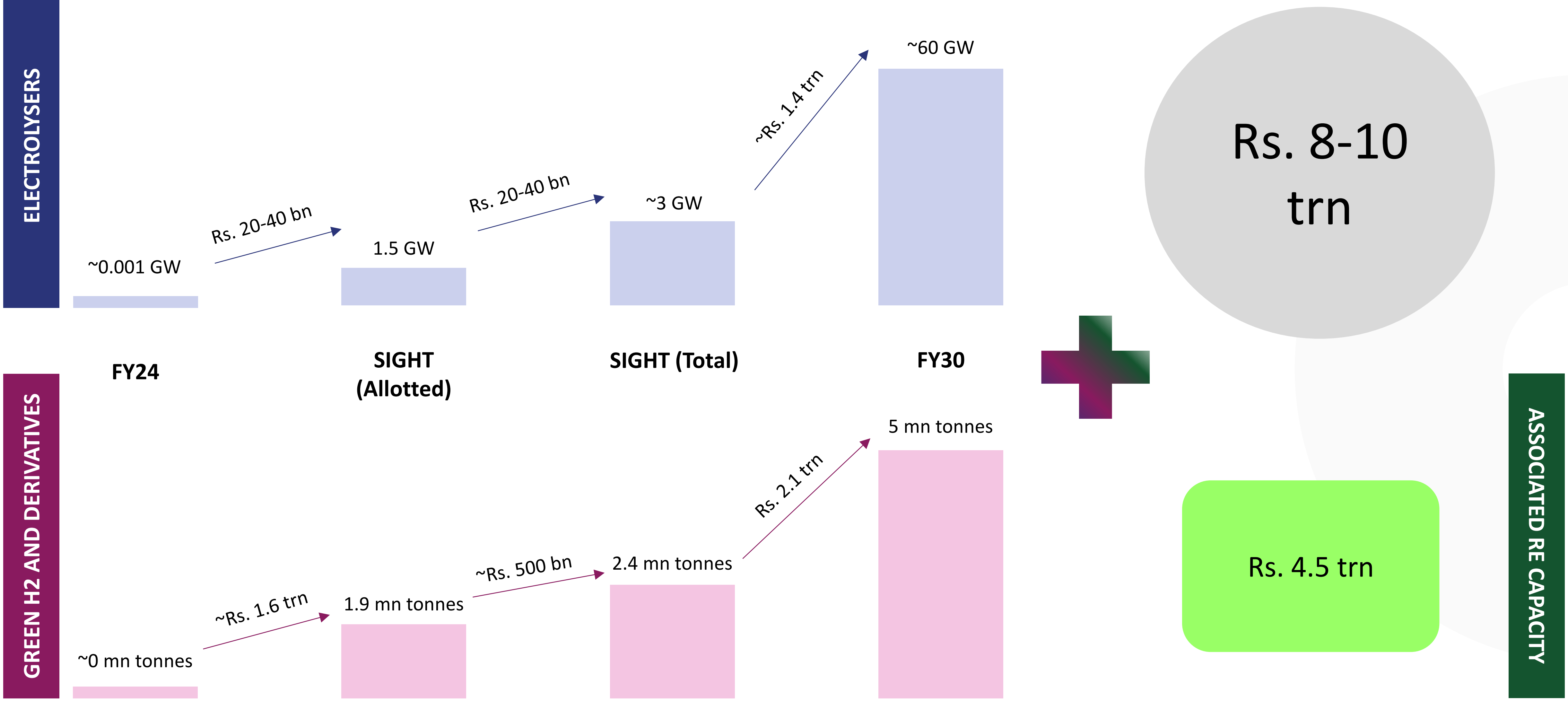


Source: CEEW, SBICAPS

GREENBACK FOR GREEN H_2: FINANCING THE FUTURE

THE G(R)AS(S) IS GREEN FOR INVESTMENTS

Note: Calculations are SBICAPS Estimates



EFFECTIVE FINANCING CONTINGENT ON ADDRESSING ISSUES

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CHALLENGES	SOLUTIONS (IN PLACE)	SOLUTIONS (NEEDED)
High cost of setup and operations vs. expected cost from consumers	• SIGHT Component 1 provides an incentive of to reduce cost for electrolysers • Waiver of ISTS charges	• Investment in indigenous stacks • Reduction in electrolyser GST from 18% • Selling of byproduct O_2 can improve viability
Logistical difficulties in arranging water, electricity, storage, offtake infrastructure etc.	Green Hydrogen Hubs which provide all inputs at a centralised location near demand centres	Increased impetus to develop RE capacity dedicated to Green H_2
Offtake agreement tenure mismatch – offtakers want lower tenure (5-7 years), while producers want higher tenure (20-30 years)	Firm demand commitments in SIGHT programme tenders for Green H_2 and derivatives	• Standard medium-term offtake agreements of ~10 years (FI expectations) • Increase in firm demand incentives
Limited debt financing	Presence of specialised power finance institutions	• Tapping into MLIs for concessional debt • Raising labelled debt in global markets • Guarantees
Stranded asset risk – high-cost producers today may be left high and dry when lower cost plants come in	Firm demand commitments in SIGHT Component 2	• Tripartite agreements with state agencies to enforce take-or-pay losses • Award of monopolies in specific hubs

05

ANNEXURE

GLOSSARY OF KEY TERMS

Item	Explanation
°C	Degrees Celcius
ADB	Asian Development Bank
AEM	Anion Exchange Membrane
BESS	Battery Energy Storage System
bn	billion
BNEF	Bloomberg New Energy Finance
BofA	Bank of America
BoP	Balance of Plant
BPCL	Bharat Petroleum Corporation Limited
capex	Capital Expenditure
CCUS	Carbon Capture, Utilisation, and Storage
CEA	Central Electricity Authority
CEEW	Council on Energy, Environment and Water
CHT	Centre of High Technology, MoPNG
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
CY	Calendar Year
EPC	Engineering, Procurement, and Construction
EY	Ernst & Young Global Limited
FDRE	Firm Despatch Renewable Energy
FI	Financial Institution
GHG	Greenhouse Gas
GST	Goods and Services Tax
GW	Giga Watt
H_2	Hydrogen
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ISTS	Inter State Transmission System
kg	kilogramme
kW	kilo Watt
L&T	Larsen and Toubro
M	Mega

Item	Explanation
MLI	Multilateral Institution
mn	million
MNRE	Ministry of New and Renewable Energy
MW	Mega Watt
NGHM	National Green Hydrogen Mission
NH_3	Ammonia
Ni	Nickel
NREL	National Renewable Energy Laboratory
NZE	Net Zero Emissions
O_2	Oxygen
Opex	Operating Expenditure
PEM	Proton Exchange Membrane
PFSA	Perfluorosulfonic Acid
PIB	Press Information Bureau
PSP	Pumped Storage Project
PV	Photovoltaic
R&D	Research & Development
RE	Renewable Energy
Rs.	Indian Rupees
SECI	Solar Energy Corporation of India
SIGHT	Strategic Interventions for Green Hydrogen Transition
SOEC	Solid Oxide Electrolysis Cell
t	tonne
tpa	tonne per annum
trn	trillion
TW	Tera Watt
USAID	United States Agency for International Development
USD	United States Dollar
w/	with
w/o	without
WEF	World Economic Forum

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