The potential of hydrogen in India

Background

- In July 2020, TERI released a policy brief titled **‘Make Hydrogen in India**’, which made the case for greater activity on green hydrogen technologies, to capture manufacturing benefits.
- On 16th December 2020, TERI launched a more detailed technical report, “**The Potential Role of Hydrogen in India: A pathway to scaling-up low carbon hydrogen across the Economy**”. The report gave an in-depth assessment of hydrogen production technologies, and the various potential end-use sectors.
- Since 2020, several developments in India on hydrogen have taken place. In 2022, the **Ministry of New and Renewable Energy launched the first phase of the National Hydrogen Policy**. Various leading industry players have also made ambitious announcements across the hydrogen value-chain.


MAKE HYDROGEN IN INDIA

Driving India towards the clean energy technology frontier

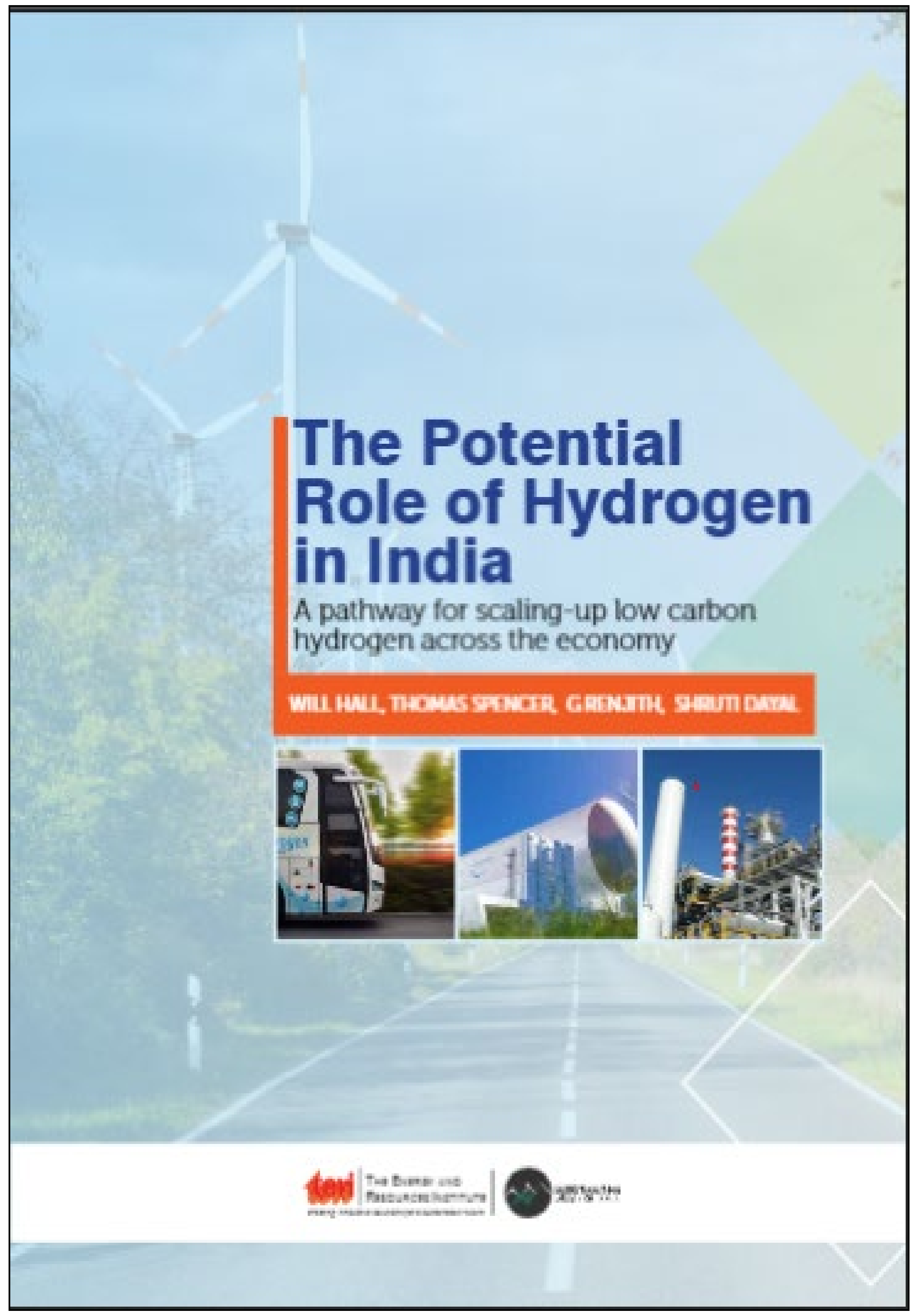
Will Hall, Associate Fellow

POLICY BRIEF

SUMMARY

- The energy transition is continuing at an unprecedented pace and scale, requiring new low carbon technologies.
- To date, India has had limited success in capturing the manufacturing benefits of certain clean energy technologies, such as solar PV and batteries.
- TERI sees green hydrogen as the next ‘clean energy prize’, which will require coordinated action from industry and government for India to capture the benefits.
- Early demand markets for hydrogen include fuel cells for trucking, balancing supply and demand in the power sector and replacing fossil fuels in industry.
- The potential scale of hydrogen use in India is huge; increasing between 3 and 10 times by 2050.
- Hydrogen can provide a supplementary role to renewables and batteries, in a transition to a carbon neutral economy.
- Hydrogen can be divided into ‘grey’ (produced from fossil fuels), ‘blue’ (produced from fossil fuels with carbon capture and storage) or ‘green’ (produced from renewable electricity).

The Energy and Resources Institute



The Potential Role of Hydrogen in India – Key Messages (8)
TERI analysis

1

A virtuous circle for hydrogen technology is emerging

Figure: Falling Costs

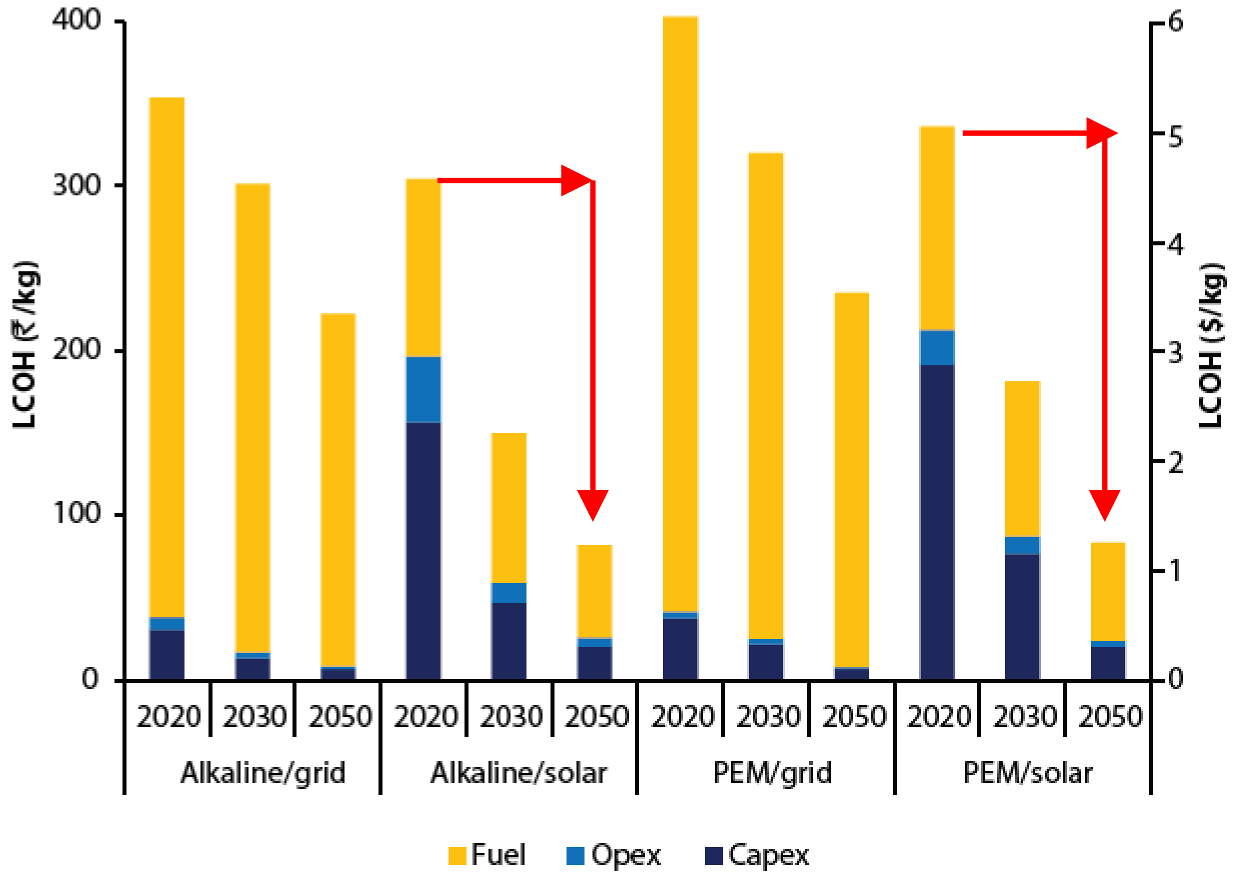


Figure: Increasing Demand

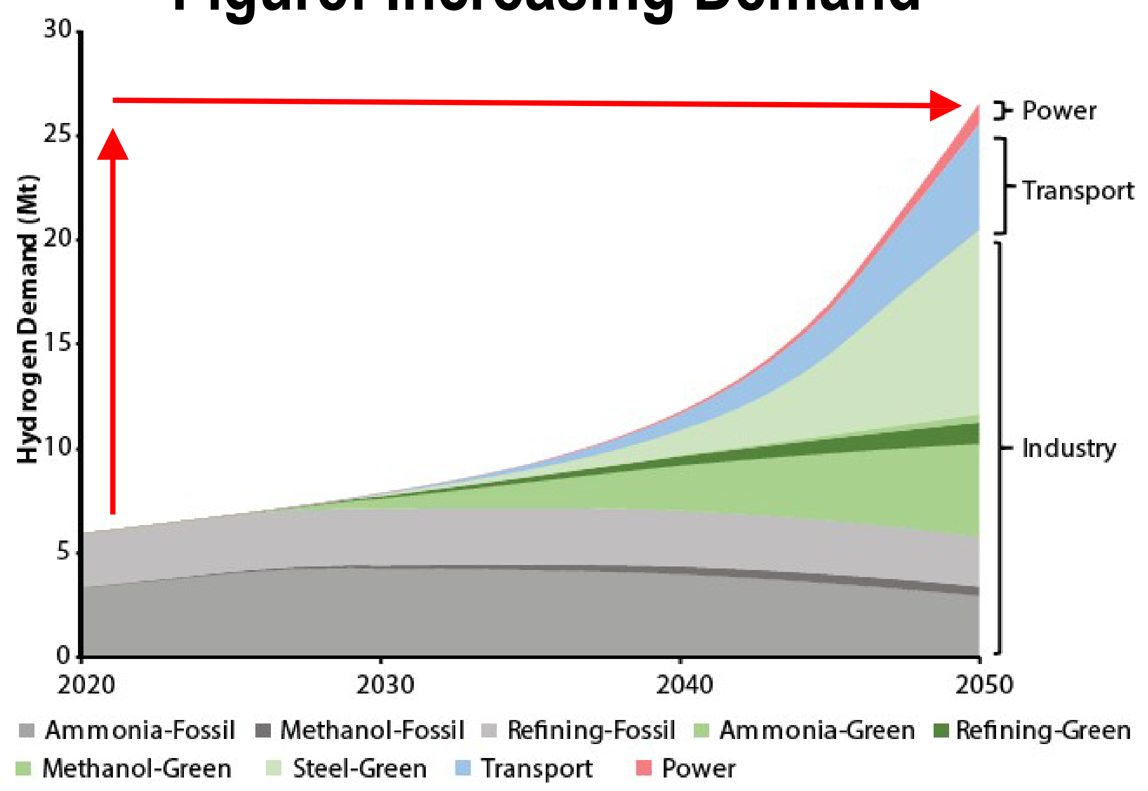
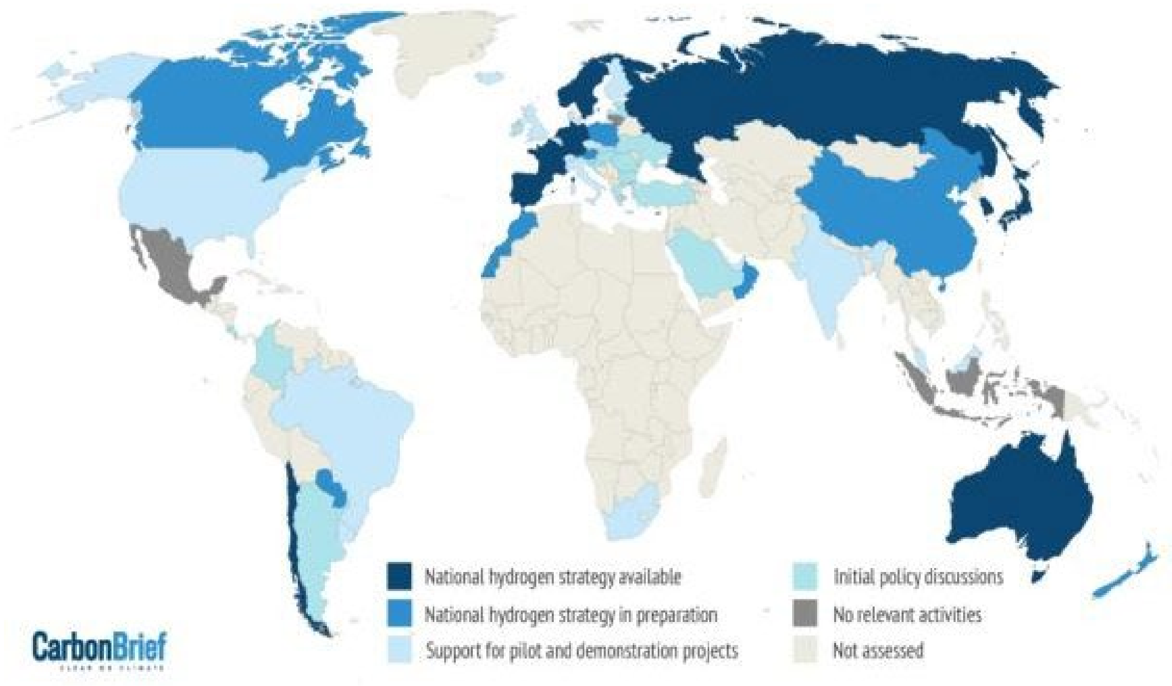


Figure: Strengthening Policy

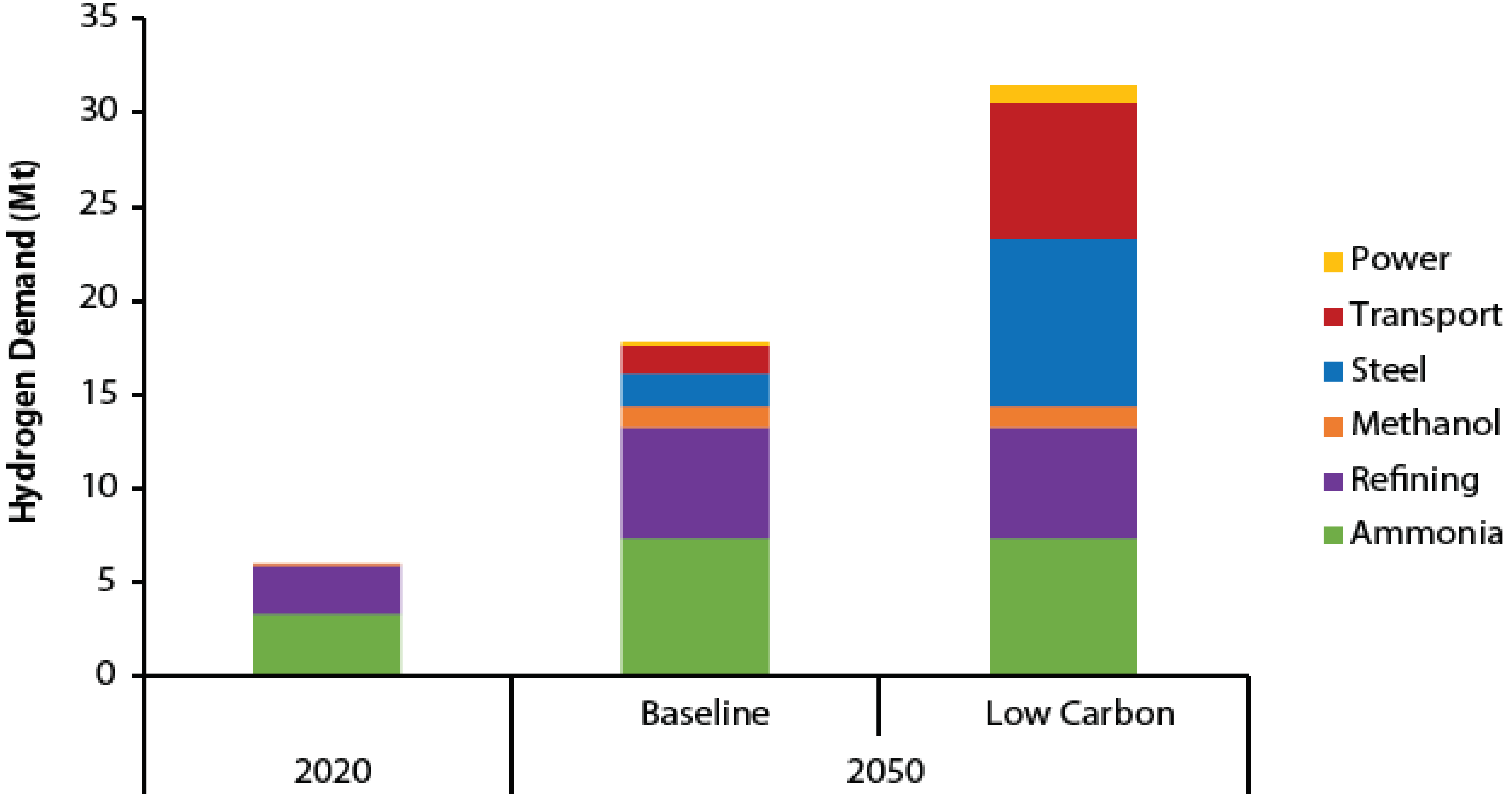


Source: TERI analysis; NRDC

2

Hydrogen demand can grow five-fold by 2050 – TERI analysis

Figure: Hydrogen demand baseline and low-carbon scenario, 2020 and 2050



Source: TERI analysis

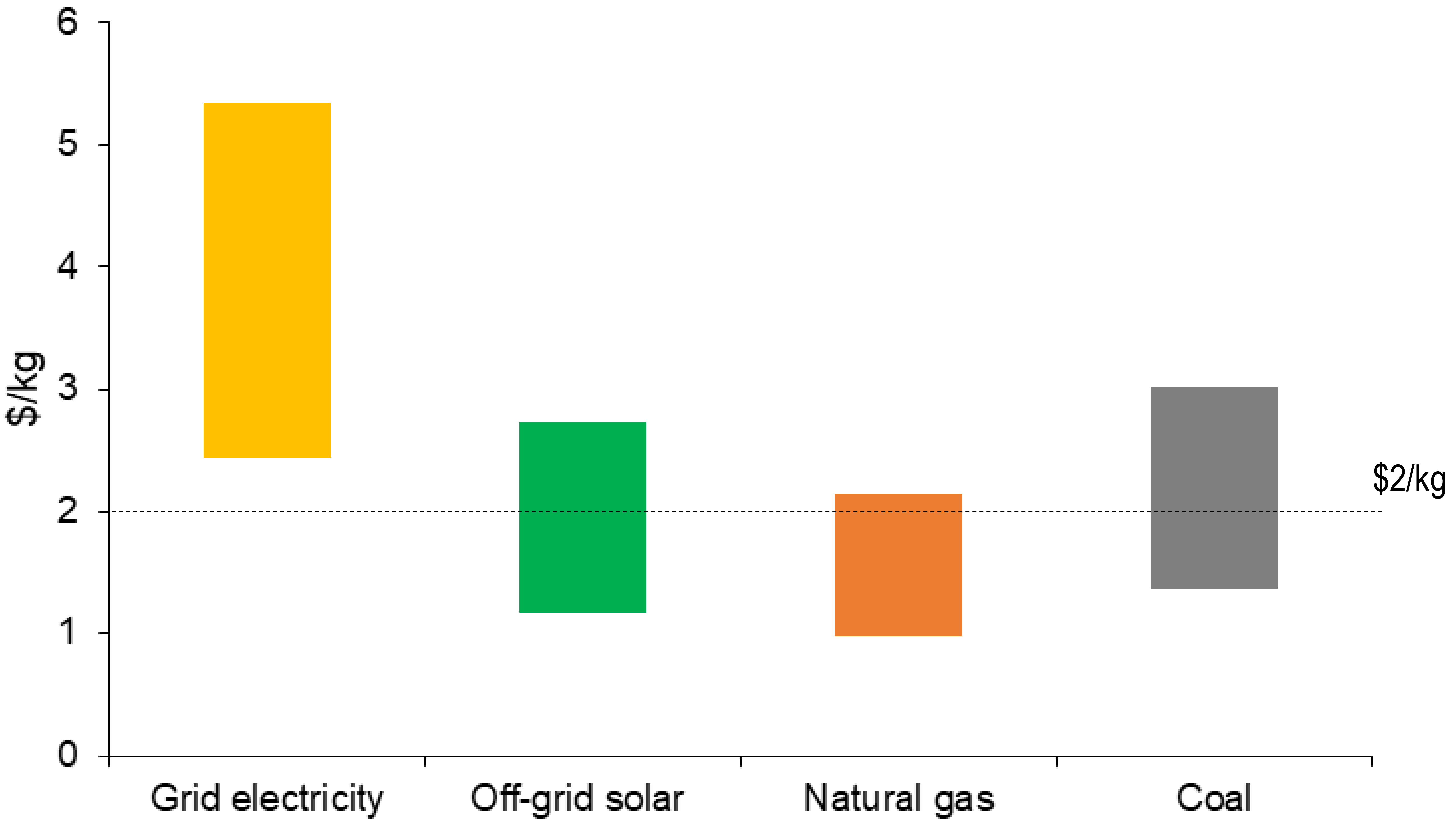
Note: Demand projections exclude potential use of hydrogen in shipping, aviation and petrochemicals

The term "Power" in the key of this figure is used to depicts the role of hydrogen in long-term power storage

3 By 2030, costs of "Green Hydrogen" from renewables will fall more than 50% and it will start to compete with hydrogen from fossil fuels

- **The costs of green hydrogen could fall from $4-6/kg to approximately $2/kg by 2030 and around $1/kg by 2050.**
- Cost reduction would be influenced by factors such as a decline in the costs of electricity and electrolyzers, increases in efficiencies of electrolyzers, and improvements in the average load factor for renewables.

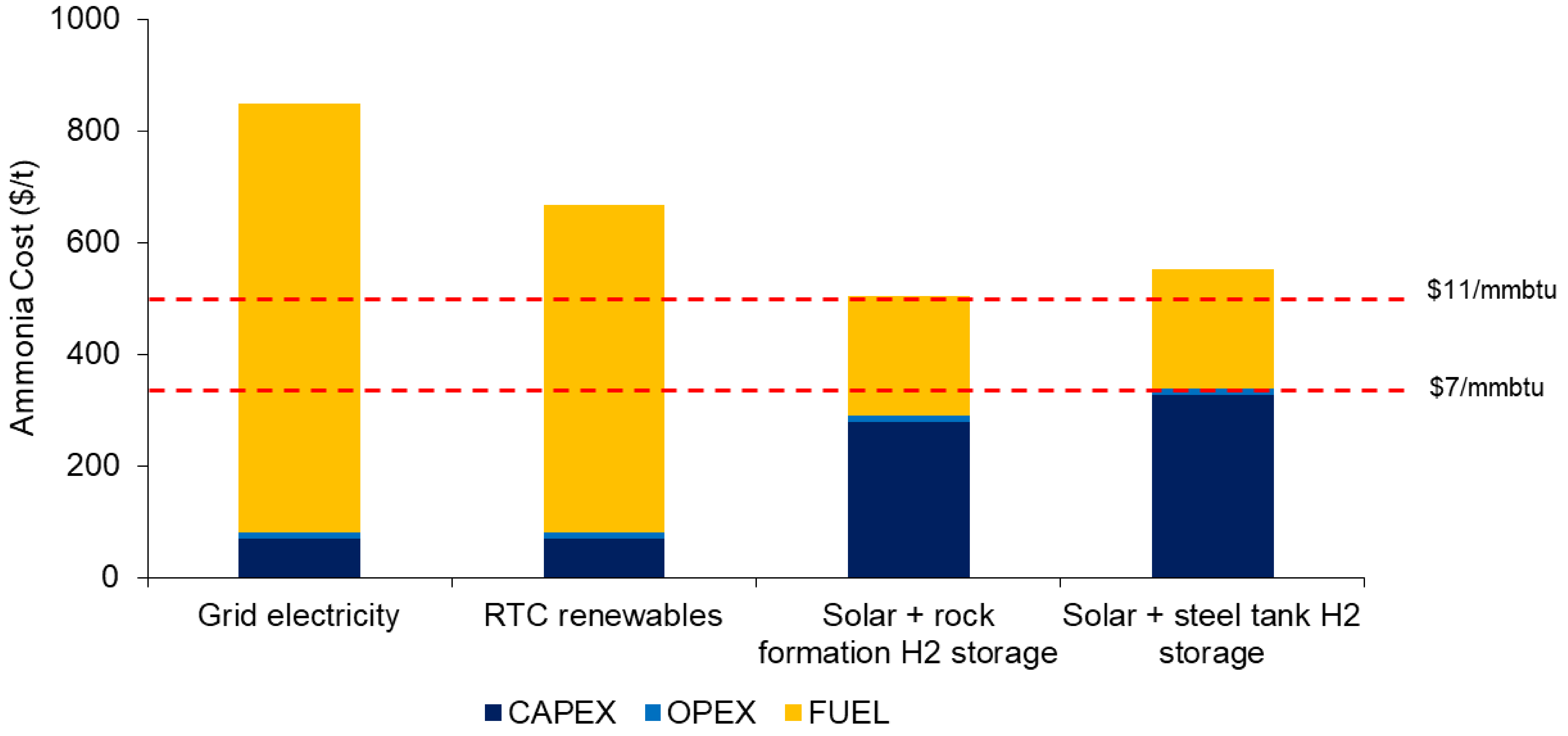
Figure: 2030 Cost Range for H_2 Production Routes in India



Source: TERI analysis

4 In ammonia (fertilizer industry), hydrogen can start to compete with fossil fuels in certain applications by 2030

Figure: Cost of ammonia production from different modes of operation, 2030



Source: Source: TERI analysis based on (IEA, 2019); (BNEF, 2020)

Note: $11/mmbtu-$7/mmbtu is the range for natural gas prices in India

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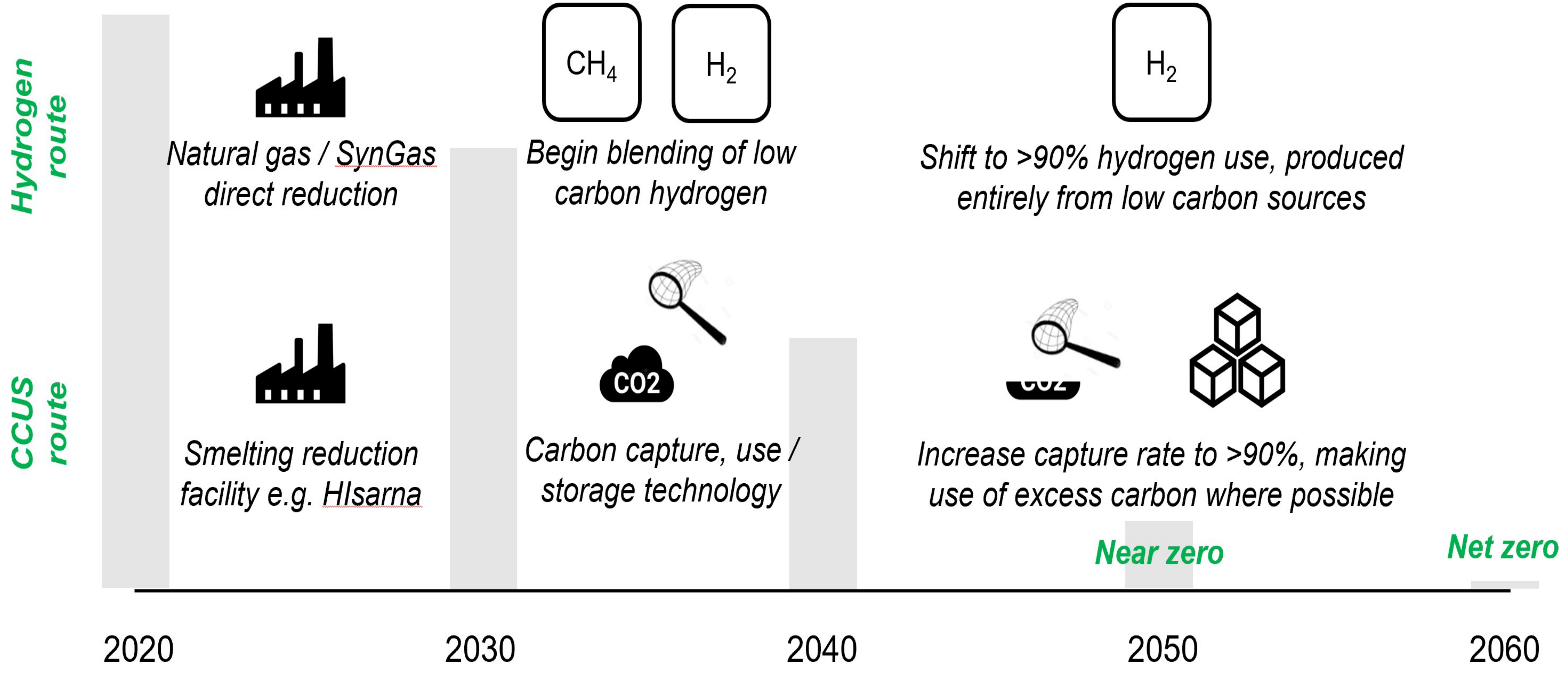
5 In the steel industry, hydrogen can be part of a cost-competitive, step-wise route to decarbonization by 2060

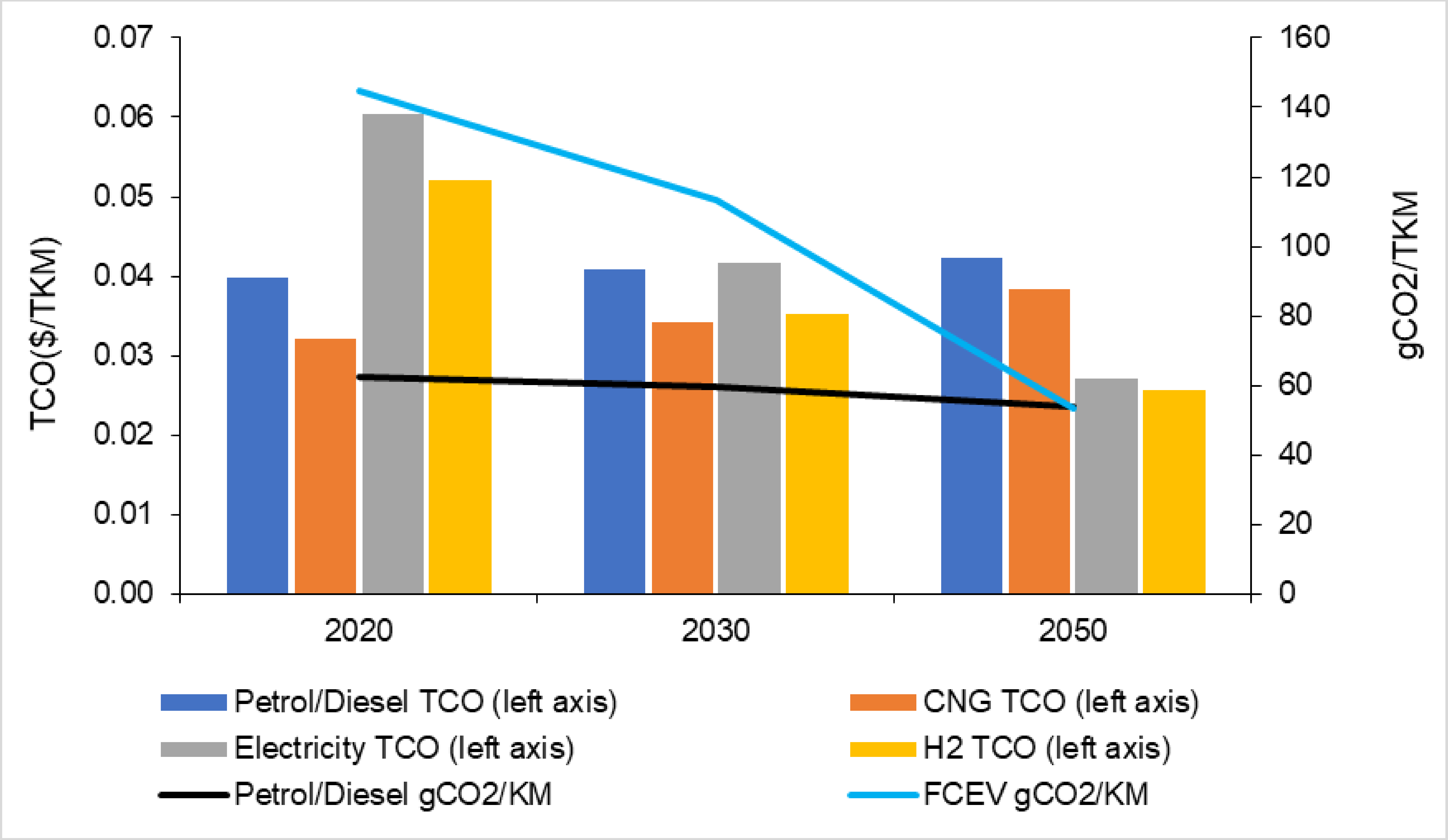
Figure: Pathways for decarbonizing primary steel production in India 2020-2060



Source: TERI analysis

6 In transport, hydrogen could play an important role in the long-distance heavy-duty vehicle segments

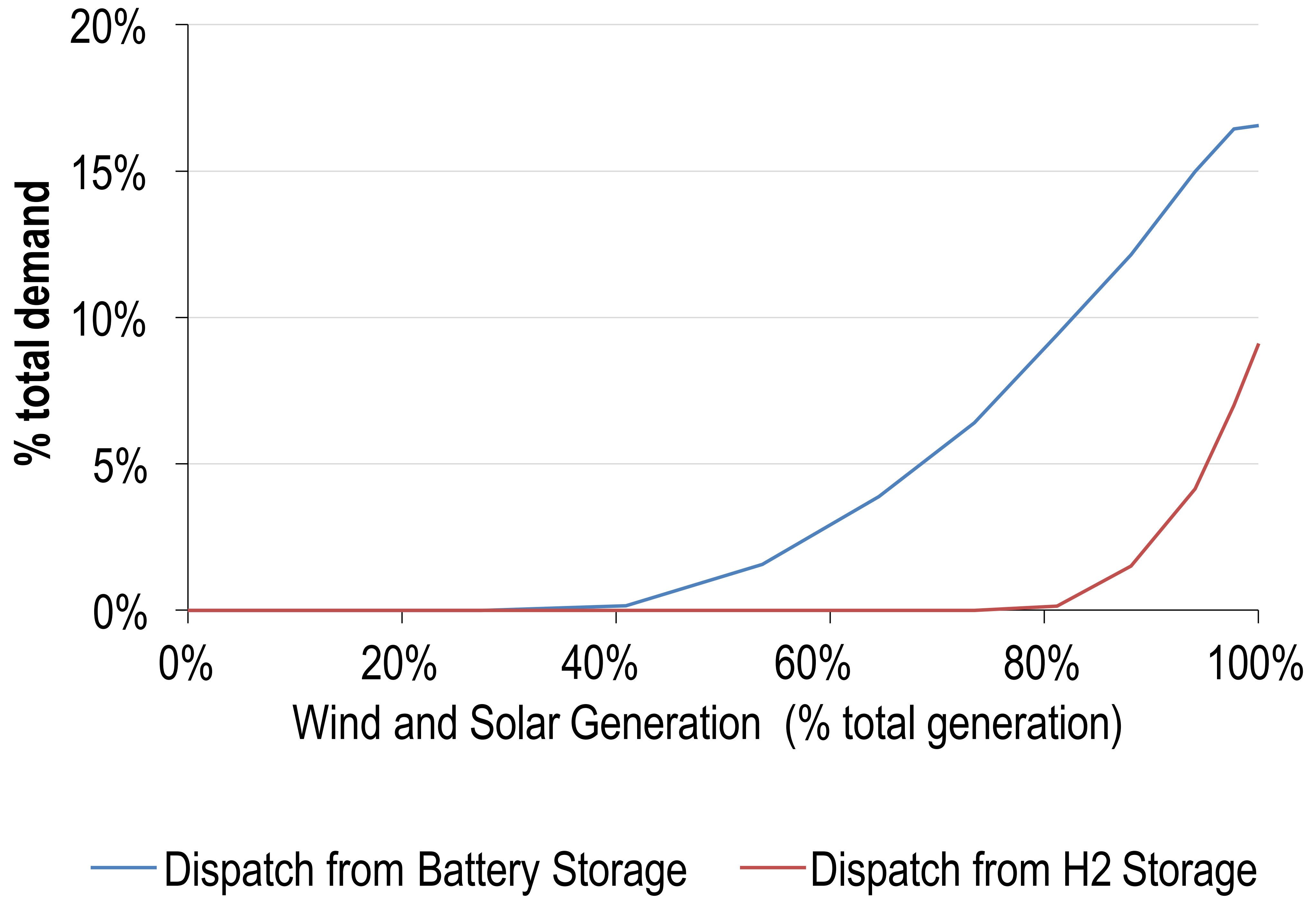
Figure: Modelled results for trucks Total Cost of Ownership (TCO) ($/TKM) and carbon intensity (gCO_2/TKM)



Source: TERI analysis

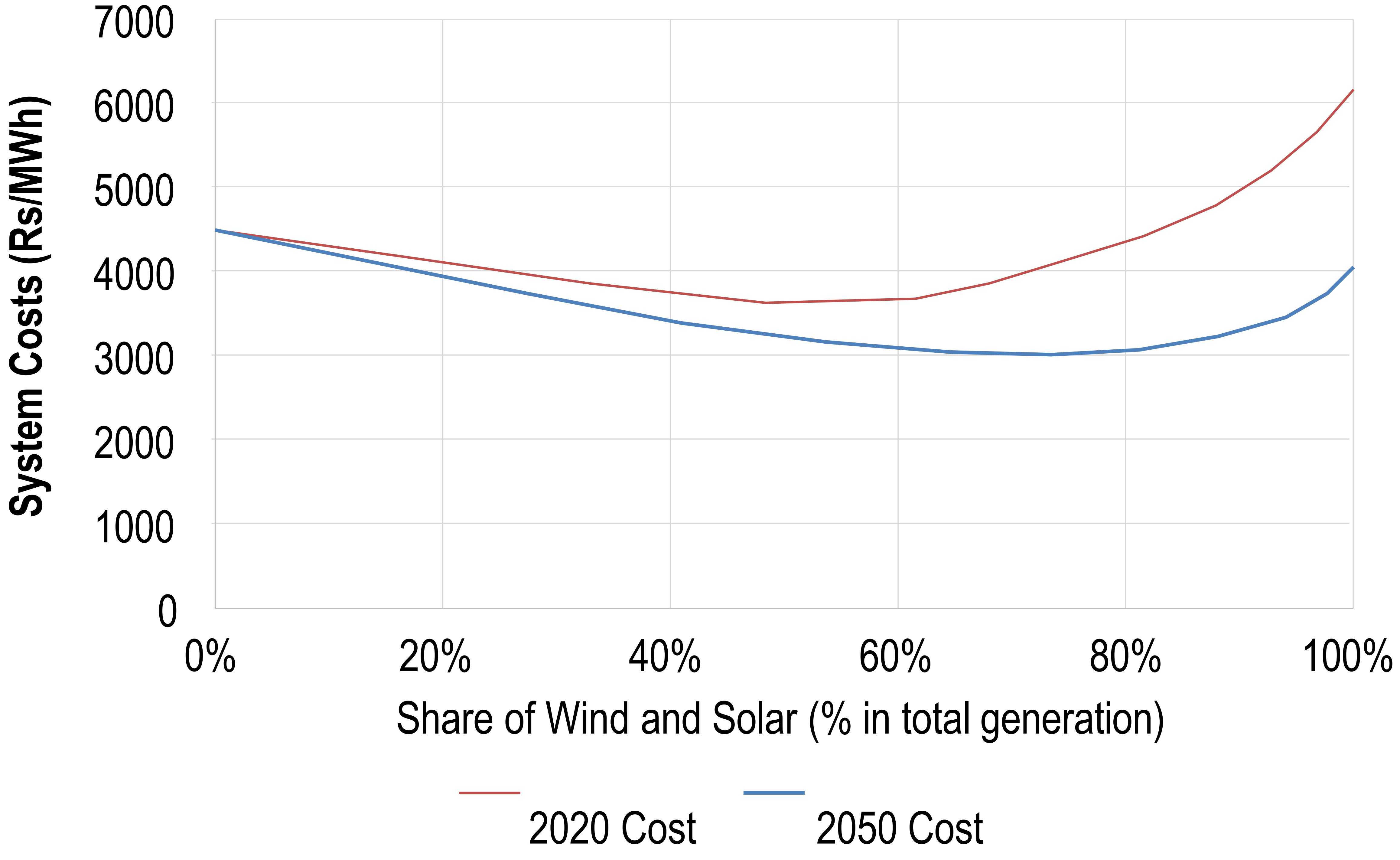
7 In power, hydrogen could provide an important source of seasonal storage, but is expensive and only required in high RE systems

Figure: Role of Seasonal and Intraday Storage With Increasing Share of VRE



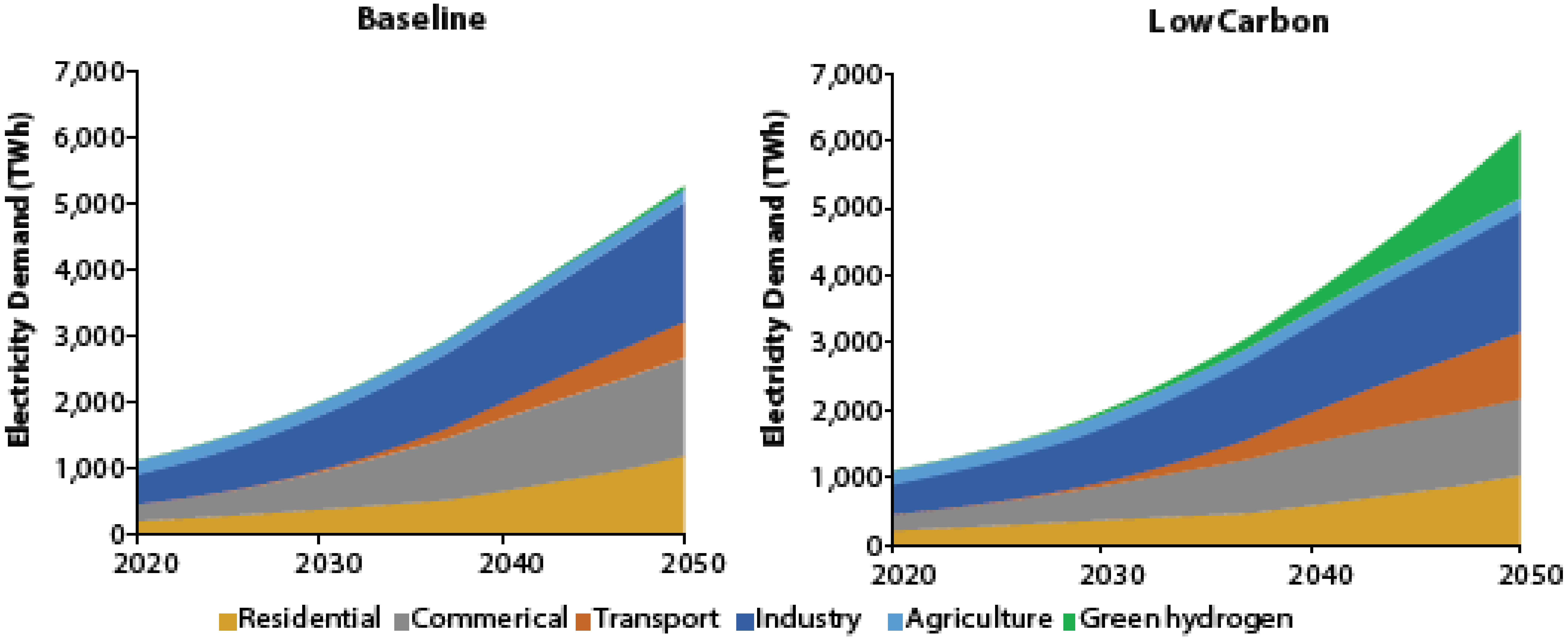
Source: TERI analysis

Figure: System Wide Costs With Increasing Shares of VRE, 2020 and 2050 Technology Costs



8 Green H_2 production could require around 1000 TWh of Green Electricity by 2050, placing further pressure on power system decarbonization

Figure: Annual electricity demand by major end-use sector, Baseline and Low-carbon Scenarios



Source: TERI analysis

RE potential and its opportunities in driving hydrogen economy

Renewable Energy Potential in India

India has set an ambitious target of achieving 500 GW non-fossil fuel energy capacity by 2030 and become net zero by 2070 at COP26.

Solar energy - India has achieved 5th global position in solar power deployment. Presently, solar tariff in India is very competitive and has achieved grid parity. National Institute of Solar Energy has assessed the Country's solar potential of about 748 GW assuming 3% of the wasteland area to be covered by Solar PV modules.

Wind energy - India currently has the world's 4th largest wind installed capacity. The total installed capacity is 39.25 GW (as on 31st March 2021) and has generated around 60.149 Billion Units during 2020-21. Recent assessments by the National Institute of Wind Energy (NIWE), indicate a gross wind power potential of 302 GW (100 meters) and 695 GW(120 meters) above ground level.

Small Hydro - In India, hydro-power plants of 25MW or below capacity are classified as small hydro. Total estimated potential is 21 GW from 7135 sites.

Bio Energy - Current availability of biomass in India is estimated at 750 million metric tonnes per year. A recent study supported by MNRE indicated estimated surplus biomass availability at about 230 million metric tonnes per annum covering agricultural residues corresponding to a potential of about 28 GW.

Source: SECI, MNRE, TERI analysis

Renewable Energy: "A Decade of Decline" – Indian trends

Solar energy prices have fallen by more than 20% in the past five years

Price fall

- 30 percent decline in wind tariff and 20 percent decline in solar tariff observed during last 5 financial years

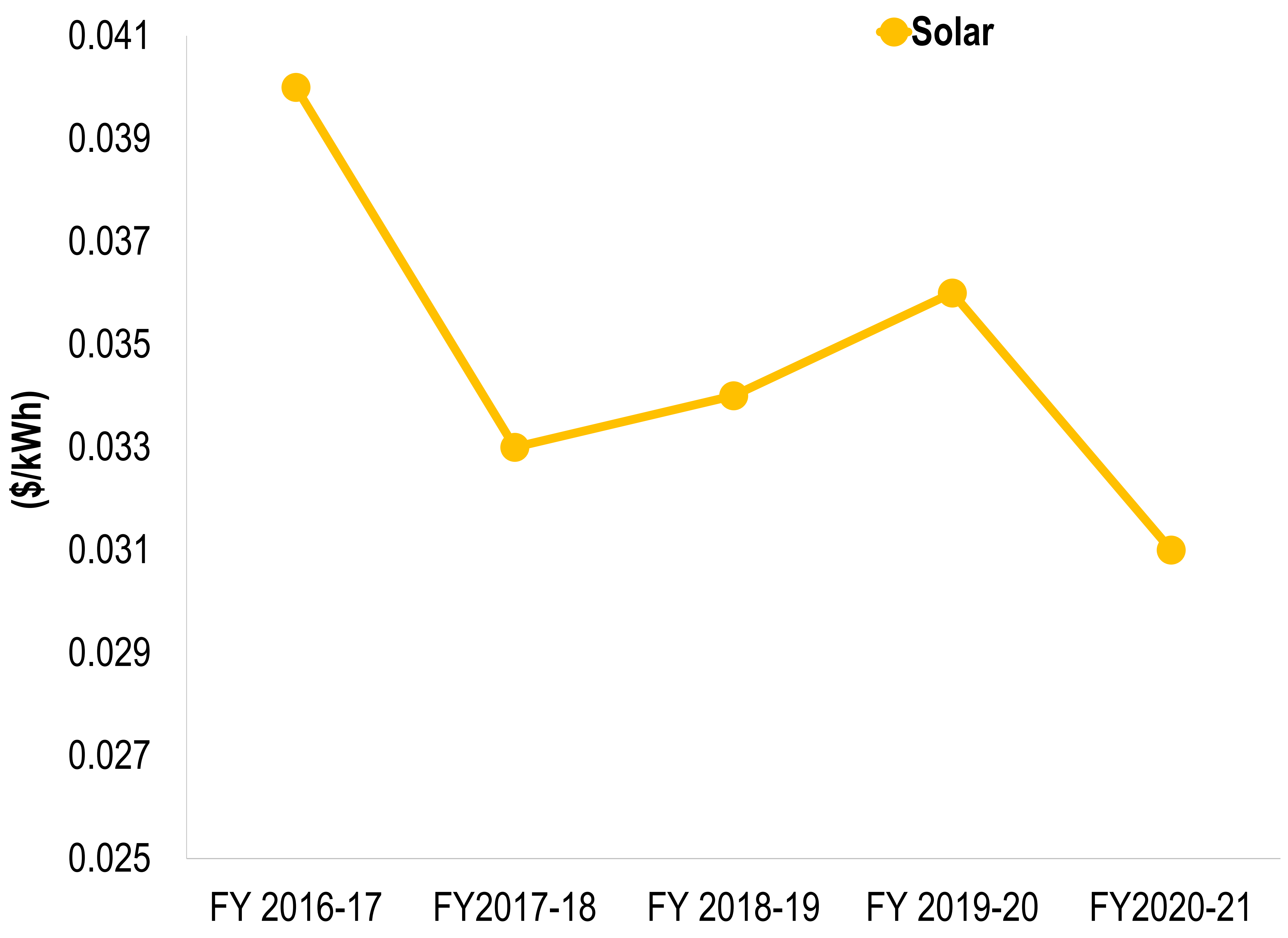
Role of Solar Energy Corporation of India Ltd (SECI)

- SECI's introduction led banks to favorably assess RE projects, and investors to accept lower returns on their investments.

Introduction of Production Linked Incentive (PLI)

- The PLI scheme for encouraging local manufacturing of solar PV modules can further reduce the cost of solar projects in the coming decades.

Figure: Falling Prices of Solar ($/kWh)



Source: SECI, TERI analysis

Future energy mix – TERI Analysis

- In 2020, solar and wind energy comprised approximately 20% of India's total installed energy capacity.
- TERI analysis suggests that solar and wind energy could constitute 56% of India's total installed capacity mix by 2030 and ~ 80% by 2050 under a Constrained RE Scenario (CRES) scenario.
- However, there are many challenges to large scale RE deployment like transmission constraints, financial health of the DISCOMs, energy storage & balancing requirements, etc

Table: Installed capacity (GW) – TERI analysis

Installed capacity (GW)										
	CRES				URES			NFS		
Year	**2020**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Coal	205	225	215	247	225	216	169	176	69	0
Gas	25	14	3	21	14	3	2	13	2	0
Hydro*	51	45	46	65	45	46	44	57	58	57
Nuclear	7	12	17	42	12	10	10	18	19	18
Solar	35	220	658	748	220	608	1472	230	789	1839
Wind	38	164	367	694	164	456	421	167	424	368
Pump Hydro**	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	8.8	8.8
Total	**367**	**686**	**1308**	**1828**	**686**	**1345**	**2124**	**667**	**1370**	**2291**

Note: For 2020, the presented figure is Gross generation excluding biomass. For 2030, 2040, and 2050, results are normalized for the entire year.
***Including small hydro ** Excluding W2E and biomass capacity of 12 GW**

- **Constrained RE Scenario (CRES)**: Least Cost Optimal Capacity with bounds on RE potential based on RE potential and availability on barren land
- **Unconstrained RE Scenario (URES)**: Least Cost Optimal Capacity Without Bounds on RE Potential
- **No fossil fuel scenario (NFS)**: Provides insight into a plausible future for India's electric power system, considering no new build-up of fossil-based generation capacity after 2025. As coal-based generation has an economic lifetime of 25 years, any capacity addition in 2025 should retire by 2050.

Source: TERI analysis

Key players

Key industry players with initiatives in Hydrogen in India

Focus areas		
Hydrogen Production	End-Use applications	Across the value-chain (Hydrogen production, storage, end-use cases)
ACME Leading Through Innovation; BHEL; Reliance Industries Limited; Bharat Petroleum; greenko; Oil India Limited; ONGC; ohmium; adani; TCC Inspiring Growth; L&T	ArcelorMittal Nippon Steel; TATA STEEL; JSW Steel; TATA MOTORS; TOYOTA; COCHIN SHIPYARD LIMITED; IFFCO Wholly owned by Cooperatives; Mahindra Rise.	GAIL; NTPC; IndianOil

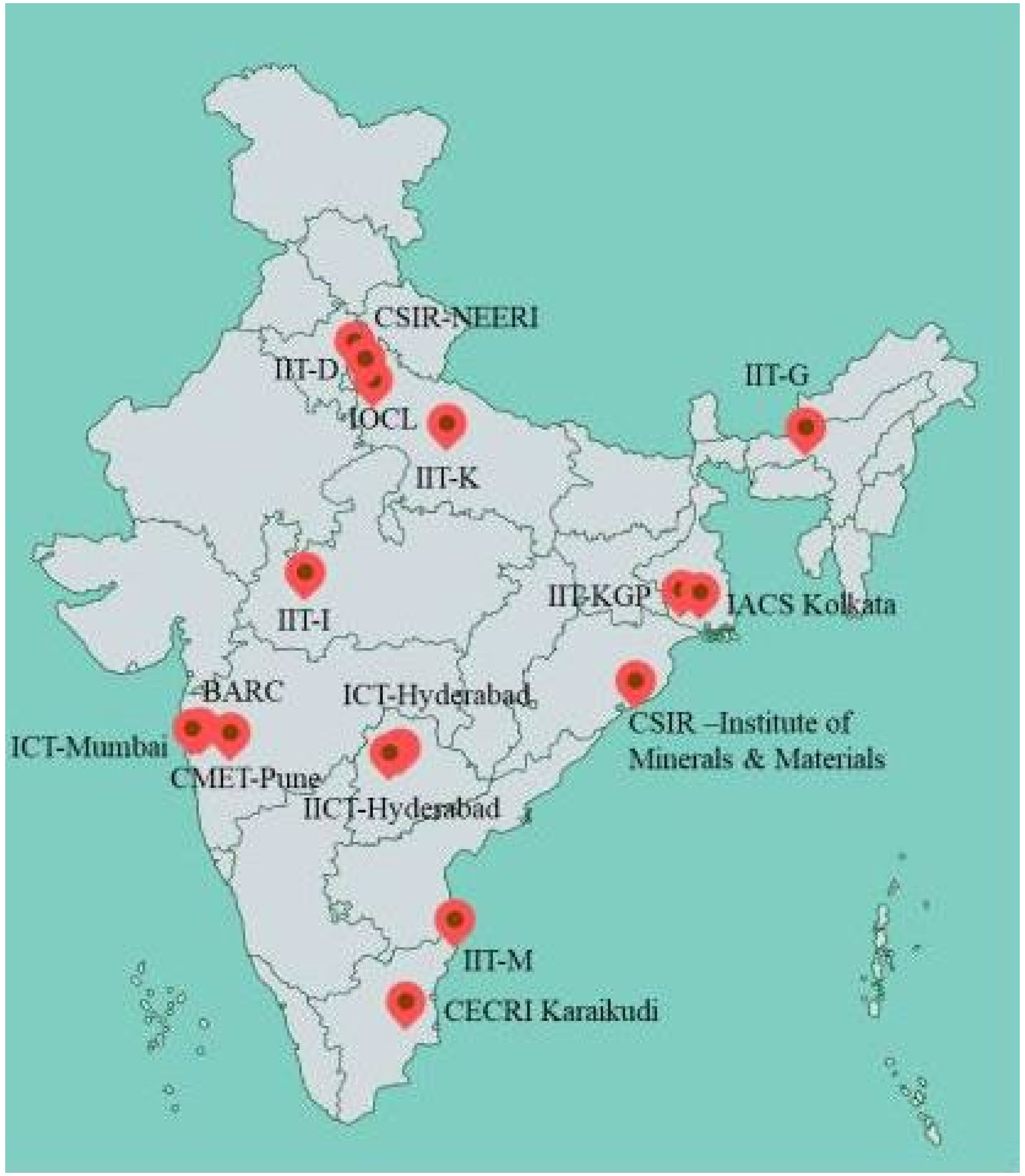
Note: The figure above includes organizations that have announced plans and projects in hydrogen

AND MANY MORE….

Academia in Hydrogen production

1. Indian Institute of Technology – Madras (IIT-M)
2. Indian Institute of Technology – Guwahati (IIT-G)
3. Indian Institute of Technology – Indore (IIT-I)
4. Indian Institute of Technology – Kanpur (IIT-K)
5. CSIR – National Environmental Engineering Research Institute (CSIR-NEERI)
6. Indian Institute of Technology – Delhi
7. Bhabha Atomic Research Centre (BARC)
8. Indian Institute of Technology – Kharagpur
9. Indian Institute of Chemical Technology – Hyderabad
10. Centre for Materials for Electronics Technology – Pune
11. Indian Association for Cultivation of Science (IACS)– Kolkata
12. CSIR – Institute of Minerals & Materials (CSIR-IMMT)
13. Institute of Chemical Technology (ICT) – Mumbai
14. Institute of Chemical Technology (ICT) – Hyderabad
15. Central Electrochemical Research Institute (CECRI) – Karaikudi
16. Indian Oil Corporation Limited – Faridabad

Figure: Map depicting key institutions in India working in Hydrogen production

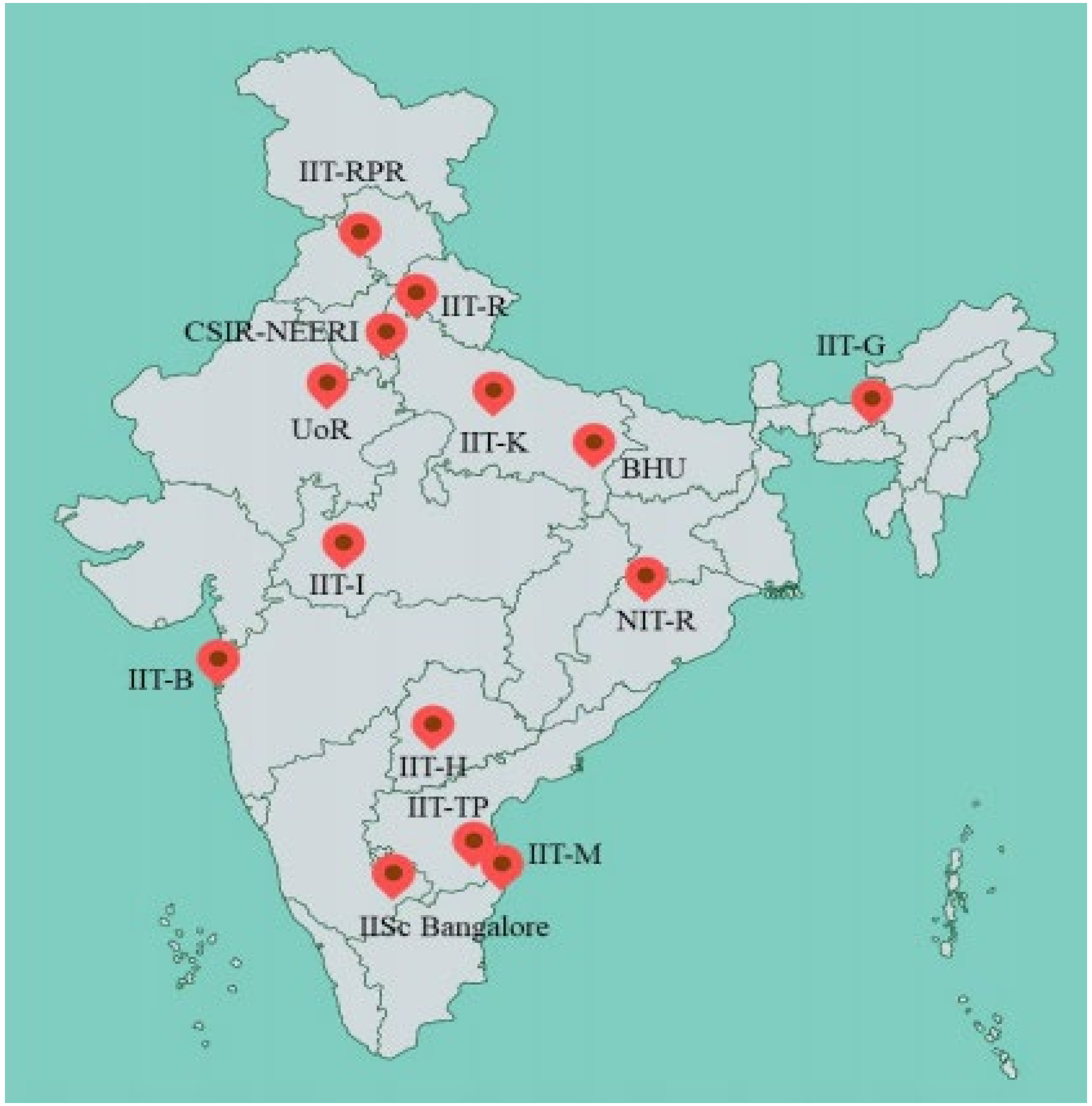


Source: DST, 2020

Academia in Hydrogen storage

1. Indian Institute of Technology – Bombay (IIT-B)
2. Indian Institute of Technology-Banaras Hindu University (IIT-BHU)
3. Indian Institute of Science – Bangalore (IISc)
4. Indian Institute of Technology – Madras (IIT-M)
5. Indian Institute of Technology – Guwahati (IIT-G)
6. Indian Institute of Technology – Tirupati (IIT-TP)
7. Indian Institute of Technology – Indore (IIT-I)
8. Indian Institute of Technology – Ropar (IIT-RPR)
9. Indian Institute of Technology – Kanpur (IIT-K)
10. Indian Institute of Technology – Hyderabad (IIT-H)
11. Indian Institute of Technology – Roorkee (IIT-R)
12. CSIR – National Environmental Engineering Research Institute (CSIR-NEERI)
13. University of Rajasthan (UoR)
14. National Institute of Technology – Rourkela (NIT-R)

Figure: Map depicting key institutions in India working in Hydrogen storage



Source: DST, 2020

Policy landscape

National Green Hydrogen Mission – Phase 1: Green Hydrogen Policy

- **On February 17th 2022** the Ministry of Power notified the **first phase** of the National Hydrogen Mission policy on green hydrogen and green ammonia, to boost production of hydrogen and ammonia using renewable energy.
- The Policy objective is for India to emerge as an export Hub for Green Hydrogen and Green Ammonia.
- The Policy includes **13 provisions . Some of these measures are**:
  - **No Inter-State transmission charges** shall be applicable for 25 years for power used to produce Green hydrogen
  - **Land in Renewable Energy (RE) parks** can be used for setting up Green hydrogen/Green ammonia
  - **Distribution licensees can supply RE to Green hydrogen/Green Ammonia manufacturers** by charging a regulated tariff (procurement cost + wheeling charges + small margin as determined by State regulator)
  - MNRE will set up **single portal for all statutory clearances** and also enable aggregation of Green hydrogen demand through its agencies.
  - Manufacturers of Green Hydrogen / Green Ammonia shall be **allowed to set up bunkers near Ports for storage of Green Ammonia for export / use in shipping**. The land for the storage purpose shall be provided by the respective Port Authorities at applicable charges.

Source: MNRE

National Hydrogen Mission – Possible policy options to promote hydrogen in India

Reports suggest that the following provisions could be introduced in the 2nd phase of the National Hydrogen Mission. These include:

The Production Linked Incentive Scheme (PLI)

- The Government of India (GOI) plans to introduce a PLI scheme for electrolysers to promote production in India.
  - The outlay of the scheme is expected to be approximately $2 billion.
  - The timeline for the scheme is expected to be 5 years starting from FY24.
  - Reducing the Goods and Services Tax to zero for a 5 year period on electrolysers.

Green hydrogen consumption/purchase obligations

- Mandating (refineries, fertiliser companies etc) to use green hydrogen and green ammonia in a phased manner.

The second phase of the Mission is currently under review with the expenditure finance committee.

Source: Hindustan Times, others

Overview: Potential Sites - Green Hydrogen

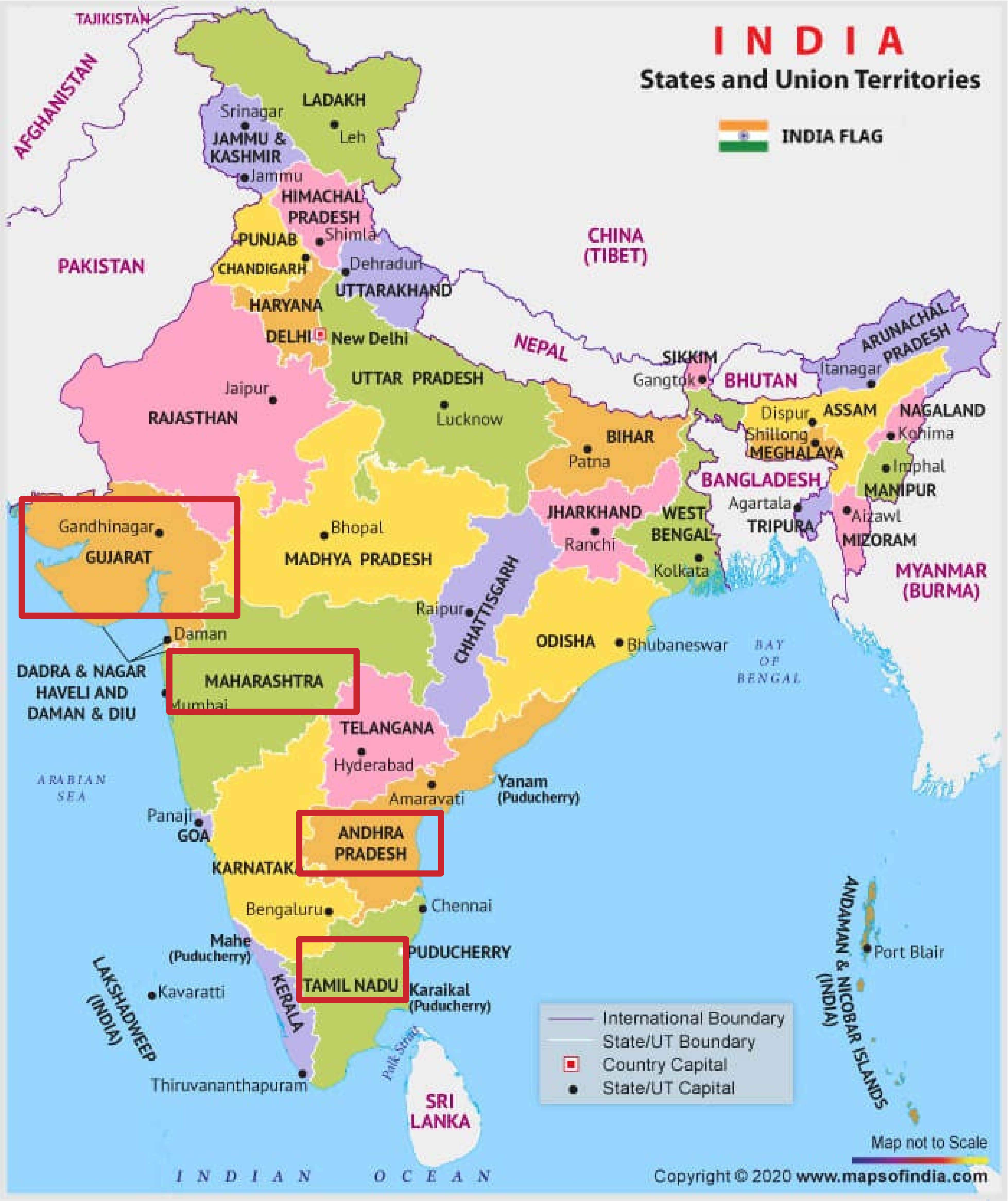
To assess the Potential States for Green hydrogen production, TERI used the following **six criteria**:

1. Renewable Energy potential
2. Logistics Support
3. Land Availability
4. Policy Support
5. State GDP
6. Targeted Consumers

On the basis of these selection criteria **4 States** were shortlisted. These include:

1. Gujarat
2. Maharashtra
3. Tamil Nadu
4. Andhra Pradesh

Only for representation



Potential Sites - Green Hydrogen - Gujarat

Selection Criteria

Renewable Energy

- The State possess a RE potential of 15GW.

Policy Support

- State level hydrogen policy are at the final stage
- Strong policy push for RE promotion

Logistics support

- 1600 km coastal line backed by 42 ports
- Dedicated SEZ for ports

State GDP

- Gross State Domestic Product is USD 260 billion.
- Special Economic Zone: 21 Operational and 26 under progress

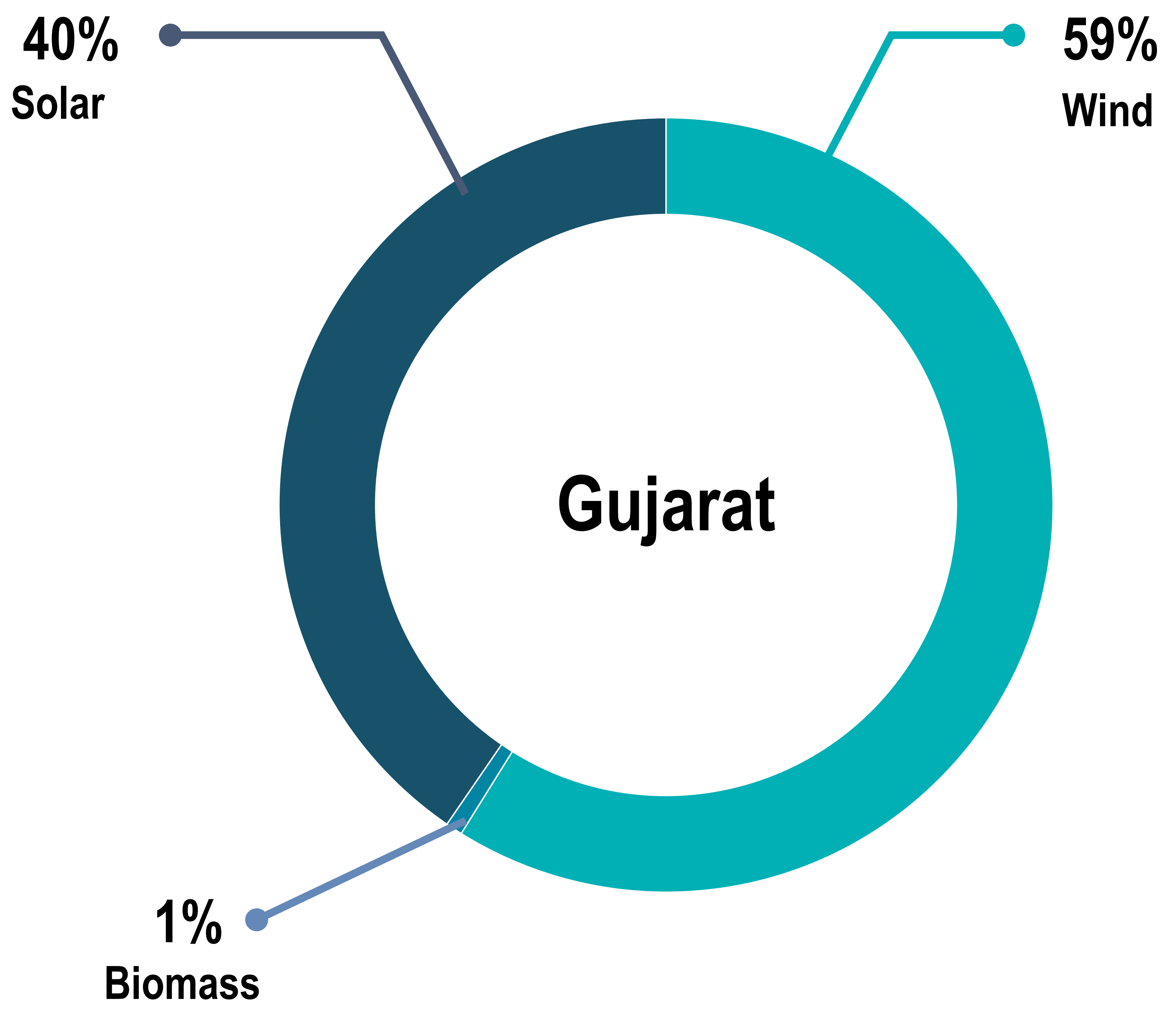
Land Availability

- 8564 hectares of land available for development.

Targeted consumers

- Chemical and petrochemical
- IT and Data centers

Renewable Energy Potential



Source :MNRE,SDA, Land Resources department, TERI Analysis

Potential Sites - Green Hydrogen - Maharashtra

Selection Criteria

Renewable Energy
- State possess a RE potential of 10GW.

Policy Support
- Strong policy push on RE promotion
- Signs MoU to run tractors on hydrogen fuel

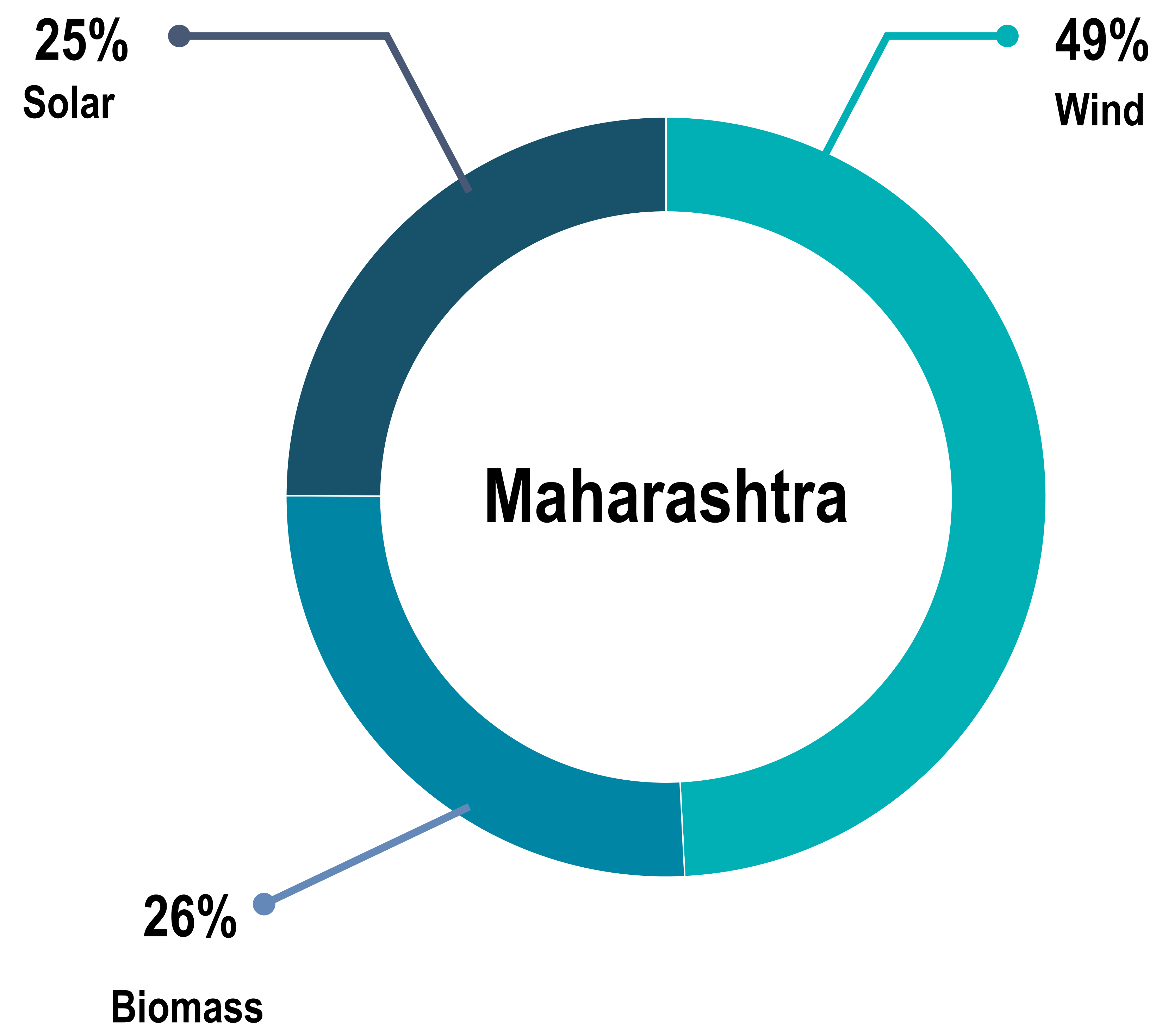
Logistics support
- 720 km coastal line backed by 48 ports
- Plans to invest USD 2.4 billion on port infrastructure development

State GDP
- Gross State Domestic Product is USD 366 billion.
- Developed 37 Public IT parks with an investment of USD 2.5 billion

Land Availability
- 12,574 hectares of land available for development.

Targeted consumers
- Refining & petrochemicals
- IT and Data centers

Renewable Energy Potential



Source :MNRE,SDA, Land Resources department, TERI Analysis

Potential Sites - Green Hydrogen – Tamil Nadu

Selection Criteria

Renewable Energy

- State possess a RE potential of 16GW.
- USD 631 million investment on solar cell manufacturing

Policy Support

- Strong policy push on RE promotion
- Plans to introduce hydrogen technologies in transport

Logistics support

- 1076 km coastal line backed by 20 ports

State GDP

- Gross State Domestic Product is USD 290 billion.
- Special Economic Zone: 50 notified SEZ

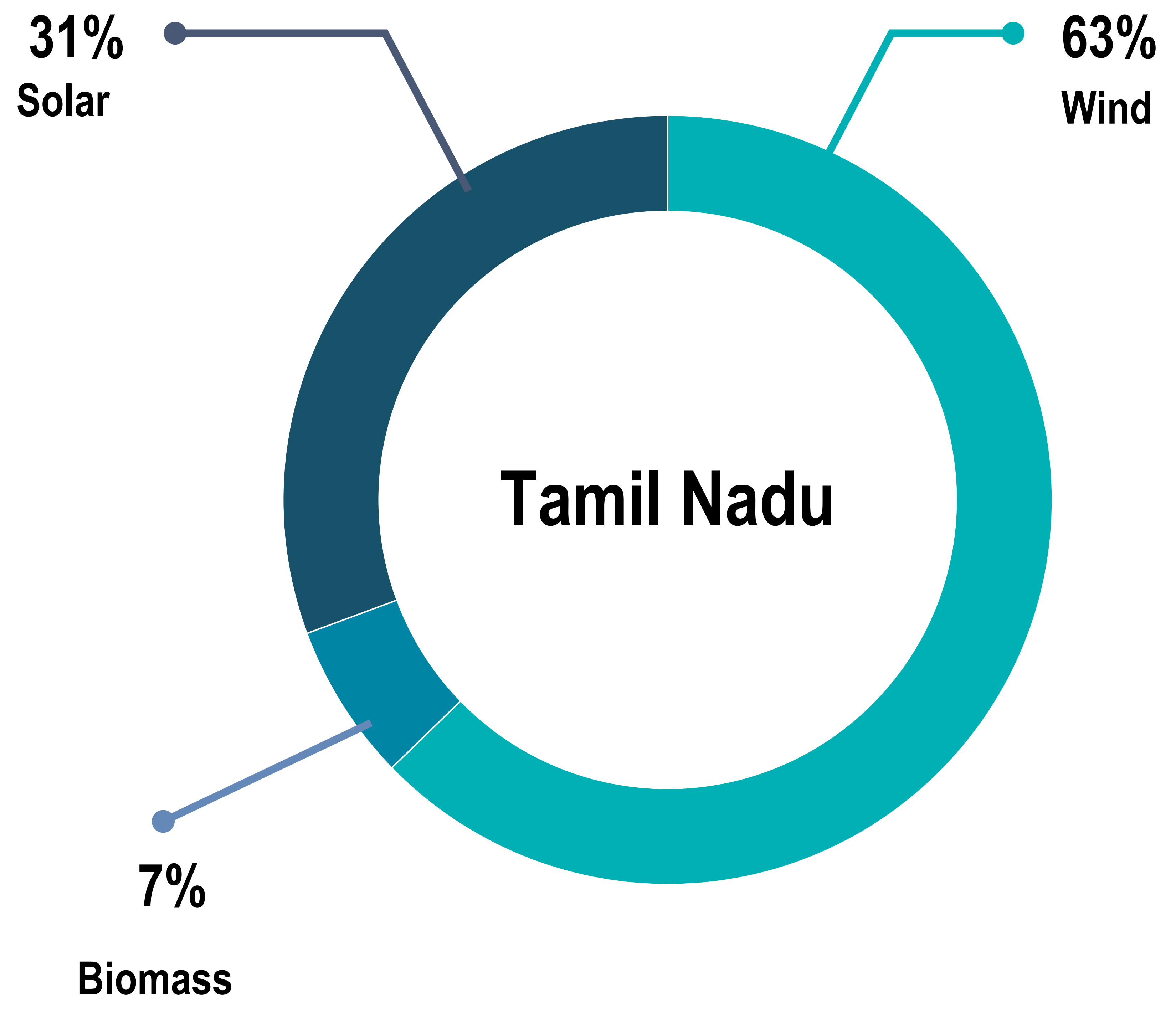
Land Availability

- 2820 hectares of land available for development.

Targeted consumers

- Chemical & Petrochemical
- IT and Data centers
- Cement & fertilizer

Renewable Energy Potential



Source :MNRE,SDA, Land Resources department, TERI Analysis

Potential Sites - Green Hydrogen – Andhra Pradesh

Renewable Energy

- State possess a RE potential of 9 GW.
- AP Green Energy Corporation with a mandate to install 10,000 MW of dedicated solar power capacity.

Policy Support

- Strong policy push on RE promotion
- Plans to develop India's first Green Hydrogen Micro grid at Visakhapatnam

Logistics support

- 975 km coastal line backed by 15 ports
- Plans to develop a Greenfield Port at Ramayapatnam in the state

State GDP

- Gross State Domestic Product is USD 135 billion.
- 32 SEZ operating in the state

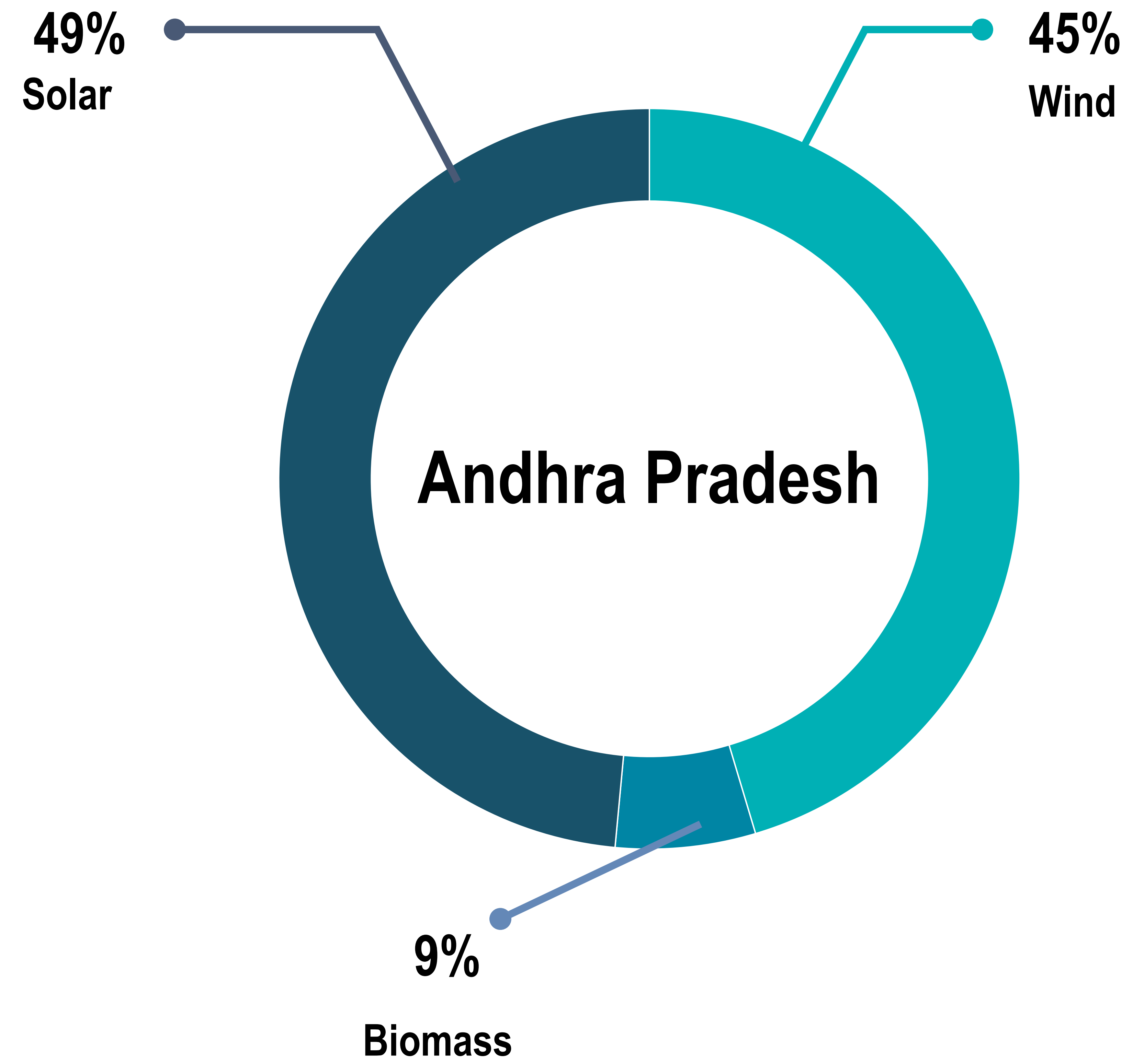
Land Availability

- 4704 hectares of land available for development.

Targeted consumers

- Chemical & Petrochemical
- IT and Data centers

Renewable Energy Potential



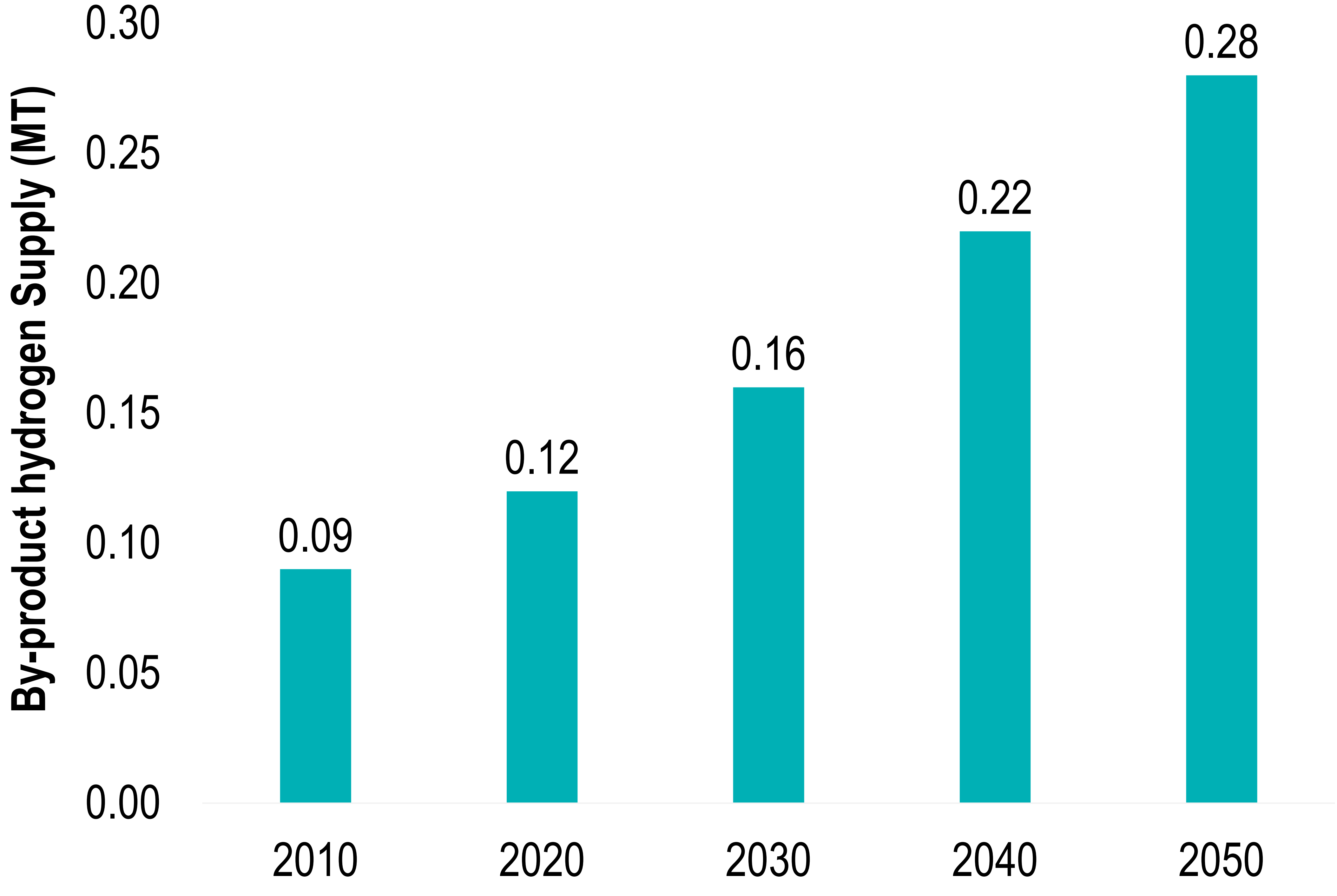
Source :MNRE,SDA, Land Resources department, TERI Analysis

Potential of by-product hydrogen

The Chlor-alkali sector could play a role in kick-starting the use of hydrogen in some industrial clusters, and could help scale-up India's nascent electrolyser manufacturing capacities.

- A major source of by-product hydrogen in India is the Chlor-alkali sector. The existing hydrogen production capacity of all **Chlor-alkali plants in India is approximately 0.12 MT.**
- **In the refining sector** hydrogen is produced as a by-product during the refining process. However, this is insufficient to meet total refinery demand, and additional on-site production is used.
- Major chlor-alkali plants are situated in the State of Gujarat.
- TERI estimates: production of by-product hydrogen from the chlor-alkali industry **could increase to approximately 0.16 MT by 2030 and around 0.3 MT by 2050**.

Figure: Estimated supply of by-product hydrogen from the chlor-alkali sector (TERI analysis)



Source: TERI analysis, based on stakeholder consultations

Way forward

Transition Pathway

Piloting hydrogen based technologies during the current decade will be crucial

Sector	Use-Case	2022-2030	2030-2040	2040-beyond
Industry	• Ammonia (fertilizer) and Refinery	● (red)	● (light green)	● (light green)
	• Steel production	● (red)	● (teal)	● (light green)
Mobility	• Light-duty passenger transport	● (red)	● (orange)	● (hatched)
	• Heavy-duty freight transport	● (red)	● (hatched)	● (hatched)
	• Shipping	● (red)	● (teal)	● (teal)
Power sector	• Short-term (daily) storage/grid management	● (red)	● (orange)	● (orange)
	• Mid-long term (weekly/monthly/seasonal) storage	● (red)	● (teal)	● (light green)

Key

- ● (red) Existing conventional technologies dominate
- ● (teal) Hydrogen starts to become competitive with existing technologies
- ● (orange) Battery technologies may be more competitive than existing technological options
- ● (hatched) Mixed paradigm with both hydrogen and battery technologies playing a role.
- ● (light green) Hydrogen will be competitive

Source: TERI analysis. Note: This table is primarily based on TERI's hydrogen report.

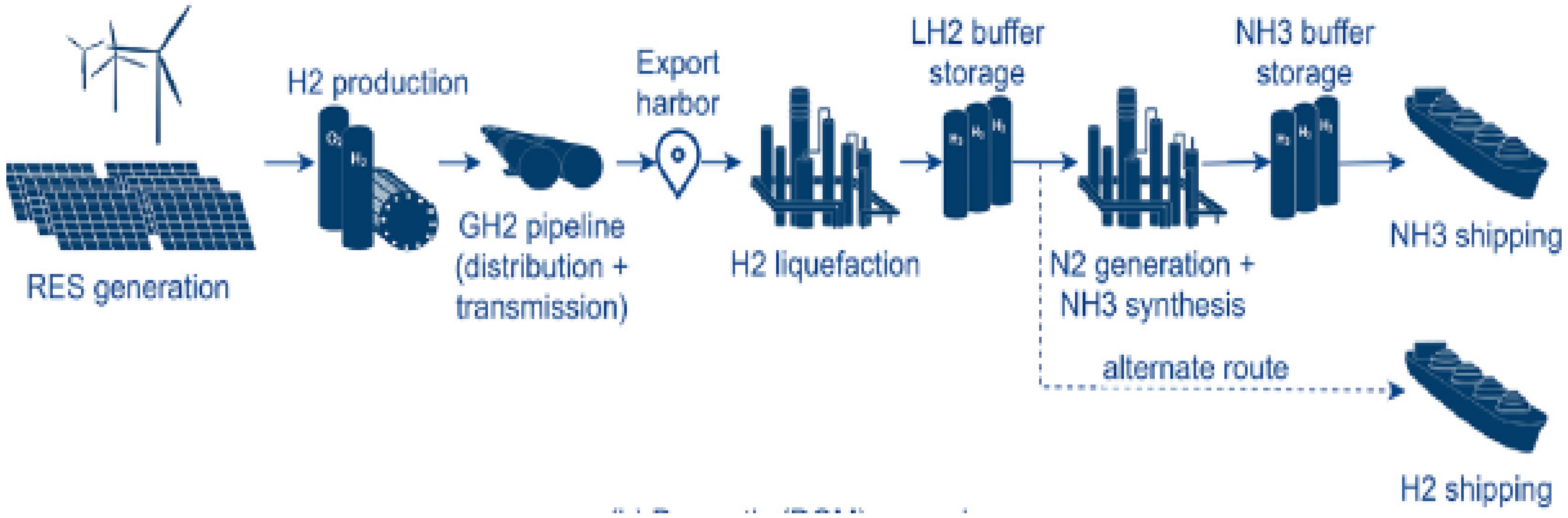
Hydrogen exports from India

The National Hydrogen Energy Mission aims to make India an export hub for Green Hydrogen and Green Ammonia

- In line with the Government of India's plan to export green hydrogen/green ammonia, **a detailed in-depth analysis** to assess the potential for exports will need to be undertaken.
- The **costs of infrastructure** for storage, transportation, compression, conversion and re-conversion of hydrogen could add significantly to the delivered costs of hydrogen/ammonia.
- **Safety concerns** for handling of hydrogen and ammonia would also need to addressed.
- A study by researchers from Forshungszentrum Julich estimates that the landed costs of shipped liquefied ammonia (direct-use) from Mumbai to Yokohama could be approximately **$4.75/kgH$_2$** .in 2030, which is comparable to landed costs from Australia.

Figure: Representation of modeled ammonia infrastructure

Export oriented supply chain



Source: Pawar, N.D., Heinrichs, H.U., Winkler, C., et al (2021)

Note: RES = Renewable Energy Sources

Indo-Japan collaboration/opportunities

Partnerships between India and Japan will be valuable, given Japan's expertise across all areas of the hydrogen value chain.

1. **Bringing together industry and Government stakeholders** to build partnerships for co-innovation between India and Japan will reduce the risks of initial deployment.

2. **Research, development and demonstration (RD&D) partnerships** and feasibility studies to assess the potential role of hydrogen in end-use cases.

3. **Pilot-scale projects** with multiple companies along a supply chain, or in a cluster eg. sector-specific **hydrogen clusters/valleys**.

4. Japanese industry **investments in hydrogen technologies in production, transport, storage and end-use sectors** such as electrolyser manufacturing, green ammonia production or other applications.

5. **Joint forums, workshops and knowledge-sharing platforms** to discuss best-practices, potential pathways for collaborative research.

6. **Discussions on standards and safety** to promote harmonization.

Conclusion

- **Hydrogen presents significant opportunities for collaboration. In India, TERI's analysis suggests that hydrogen demand could increase five-fold to 28Mt by 2050.** The Government of India has given policy support to scale-up India's hydrogen ecosystem. The recent launch of The Green Hydrogen Policy 2022, the first phase of the National Hydrogen Mission, provides incentives for the manufacturing of green hydrogen and green ammonia. Several industry stakeholders are also undertaking projects across the hydrogen value-chain in hydrogen production, storage, and transportation to develop India's hydrogen ecosystem.

- **This year, 2022, marks the 70th anniversary of the establishment of diplomatic relations between India and Japan**. Both Japan and India have set ambitious targets for their energy transitions, with India announcing plans to become net-zero by 2070, and Japan announcing a target of achieving net-zero by 2050. **For both India and Japan hydrogen will serve as an important component to decarbonize difficult-to-abate sectors and energy systems**.

- **On the demand-side**, industry (especially the **iron and steel sector, fertilizer sector and the refinery sector**), mobility, and the **power sectors** could be major segments for future collaborations. **On the supply-side,** hydrogen production, development of hydrogen technologies such as electrolysers, and the development of hydrogen storage, and transportation could be areas of future collaborations.

- **Partnerships** on research, development and demonstration through bilateral and multilateral routes involving both the private and public sector **will be crucial** in the coming years to build the green hydrogen ecosystem and drive down costs.