The Potential Role of Hydrogen in India

A pathway for scaling-up low carbon hydrogen across the economy

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EXECUTIVE SUMMARY

Harnessing the hype on hydrogen

Hydrogen has long been the ‘fuel of the future’ but has to-date never quite made it as a major player in the energy system. Today, a number of key developments suggest that the time for a substantial role for hydrogen in the energy system has come. First, concern about global climate change is increasing, and it is becoming clear that decarbonization of the energy system necessitates new low carbon fuels and chemical feedstocks. Second, technology innovation in electrolysers and electricity generation from zero-carbon renewables is making the prospect of abundant low carbon hydrogen realistic.

However, it is important to put this hype in perspective. To be deployed at scale, hydrogen will need to compete with incumbent fossil fuels and emerging low carbon alternatives, such as battery electric vehicles. Although cheap and abundant, there will be competing demands for low carbon electricity and the production of hydrogen from electrolysis is an extremely electro-intensive process. Moreover, the use of hydrogen in end-uses is not always the most efficient solution, with direct electrification being more efficient in many applications. Finally, the specifics of hydrogen deployment will depend on country context. Hydrogen value chains may look quite different in a context of abundant and consistent zero-carbon hydroelectricity, like Scandinavia, versus a context of abundant but variable solar electricity like India.

For this reason, it is necessary to assess the potential role of hydrogen from a systems perspective, considering all potential end-uses, production routes, and value-chain configurations. This report represents a first-of-its-kind comprehensive assessment for the Indian context.

An emerging virtuous circle for hydrogen deployment

Historically, the deployment of new energy technologies has not been linear. Mass deployment of a technology typically requires technological innovation in the technology itself, as well as in a host of enabling technologies within the broader value chain. For example, while the principle of electric incandescent lighting was demonstrated in the early 19th century, its mass deployment would await multiple enabling innovations in electricity generation and distribution in the last decades of the 19th century.

Today, hydrogen faces a similar situation, whereby numerous technology developments are coming together to enable the successful penetration of hydrogen in the energy system. These include:

- Growing demand in numerous end-use sectors like industry.
- Supply-side innovation in production technologies, notably electrolysers and renewables.
- Enabling technological developments, for example, the development of high renewables power systems creating ‘technology problems’ which hydrogen can help to solve (notably excess renewables generation, need for long-term electricity storage).
- Growing policy interest in driving deep decarbonization of energy systems, which will require chemical energy carriers like hydrogen, and in capturing the industrial benefits of hydrogen.

These factors are beginning to drive an emerging virtuous circle for hydrogen deployment in the energy systems of several major economies. It is important that India seizes on this emerging virtuous circle as hydrogen could be a crucial tool for a low-emissions, cost-effective, and less import-intensive energy sector for India.

Hydrogen demand could increase 5-fold by 2050, with use in industry being the major driver

Hydrogen demand could increase by at least 5-fold by 2050, continuing to grow in the second half of the century. Demand for hydrogen today is at around 6 Mt per annum, coming solely from industry sectors, such as fertilizers and refineries. This can increase to around 28 Mt by 2050, driven by cost reductions in key technologies, as well as the growing imperative to decarbonize the energy system. Demand will continue to be largely focused in industry sectors, either expanding in existing sectors, such as fertilizers and refineries, or growing into new sectors, such as steel. Hydrogen will play some role in the transport sector in heavy-duty and long-distance segments, and a minor role in the power sector as a long-term storage vector. Beyond 2050, we can expect demand for green hydrogen to continue to grow, particularly in the steel and road transport sectors, as well as in shipping and aviation. Reaching a net-zero target by 2060 could require around 40 Mt of green hydrogen, a 7-fold increase over today.

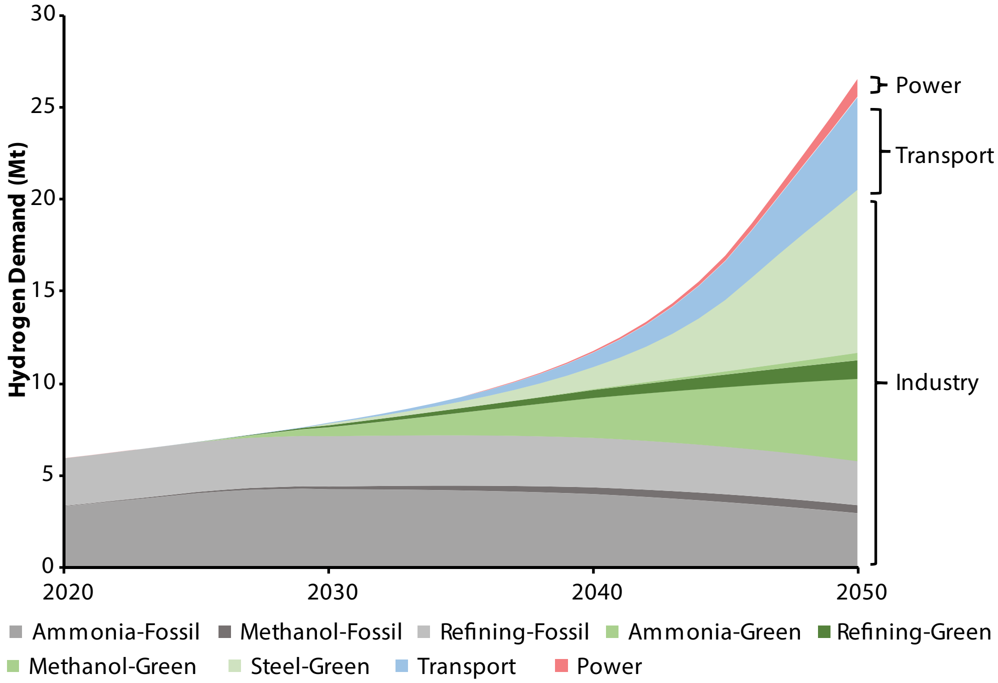

Figure 1: Hydrogen demand projection in the Low-Carbon scenario, 2020-2050

Source: TERI analysis

By 2030, costs of hydrogen from renewables will fall more than 50% and will start to compete with hydrogen produced from fossil fuels

As of today, essentially all of the hydrogen consumed in India comes from fossil fuels. However, by 2050, nearly 80% of India's hydrogen is projected to be 'green' – produced by renewable electricity and electrolysis. Based on a comprehensive assessment of possible production routes conducted in this report, it is clear that green hydrogen will become the most competitive route for hydrogen production by around 2030. This is driven by dramatic cost declines in key production technologies such as electrolysers and solar PV. For example, the cost of alkaline electrolysers is projected to drop from around Rs. 6.3 Cr/MW today to around Rs. 2.8 Cr/MW by 2030. The decline in electrolyser costs will be partly driven by large-scale deployment in India and globally, by a virtuous circle between falling costs and strengthening policy to promote hydrogen. Improving efficiencies of electrolysers, as well as increasing load factors of solar plants, will also play an important role in driving the costs of green hydrogen below Rs.150/kg by 2030 ($2/kg) – versus Rs. 300–440/kg ($4–6/kg) as of today. At this price, green hydrogen starts to compete with hydrogen produced from natural gas allowing it to make inroads into various end-use segments. India's lack of domestic natural gas supply and high cost of imports make green hydrogen competitive sooner than in other parts of the world.

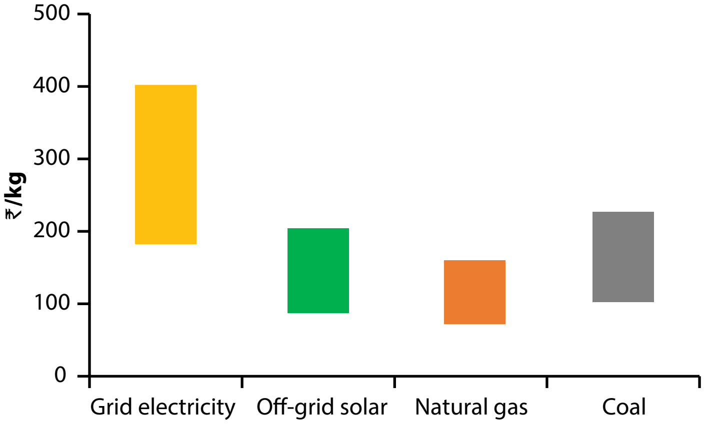

Figure 2: Levelized costs of hydrogen from different sources, 2030 range

Source: TERI analysis based on (IEA, 2019; BEIS, 2018; BNEF, 2020)

Given the scale of the prospective market, India should be proactive in manufacturing electrolysers to produce green hydrogen

The pace of developments in hydrogen technologies is accelerating, driven by growing interest from governments and businesses around the world looking to drastically reduce emissions from their energy systems, whilst maximizing the use of domestic resources. Several leaders are emerging in this sector, including Japan, the European Union, and China. A window of opportunity still remains for India to capture large parts of this market, using the advantage of a large domestic market, competitiveness of green hydrogen, and low-cost labour. Policies should therefore be oriented to incentivize domestic manufacturing of electrolysers, in line with the Government of India's 'Make in India' programme. The government should set targets for electrolyser deployment by 2030 and facilitate companies to establish electrolyser manufacturing facilities in India.

Driven by a range of factors, the deployment of hydrogen in different sectors will occur on different timeframes and for different reasons

The term 'hydrogen economy' is a misnomer, given that hydrogen is not a panacea for the challenge of energy transition, and will not be suitable for use in all areas of the energy system. Hydrogen's suitability depends on the specific characteristics of each sub-sector, notably on the need for energy-dense fuels (long-duty transport and long-term electricity storage in power); the need for hydrogen as a feedstock and fuel (ammonia, steel, methanol); or the need for high grade process heat, for example in industry. Importantly, hydrogen will have to compete with other low carbon technologies, notably direct electrification through for example, battery electric vehicles. Thus, it is important to provide a detailed analysis for each sub-sector, as we do in this report. Table 1 provides an overview of the key findings of this analysis, which are elaborated in the following paragraphs.

Table 1: The role of hydrogen across key sectors

Sector	Use-Case	2020s	2030s	2040s
Transport	Light-duty passenger and freight transport	BEVs competitive with both FCEVs and ICEs	BEVs competitive with both FCEVs and ICEs	BEVs competitive with both FCEVs and ICEs.
	Short-distance, regular-route heavy-duty transport	BEVs becoming competitive with ICEs. FCEVs not competitive.	BEVs competitive with both FCEVs and ICEs.	BEVs competitive with both FCEVs and ICEs.
	Very long-distance heavy-duty freight transport	ICEs competitive.	FCEVs and BEVs becoming competitive with ICE.	FCEVs likely to be competitive with ICE. BEVs partly competitive.
Industry	Ammonia production	Fossil fuels competitive. H_2 becoming competitive.	H_2 competitive (ammonia and refineries) and partly competitive (steel).	H_2 from renewables competitive.
	Steel production			
	Refineries hydrogen demand			
	Methanol production	Fossil fuels competitive.	Fossil fuels competitive. H_2 partially competitive.	Fossil fuels competitive. H_2 partially competitive.
	Industrial heat	Fossil fuels competitive. Direct electrification partly competitive.	Fossil fuels competitive. Electrification increasingly competitive.	Fossil fuels likely to be competitive. H_2 and direct electrification may be partly competitive.
Electricity storage	Short-term (daily) storage	Li-ion batteries competitive.	Li-ion batteries competitive.	Li-ion batteries competitive.
	Short-term (weekly/monthly/seasonal) storage	Long-term balancing from fossil and hydro. Long-term storage needs minimal.	H_2 becoming competitive but minimal need as wind and solar still below 60-80%.	H_2 competitive. Long-term storage required in a high wind and solar system.

Legend: Brown = fossil fuels dominate. Yellow = direct electrification without using H_2 as an energy vector, e.g. battery electric vehicles or li-ion batteries in electricity storage. Blue = hydrogen. Green = mixed paradigm with several technologies including hydrogen.

Source: TERI analysis.

Note: This table only covers the use cases assessed in this report and is not exhaustive.

In transport, battery electric vehicles will be competitive across all segments, limiting the role of hydrogen to long-distance and heavy-duty applications

Over the past decade, we have experienced extremely rapid cost reductions in battery technologies, alongside significant improvements in performance. This has made Battery Electric Vehicles (BEVs) lower cost, with greater range and faster recharging times, making them more attractive to consumers across a growing number of segments. Hydrogen Fuel Cell Electric Vehicles (FCEVs) must compete with the ever-improving BEV technologies to have an impact on transport decarbonization. Based on our analysis, from the medium-term, BEVs will dominate most of the smaller, shorter-range passenger vehicles, including two-, three-, and four- wheelers, as well as city buses and last-mile freight. However, FCEVs could remain competitive in longer-distance, heavier-weight vehicle segments, such as heavy-duty trucking. Even in these heavy-duty segments, the eventual winner of the competition between BEVs and FCEVs is not yet clear, as technologies are progressing rapidly.

In industry, steel and ammonia will drive growth in hydrogen demand, followed by refineries and methanol

Industry is the main consumer of hydrogen in India, and this will remain the case out to 2050, with industry making up 80% of total demand in our **Low Carbon** scenario (Figure 1). Today, this is mainly driven by ammonia production and refineries, both of which will increase. According to the analysis of this report, ammonia produced using green hydrogen from dedicated renewables paired with storage could start to compete with natural gas-based ammonia by 2030. Likewise, by the 2030s, steel production based on green hydrogen is projected to be competitive with steel from the traditional fossil fuel routes. Indeed, because of the size of the sector, steel is the main driver of green hydrogen demand in our **Low Carbon** scenario, using hydrogen as a reducing agent to replace coal. With a concerted policy push, it may be possible to foster a domestic methanol industry based on green hydrogen, although this would have to compete with lower cost coal-to-methanol. Although refinery output declines in our **Low Carbon** scenario as transport fuel demand peaks and begins to decline by 2050, green hydrogen could compete with fossil-based hydrogen in India's large refinery sector by 2030. Although further analysis is needed, it is unlikely that hydrogen will compete in industrial heat applications – India should actively explore heat electrification technologies, wherever feasible.

In power, hydrogen could be a cost-effective way of providing inter-seasonal storage in a high variable renewable electricity system from 2040

As India's electricity grid decarbonizes further via the integration of growing shares of wind and solar, more electricity storage will be required to help manage the variability of renewables. Improvements in battery technologies mean that they are already able to provide cost-effective short-term storage to manage intra-day variability. However, as the grid reaches higher and higher shares of variable renewables, there will be fewer coal-fired plants that are able to manage the longer periods of demand and supply variation, such as low wind output during the winter months. As a result, hydrogen could play a role as a long-term storage vector, absorbing excess electricity during certain periods of the year, to be used again at times of sustained low renewable output. This only becomes a necessary option of managing grid variability at high penetrations of variable renewables in total generation, i.e. above 60–80% of total generation. India is unlikely to reach this level of variable renewables penetration until around 2040.

Hydrogen production from renewables is an energy-intensive process, and direct electrification should be preferred wherever possible

As well as the inherent suitability and competitiveness of hydrogen in different sub-sectors, it is important for policymakers to consider hydrogen deployment from a system-wide perspective. Given the energy-intensive processes required to produce hydrogen, it should be targeted in sectors where direct electrification is not possible. For example, producing 1 kg of hydrogen requires 50 kWh of electricity, based on electrolyser efficiency of 70%, resulting in an energy loss of around 30%. There is then a further energy loss if this hydrogen is stored and converted back to electricity, as is the case for transport and power applications. A corollary of these conversion losses is that the CO_2 intensity of electrolytic hydrogen production is higher than that of the input fuel, electricity. This means that for electrolytic hydrogen to be competitive with fossil fuels, for example in transport, the input electricity must be very low emissions. Hydrogen deployment should thus be prioritized in sectors where no alternatives exist, and its production must be based largely on zero-carbon electricity for net emissions reductions to be achieved.

Industrial clusters are an attractive model for the early development of hydrogen infrastructure

Based on a detailed spatial modelling of India's main industrial clusters, which includes their access to nearby renewable resources, we show that low-cost and reliable green hydrogen production is possible based largely on variable wind and solar. This includes an analysis of a cluster in Gujarat, where we find a concentration of chemical and petrochemical facilities, which can produce hydrogen at $2/kg by 2030. The analysis also looks at an eastern state, Odisha, with a concentration of steel plants, where hydrogen production costs are slightly higher due to lower quality renewables resources nearby. This analysis also highlights the importance of flexible electrolysers and low-cost hydrogen storage to ensure that a near-constant level of hydrogen demand can be met. Finally, whilst independent hydrogen clusters look attractive, it will still be important for such systems to be connected to the electricity grid to allow export of excess electricity or use grid electricity as a last resort, when needed.

Scaling up the use of domestically produced hydrogen can significantly reduce energy imports

India currently imports 85% of its oil, 50% of its natural gas, and 30% of its coal. This comes at a significant expense, exposing India to the frequent price fluctuations of international energy markets. Domestic production of hydrogen from renewable electricity will significantly reduce energy imports, whilst supporting a domestic energy industry. This improves India's energy security, thereby reducing commodity price uncertainty for major industries. By 2050, annual energy imports could be reduced by around 120 Mtoe (around 20% of today's final consumption), reducing import costs by around Rs.150,000 Cr ($20bn) each year.

To accelerate the adoption of hydrogen technologies in India, a step-change in government policy and business actions is required

To achieve the ambitious vision set out in this report, a step-change in government policy and business actions will be required. This includes greater cross-sectoral coordination within the government, to help realize the economy-wide benefits and interactions of hydrogen technologies. There must also be a shift from early-stage R&D programmes towards later-stage commercialization support to help bridge the 'valley of death'. To ensure that low carbon hydrogen is favoured over high emission alternatives, an emissions penalty could be introduced at some stage, either in the form of more stringent regulations, or a carbon tax. To support the demand for green products made using green hydrogen, green product standards should also be introduced. Finally, to support these government-led initiatives, the private sector should target their activity towards competitive projects, while partnering with international technology providers wherever necessary.