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WORKING PAPER - GREEN HYDROGEN

Executive Summary

Recently, the governments of the U.S. and India have both turned their attention to the development of hydrogen as they look to meet emissions reductions goals. U.S. legislation, including the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA), along with the Department of Energy's Hydrogen Shot initiative, use tax credits and direct funding to reduce the cost of hydrogen and create regional hubs to advance the development and deployment of clean hydrogen. India launched the National Hydrogen Energy Roadmap in 2006 to develop a research and development ecosystem and launched the National Green Hydrogen Mission (NGHM) in 2021. The NGHM seeks to scale up green hydrogen production and utilization across multiple sectors, ultimately making India a global green hydrogen hub.

As these initiatives get off the ground, there are several aspects of green hydrogen development, production, and deployment that need to be addressed in order to fulfill the promise of hydrogen programs in the U.S. and India, and to ensure that the production of hydrogen reduces overall emissions, particularly in the highest emitting industrial and power sectors.

To achieve the domestic goals laid out by both the U.S. and Indian governments, the two governments can collaborate in a number of ways to ensure effective development and deployment of green hydrogen and to address gaps in global hydrogen governance. These will include the development of:

1. A joint certification system for green fuels and a common taxonomy, as the current pathway to utilize hydrogen as well as certification schemes vary by country;
2. A mutually acceptable Measurement, Reporting and Verification protocol that provides guarantees of origin for green fuels;
3. Harmonized regulation standards to support the interoperability and trade in green hydrogen technologies;
4. A regional Green Hydrogen Price Index to increase price visibility, trade, and competitiveness;

5. Hydrogen hubs to share knowledge and experiences on how to accelerate the development process.

To reduce the cost of hydrogen, there are five recommended actions that India and the U.S. can undertake. First, they should build a clean steel partnership, jointly applying their resources to hasten the transition to green steel, thus providing market demand for green hydrogen. Second, India and the U.S. should build a green ammonia partnership, which could lead to cost reductions and supply crucial demand for green ammonia, and steer investment away from fossil-fuel based urea fertilizer production. Third, India and the U.S. should co-create viable markets and trading systems for green hydrogen and derivatives to lower the risk profile and lower the cost of green hydrogen finance. Fourth, the two countries should support efforts by the maritime sector to become Paris-aligned through the scaling up of green hydrogen and other steps to signal demand for zero-emission fuels. Finally, the U.S. and India should work together to develop the requisite market structures and trade mechanisms to support green hydrogen and derivatives.

Introduction

The purpose of this paper is to provide a deeper discussion on the state-of-play of hydrogen technology and policy in the U.S. and India, background information on global governance and cost reduction, and to present specific policy recommendations to be discussed and refined during the U.S.-India dialogue session on April 19, 2023. The revised recommendations will form the foundation for a memorandum to be shared with U.S. and Indian government officials following the dialogue.

In 2021, a meeting of the U.S.-India Track II Dialogue on Climate and Clean Energy produced a memorandum with recommendations on how the U.S. and India could leverage their leadership within the Quadrilateral Security Dialogue (Quad) to push for a Green Hydrogen Alliance. The proposed Green Hydrogen Alliance would advocate for a framework for research, development and demonstration, pooled funding and resources, pilot projects, and the development of a common set of standards. Following the Quad Leaders' Summit in September 2021, the Biden administration announced a clean hydrogen partnership which included several of the recommendations produced during the dialogue.

In March 2022, hydrogen was also a dialogue topic during the Subnational Cooperation Working Group. The working group discussed the current state-of-play for green hydrogen investments in the U.S. and India as well as the potential for a U.S.-India partnership to develop a global green hydrogen coalition. The proposed coalition would scale up the development and implementation of green hydrogen, including implementing green maritime shipping corridors between Quad nations.[1]

In October 2022, hydrogen became a topic of its own working group discussion. The group recommended various avenues of short- and long-term bilateral collaboration in this space. Acknowledging that, in the long term, electrolysis will be the way to produce green hydrogen, suggestions regarding creating a clean steel partnership, a green ammonia partnership and co-creating viable markets and trading systems to lower the risk profile were made. In the near term, it was highlighted that there is a bilateral opportunity to have a more diverse portfolio of hydrogen production by including biomass-to-hydrogen pathways. The suggestions from October are further fleshed out in this paper.

Hydrogen State-of-Play

United States

The U.S. produces approximately 10 million tons of dedicated hydrogen, which is production where hydrogen is the intended product, of which 95% is gray hydrogen from steam reforming natural gas.[2] Demand for hydrogen is mainly in the refining, fertilizer, and chemical (e.g. methanol) sectors. The U.S. has about 1,600 miles of pipeline, much of it near refineries along the Gulf Coast, dedicated to transporting hydrogen.

The U.S. Department of Energy (DOE) launched the Hydrogen Shot initiative in June 2021 which aims to reduce the cost of clean hydrogen by 80% to $1 per 1 kilogram (kg) in a decade.[3] This was the first of DOE's *Energy Earthshots* initiative, a larger strategic framework to "accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade."[4] DOE has outlined a national strategy for a pathway to 10 million tons of clean hydrogen by 2030, 20 million tons by 2040, and 50 million tons per year by 2050.[5]

On February 15, 2022, DOE launched several clean hydrogen initiatives under the IIJA.[6] The Regional Clean Hydrogen Hubs program would provide $8 billion to advance the production, processing, delivery, storage, and end-use of clean hydrogen, including innovative uses in the industrial sector. The funding will be used to establish up to 10 hydrogen hubs (H2Hub) across the country to create a network of clean hydrogen producers and consumers to create a clean hydrogen economy.[7] As of February 2023, there were 22 proposed H2Hub projects that are encouraged by DOE, meaning the applications are on a pathway to completion. The selection process for the funding of these hubs is expected to conclude sometime this year. These proposed projects include single and multi-state agreements and coalitions between private utilities and energy producers. Of these, 15 plan to use renewable energy as a feedstock for hydrogen production, nine will use fossil fuels as a feedstock, and seven will use nuclear as feedstock. All of the proposed H2Hubs plan on developing industrial end uses for hydrogen, including in the steel industry and as a chemical feedstock. Other planned end uses for hydrogen are in the transportation sector for trains, planes, and trucking, for electric power generation, and for residential and commercial heating.[8]

Additionally funding from IIJA includes $1 billion for a Clean Hydrogen Electrolysis Program to reduce costs of hydrogen produced from clean electricity and $500 million for Clean Hydrogen Manufacturing and Recycling Initiatives to support equipment manufacturing and strong domestic supply chains.

The Inflation Reduction Act (IRA) also encourages hydrogen in the U.S. by including a clean hydrogen production tax credit (PTC) of up to $3 per kg for ten years.[9] The tax credits are on a sliding scale with the most credit going to clean hydrogen sources that provide a 60% reduction in greenhouse gas emissions compared to fossil-fuel based gray hydrogen. This would allow green hydrogen production to benefit most from the tax credit and accelerate the timeline for green hydrogen to become globally cost-competitive with gray and blue hydrogen by 2030.[10] Through the lifetime of IRA tax credits, the cost of U.S. production of green hydrogen is projected to decrease to $0.5 to $1.5 per kg from its current cost of $5 per kg.[11] Ensuring the climate benefits of these tax credits requires an accountability system to guarantee the hydrogen source is actually low-emitting and that there is an efficient end use of the low-cost hydrogen.

A major consideration regarding hydrogen in the U.S. is its potential to exacerbate historical environmental and health inequities in communities of color. Environmental justice (EJ) advocates in the U.S. have expressed a worry that the oil and gas industry has set the agenda for hydrogen development across the U.S., which may or may actually stall the movement away from fossil fuels and may not be safe for nearby communities. Hydrogen is being proposed for blending in natural gas pipelines for blending in natural gas pipelines. This could stall the transition away from fossil fuel infrastructure, delay the transition to electricity for heat, utilities and appliances, and maintain dependence on natural gas. At the same time, it is unclear if the natural gas pipelines will be able to safely handle hydrogen. Many EJ advocates are only willing to engage on green hydrogen, as opposed to gray or blue hydrogen, as an alternative fuel for heavy industries that otherwise have few cleaner alternatives such as steel, cement, and shipping. DOE is seeking to include equity and justice considerations in its hydrogen strategy by suggesting effects, costs, and benefits of proposed projects be provided to stakeholders in advance of community engagement. DOE also suggests H2Hub applicants use community benefit agreements to include local communities in the decision-making process. However, EJ advocates have been vocal against hydrogen being included in any investments targeted towards disadvantaged communities.

India

India launched the national hydrogen energy roadmap in 2006 to develop a research and development ecosystem.[12] The current emphasis on green hydrogen is an extension of this roadmap to move the ecosystem from lab-to-pilots and pilot-to-commercial scale. On January 4, 2023, the Union Cabinet approved the National Green Hydrogen Mission (NGHM) to aid the Government in meeting its climate targets of energy independence by 2047 and net-zero by 2070 and making India a green hydrogen hub.[13] In 2022, the Ministry of Power (MoP) published an enabling green hydrogen/ammonia policy, which is a precursor to the NGHM, led by the Ministry of New and Renewable Energy (MNRE).[14] This policy: (i) waives the interstate transmission charges of renewable power for 25 years for green hydrogen projects commissioned before 2025; (ii) aims to promote exports of green ammonia and has provisions for bunkering and exports near ports; (iii) provides for banking renewable energy and sets norms for the banking charges; and (iv) targets producing 5 million tonnes per annum (MTPA) of green hydrogen by 2030.

In 2020, demand for hydrogen in India was 6 million tonnes per year. Hydrogen demand in India is roughly split between the fertilizer and refining sectors. Hydrogen production at fertilizer plants in India is largely concentrated along natural gas pipelines. With hydrogen costs expected to decrease by 50% within the decade, demand for hydrogen is expected to increase to 28 million tonnes by 2050 with 80% being green hydrogen.[15] The NGHM aims to scale up green hydrogen production and utilization across multiple sectors. It will support the development and commercialisation of local green hydrogen technologies to reduce dependence on imported fossil fuels and enable decarbonisation of the economy. The NGHM has a budgetary allocation of approximately $2.4 billion to reduce the production cost of green hydrogen. This financial support will create the necessary economies of scale for reducing the cost of green hydrogen. The mission also has budgets for pilot demonstrations across the green hydrogen value chain. Additionally, there will be provisions for research and development and standards development. Finally, there is the intent a single window clearance mechanism to rapidly provide approval for green hydrogen projects. In India, electrolyzer manufacturing is in its very early stages. A few companies have started investing in setting up manufacturing units, while project developers like ACME, Greenko and Renew have announced plans to set up green hydrogen/ammonia plants targeting the international export markets.

Green hydrogen can be blended in natural gas pipelines, but blending demonstrations have proven that only a low-hydrogen-percentage blend is feasible and that too under very specific scenarios with limited end-usage applications.[1] Despite these successful trials, significant research and testing is required across the entire hydrogen and natural gas supply chain to fill current knowledge gaps and better inform decision makers on future blending projects.[2] India imports over 50% of its natural gas in the form of LNG. Access to reliable and reasonably priced LNG will allow steel capacity growth that in the future may transition into green hydrogen. Natural gas is treated as a bridge fuel to green hydrogen. While some raise the concern of sector-specific LNG lock in, and legitimate concerns regarding methane leakage, there seems to be general agreement that the locking-in of natural gas in India is not a concern given that the green hydrogen price is expected to reach parity with natural gas in a decade and subsequently become cheaper than imported LNG. In India, no new gas based plants are planned and there is anticipated commercial barrier to adopting green hydrogen once its cost is competitive. Furthermore, given the government’s push for the adoption of green hydrogen, there is no political barrier – natural gas giving way to green hydrogen is being pitched as an essential pillar of India’s energy security planning.

India has recognized the potential for the shipping sector to drive demand for green hydrogen in the short term in its own national strategies. As part of the green hydrogen consumption targets set by the government of India, India’s NGHM has identified shipping as a key sector for pilot projects. The strategy sets a goal for India’s largest fleet operator, the state-run Shipping Corp. of India (SCI.NS), to retrofit at least two ships to run on green hydrogen-based fuels by 2027, while India’s oil and gas companies will be required to charter at least one ship each to be

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[1] https://pib.gov.in/PressReleasePage.aspx?PRID=1888334
[2] https://www.nrel.gov/docs/fy23osti/81704.pdf

powered by green hydrogen or derived fuels by 2027, and to add one more hydrogen-powered ship per year. Green ammonia bunkering facilities will be established in at least one port by 2025 with similar facilities to be created at all major ports by 2035. Two ports on India's east coast and one port on the west coast will be developed by the Ministry of Ports, Shipping, and Waterways (MoPSW) as hydrogen hubs under the Green Shipping Initiative as part of the Maritime India Vision 2030.[16] At the international level, India and the U.S. have both been vocal supporters at the International Maritime Organization (IMO) of a 5% target on net-zero/zero emission fuel use by 2030 (with small variations in specific terms used). Aligning terminology and making it clear that the target relates to scalable fuels produced from renewable energy would greatly help the IMO to achieve consensus on this important milestone.

The energy transition timing in India is important. The availability of green energy solutions in the short to medium term (2-5 years) is essential to ensuring sustainable industrial growth. However, a lack of solutions during this time period would likely result in deployment of fossil fuel-based equipment and processes to meet the demand growth. This is especially the case for the steel industry where an additional 120 million tonnes per annum capacity is being planned through the blast furnace route. A typical lifetime of a blast furnace is 40-50 years with the potential for further extension. This could lock in coal beyond the Indian net-zero target. While India targets to more than double its steel capacity to 300 million tons by 2030,[17] according to Niti Aayog,[18] the green steel capacity is projected to reach 15-20 million tonnes by 2030.This capacity can be further augmented if access to green hydrogen-based steel production technologies are made available to India.

Global Marketplace Governance

Uniformity in how the green hydrogen marketplace is regulated will be critical to ensuring effective development and deployment of green hydrogen. There are several areas around which agreement between the U.S. and India would make it easier for the two countries to come together and encourage green hydrogen both domestically and internationally.

1. *India and the U.S. should jointly develop the certification system for green fuels*

   The pathway to utilizing hydrogen for decarbonization varies by country. The certification system should take into account the unique features of the individual countries. For example, in the case of green hydrogen in India, producers would like to either bank their renewable power or rely on grid power (that is not 100% renewable) to increase the capacity utilization of their plants, i.e., run electrolyzers at near 100% load, which will help reduce the levelized cost of hydrogen. Banking refers to the exchange of power by a producer with the grid where the producer transfers any excess renewable power into the grid (usually during peak generation) and then takes back an equal amount of power back later in the day (or night) when there is a drop in the renewable power supply. This is an accounting practice and does not always involve storage of renewable power. If the certification system does not allow for banking, then the corresponding hydrogen produced may not be considered green and hence not tradeable.

Flexibility is also desired in transmission of renewable energy across the national grid to not only reduce the hydrogen transportation costs but also decrease the emissions arising out of moving the clean fuel. These flexibilities are necessary in the early stages of market creation to achieve cost reduction and scale. However, there is a need for all stakeholders to speak the same language, which requires a clear taxonomy and certification mechanism. A globally accepted definition of green (or clean) hydrogen is also important to better integrate clean fuels into the global economy and meet the rapid scaling needed to achieve cost parity with fossil fuels. India and the U.S. can set up a committee of relevant stakeholders at each end to develop the certification system.

2. *India and the U.S. should develop a mutually acceptable Measurement, Reporting, and Verification (MRV) protocol*

Consumers of green hydrogen and derivatives will pay a premium for green fuels and therefore need assurance on the emissions intensity of the green fuels. There is a need to develop a robust MRV system that will provide guarantees of origin for green fuels and provide assurance that the fuel is green to the extent claimed. Developing such an MRV system that is acceptable to all parties needs coordinated actions from all countries in the ecosystem. The MRV protocols should also clearly lay out the requirements for auditors, specifically on the technical capabilities. Finally, there is a need to train the workforce in the hydrogen ecosystem for MRV certification of green fuels. A joint working group with the relevant technical capabilities and experience should be setup to develop the MRV protocol.

3. *India and the U.S. should harmonize and where necessary co-develop regulations and standards*

The green hydrogen ecosystem is a relatively new concept, and many countries lack the infrastructure and technical know-how to handle components across the value chain. Without well-coordinated global action, each country will have its own operational and safety standards for various equipment in the green hydrogen value chain, which might be different from the manufacturing country. This will impede the interoperability and trade in green hydrogen technologies. Therefore, streamlining standards on equipment used for production, storage, transport and use of hydrogen across geographies to enable unconstrained trade in hydrogen technologies is necessary.

Global coordination would enable provisions for technical supervisory committees that will establish either new standards and protocols or harmonize existing ones, build capacity in countries to adopt these systems, and conduct periodic inspections to ensure that participating countries/companies are adhering to the established standards. Common standards and practices can include a portfolio of testing, inspection, and certification methods and protocols for equipment based on globally acceptable benchmarks. The ability to seamlessly trade green hydrogen and derivatives, which is necessary to bring down costs, will depend on mutually acceptable protocols on trade between countries.

4. *India and the U.S. should collaborate on developing hydrogen hubs*

Hydrogen is the lightest element and transportation is an expensive proposition. One way to tackle this challenge is to produce and use the hydrogen in collocated facilities. Both India and the U.S. are planning to develop hydrogen hubs. These will quite likely include greenfield developments in both countries. Hence, sharing of knowledge and experience in identifying and setting up hydrogen hubs will benefit both countries. A platform should be created for all stakeholders to share information and experience, and if possible collaborate and participate in hydrogen hubs in either of the countries.

5. *India and the U.S. should develop a regional Green Hydrogen Price Index*

Currently, the price of green hydrogen is being set through mostly bilateral deals. The general market has no visibility of the prices, and hence achieving competitiveness in the market will take time. Also, trading in green hydrogen will be difficult without something to peg the price against. Lowering the price of green hydrogen is essential to achieve scale, and better price discovery is possible through the indexing of prices in the global markets, similar to Henry Hub (U.S.) or National Balance Point (UK) for natural gas. The index can be region-specific to reflect the renewable resources and economic conditions.

Cost Reduction

A critical piece of the green hydrogen development and deployment puzzle is the need to bring down the price of green hydrogen to make it competitive with fossil energy. Green hydrogen production can be broken down into two main components - the electrolyzer stack and the balance of the plant, which refers to all the other plant processes. Electrolyzers perform the essential function of splitting water into hydrogen and oxygen molecules. The capital costs of the electrolyzer currently represent almost one third of the total cost of green hydrogen production.[19] The balance of the plant encompasses energy and material inputs, products, and byproducts and contributes the remaining cost of production. Figure 1 illustrates the average cost breakdown of a one-megawatt (MW) polymer electrolyte membrane (PEM) electrolyzer, showing in detail the cost breakdown of electrolyzer production and specific balance of plant processes.

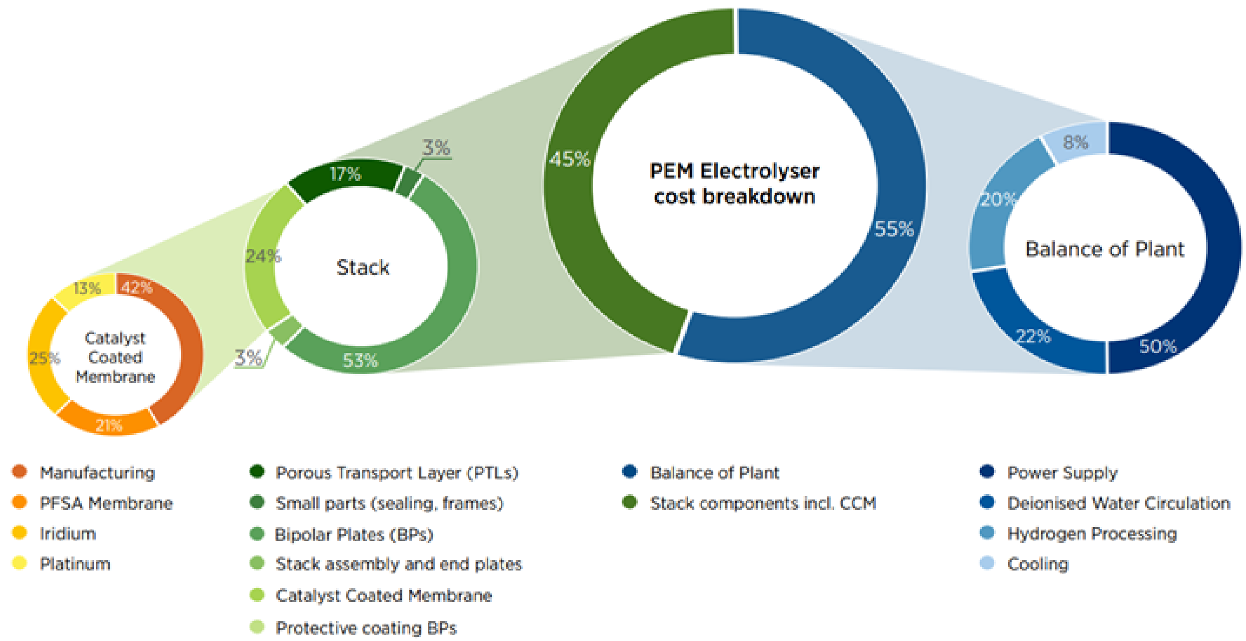

Figure 1 | Average cost breakdown for a 1 MW PEM electrolyzer
Source: Emanuele Taibi, et al. 2020.

Of the many electrolyzer technologies, PEM and alkaline electrolyzers are the most mature. PEM electrolyzers are preferred for their efficiency, output pressure, and small facility footprint, but the material inputs of iridium and platinum currently make up over a third of their cost and place limits on PEM production capacity. Alkaline electrolyzers are larger but have the lowest cost of current electrolyzer technologies and rely on readily available catalyst elements - nickel and iron. Anion exchange membrane and solid oxide electrolyzers are less mature technologies but offer future promise in the form of cost and mineral inputs and efficiency, respectively.

Key strategies for reducing costs overall include improvements in electrolyzer efficiency, mineral requirements, electrolyzer stack design, and operational efficiency of the balance of the plant, reduction in renewable electricity costs, and increasing scale of production. Electrolyzer efficiency is an active area of research, with current technologies operating in the 70-80% efficiency range depending on electrolyzer type and operating conditions. Optimizing efficiency while reducing dependence on expensive minerals will be key to driving costs down in the long run.

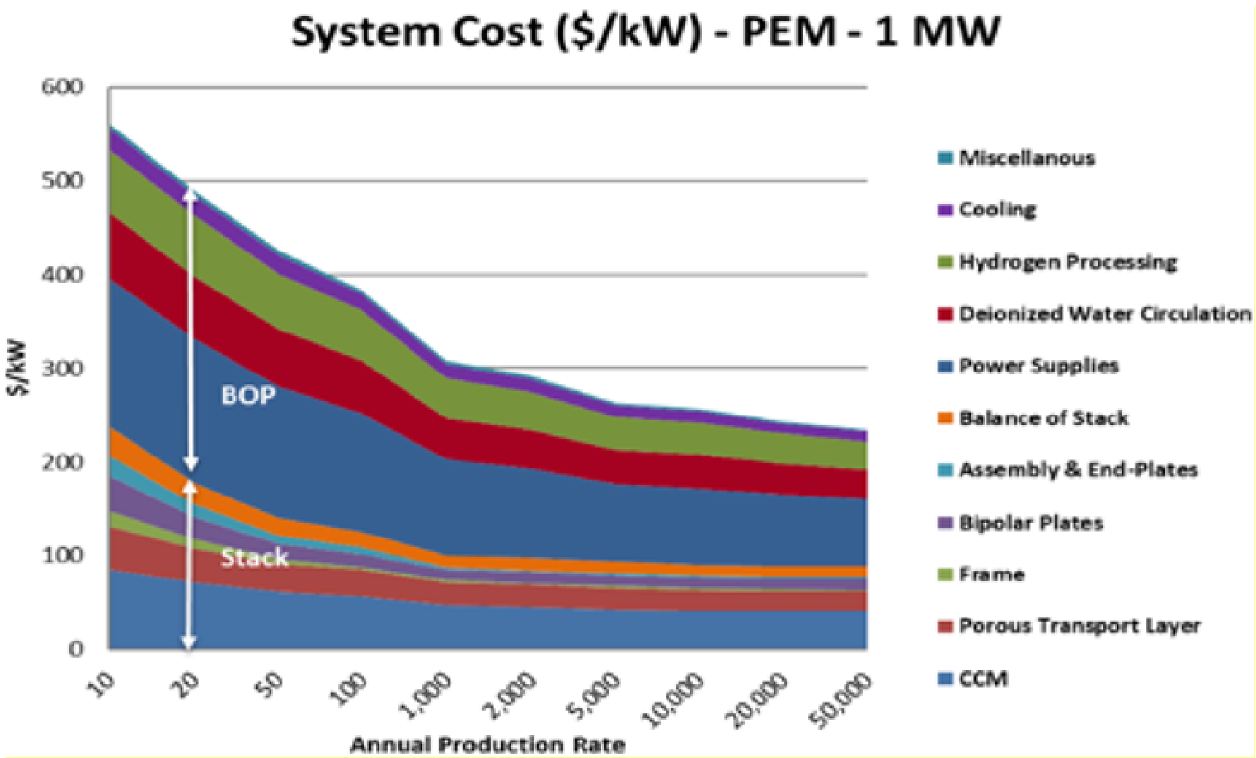

Figure 2 | Cost breakdown for the production of 1 MW PEM electrolyzers as a function of manufacturing scale

Note: Annual Production Rate refers to the number of 1 MW PEM electrolyzers produced per year. Note that the x-axis intervals are not regular.

Source: Mayyas et al., 2019.[20]

Figure 2 shows the cost breakdown for the production of one-MW PEM electrolyzers as a function of manufacturing scale. Note that production costs dropped from $550/kW to around $380/kW - a reduction of about 30% - when production capacity increased from 10 to 100 units. There is a limit on the need to scale electrolyzer production. Above 1000 units, scaling production leads to diminishing returns, with an increase in annual production from 1000 units to 2000 units only leading to around a 3% reduction in cost.

Electrolyzer and balance of the plant cost reductions could combine to reduce production costs by an estimated 80% relative to 2020.[21] Figure 3 shows potential cost reductions in green hydrogen production given a range of technology and learning achievements. The greatest reductions will come from decreased electrolyzer costs and renewable electricity.

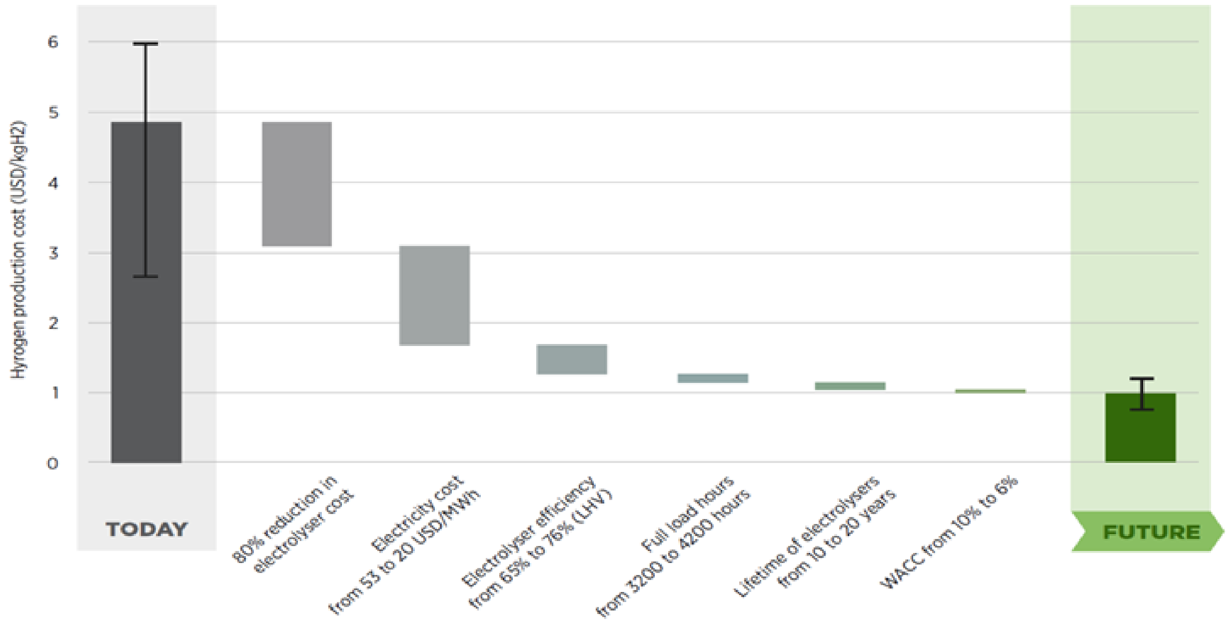

Figure 3 | Estimated achievable cost reductions in green hydrogen production

Note: 'Today' captures the 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).

Source: Emanuele Taibi, et al. 2020.

Cost Reduction Recommendations

To achieve the cost reduction that is needed to spur domestic goals on research, development and deployment of green hydrogen so that it can effectively displace fossil-fuels, a number of initiatives should be explored.

Steel: India and the U.S. should build a clean steel partnership

The U.S. and India have very different steelmaking profiles. India is the fourth largest iron ore producer in the world – producing over 200 million metric tons, which is four times more than is produced in the U.S. – and primarily uses coal in primary steel production. While U.S. primary steel production is still overwhelmingly reliant on coal, as well, the greater availability of steel scrap in the U.S. and an increasing reliance on imported primary steel products has led U.S. steel production to gradually move away from coal- and ore-based primary steel production and to move towards electricity- and scrap-based secondary steel production.

In both countries, however, electric arc furnaces (EAFs) traditionally used in secondary steel production to make low-quality steel products such as rebar are increasingly able to produce high-quality primary steel products using direct reduced iron (DRI) as an input. As hydrogen can either be blended or used solely in DRI production, this process can bypass the higher emissions blast furnace-basic oxygen furnace (BF-BOF) route and provide a path for hydrogen-based steelmaking.

The U.S. currently produces around 7 million metric tons of DRI,[22] which is primarily melted in EAFs to produce steel products. Most of this DRI is made using natural gas, which results in much lower emissions than the BF-BOF route. In order to further decarbonize the steel industry, green hydrogen can be blended with natural gas in existing plants, and the portion of hydrogen used could be increased with minimal modifications to existing plants.[23]

Meanwhile, India is currently the global leader in DRI production, producing 39 million metric tons in 2021.[24] In India, coal-based DRI production provided a majority (77%) of DRI in 2021, while natural gas-based DRI provided the remaining 9 million metric tons. Due to limited availability of natural gas at competitive rates, gas based DRI plants are expected to witness limited growth in India, until low-cost domestic hydrogen becomes available for these plants to switch over. As stated in India's NGHM, the country plans to replace coal and natural gas with hydrogen in the DRI process. This green hydrogen-based DRI-EAF steelmaking route is central to many countries' plans to decarbonize their steel industry, including in the United States.

Given the common goals shared by the two countries to shift to hydrogen-based DRI-EAF steel production, India and the U.S. can create an important partnership that would hasten the transition to green steel, which would decarbonize the industry and provide demand for green hydrogen. This demand would lead to scaling of green hydrogen production and cost reductions of both green hydrogen and green steel production. As countries are establishing low-emissions steel partnerships, India and the U.S. should focus on building a clean steel research partnership.

The partnership would identify collaborative opportunities such as: using hydrogen as an alternative input to pulverized coal injection, piloting of natural gas-based DRI plants that have capabilities to rapidly transition to run on 100% hydrogen,[25] alternative energy sources such as biomass or electric heaters for heating the reducing gas,[26] coupling of DRI process with EAF powered by renewables, and also ensuring hydrogen supply security through low-carbon hydrogen production infrastructure. A partnership focused on collaboration to address these key issues would set the stage for primary steel production to be increasingly reliant on green hydrogen in both countries and around the world.

Ammonia: India and the U.S. should build a green ammonia partnership

Nitrogen-based fertilizer production in the U.S. and India relies heavily on natural gas as a feedstock. India currently imports approximately 40-45% of ammonia-based fertilizer feedstocks such as natural gas.

The import of finished nitrogen-based fertilizer products to supplement domestic production has increased over the years; imported ammonia constituted 28% of domestic consumption during 2021-22. Ammonia production in India is not only connected with domestic fertilizer applications but is also driven by demand in the international market. India also exports ammonia to international markets,

The Government of India has a long-term vision to reduce the chemical fertilizer inputs into agriculture which is reflected through initiatives like the National Mission on Natural Farming, and PM-PRANAM (Promotion of Alternate Nutrient for Agriculture Management Yojana) which were introduced in the last union budget for the promotion of alternate fertilizers and reduce the use of chemical fertilizers in the country.

The Government of India intends to increase domestic production of urea over the next few years to reduce reliance on imports.[27] Growing demand from both the domestic fertilizer sector transitioning to green ammonia and demand from international markets are expected to bolster green ammonia production in India provided there is availability of technology and financing support

Public and private green ammonia initiatives in the U.S. should seek to form research and development partnerships with fertilizer producers in India to spark advancements in production technologies and efficiencies in both countries. An important outcome of this partnership would be to steer investments away from natural gas-based urea fertilizer production in India and towards lower-emissions processes and products.[28] As urea is a carbon-rich product, the carbon that is currently sourced from natural gas in the fertilizer plant must be sourced from elsewhere if urea is to remain a key application technique for nitrogen-based fertilizers. A partnership between the two countries could help identify non-fossil sources of carbon dioxide for urea production while also working towards greater use of nitrogen-based fertilizers that don't contain carbon. This is significant as ammonia production in India is expected to increase both for domestic use and export.

As the U.S. is currently the only country to use pure NH3 - known as anhydrous ammonia - in large quantities to fertilize crops, a U.S.-India partnership could also develop markets for this product in India over time, thus increasing potential demand for green hydrogen in the fertilizer industry. It is important to note that pure, anhydrous ammonia is an air pollutant, and a toxic irritant that can cause death at very high exposures. Moreover, excessive nitrogen fertilizer application or pollution events can disrupt the soil's nitrogen cycle and yield adverse ecological effects, namely biodiversity loss or higher susceptibility to natural risk factors.[29] Handling pure ammonia requires technical know-how and adherence to strict safety measures. India would benefit from knowledge-sharing, regulatory models, and experience gained in the U.S. that can promote safe and rapid advancement in anhydrous green ammonia production and use in India. Ammonia is an understood and useful component for food growth, but, given these risks, should not be considered a perfect replacement for other sustainable agriculture practices that can also improve yields, crop health, and income for farmers.

Low-emissions production of nitrates, sulfates, and phosphates - other forms of carbon-free, nitrogen-based fertilizers - should also be explored in the partnership, since soil conditions, temperature, and specific crop needs must be taken into account when choosing an appropriate nitrogen-based fertilizer application method.

Shipping: support Paris-aligned targets for shipping decarbonization & using lifecycle "Well-to-Wake" accounting

Decarbonization of the maritime sector, which currently produces approximately 3% of global GHG emissions, can and should play a key part in driving demand for green hydrogen, primarily through its demand for green hydrogen-derived fuels, such as ammonia and methanol. Shipping currently uses heavy fuel oil, and it is expected that green hydrogen or green hydrogen-based compounds such as ammonia or methanol will play a big role in decarbonizing the sector[30]. Shipping is often identified as the largest single predicted demand sector for green hydrogen in the future. One study estimates approximately 130 million tonnes of hydrogen demand for shipping by 2050, whereas in the same study steel and chemicals in combination account for 170 million tonnes of annual offtake. Aviation is also expected to consume significant amounts of hydrogen – more than 80 million tonnes annually, but still significantly less than the shipping demand.[31]

In order for this potential to materialize, however, strong policy signals are needed to assure the green hydrogen production sector that there will be strong demand for green hydrogen products in the shipping sector. Currently the discussion is fragmented: shipping interests worry that there will not be enough green hydrogen and derived fuels to meet ambitious decarbonization targets if they set them, while at the same time green hydrogen producers are concerned about adequate demand. To address this disconnect, at COP27, leading organizations and initiatives across the shipping value chain joined with the largest producers of green hydrogen in a joint statement committing to the rapid and ambitious production and use of low-carbon fuels based on green hydrogen to accelerate decarbonization of global shipping[32]. This step must be augmented with action at national and international levels to create incentives such as targets for green hydrogen use and production in the sector or support mechanisms.

Current negotiations at the International Maritime Organization (IMO) on revising the GHG reduction targets in its GHG Strategy constitute a major opportunity for sending a strong policy signal to support demand for green hydrogen. IMO member states are debating the level of emissions reductions they will strive to achieve by 2050, the interim targets needed to achieve that target, and the means by which they will calculate those emissions. The 2023 Revised IMO Strategy is a critical opportunity to provide clear signals to the green hydrogen production sector that there will be strong demand for green hydrogen products in the shipping sector.

To date, the majority of hydrogen investment is in and driven by developed economies;[33] if this continues, it creates the risk of leaving developing countries 'behind' in the transition. Signaling strong demand for green hydrogen and derived fuels in the international shipping sector could also be a critical enabler of wider hydrogen economy opportunities and benefits in developing countries broadly. Of the primary hydrogen demand sectors, using and/or exporting zero-emission shipping fuels is one of the easier ways to start creating hydrogen-related investments because:

- IMO regulation is global. Policy to incentivize green ammonia use in other sectors such as agriculture domestically could act against national competitive advantage by distorting trade. IMO policy acting on international shipping affects all states equally so there is no competitive distortion. In a decarbonized energy system, shipping fuels produced from hydrogen are expected to have approximately three times the global market demand of either ammonia or methanol for use as chemicals.
- Zero-emission shipping fuels are likely to be simpler and lower cost to produce than synthetic fuels used in the aviation sector.[34]

Given the ability of the shipping sector to drive significant need for green hydrogen and the concomitant potential cost reduction associated with such a scale up, we recommend:

The U.S. and India support Paris-aligned targets for shipping decarbonization.

The U.S. and India have already established some collaboration on green shipping through a Quad Shipping Task Force and Green Shipping Network, announced at the Quad Leaders' Summit in September 2021.[35] Recognizing that Quad countries (the U.S. and India, as well as Australia and Japan) represent major maritime shipping hubs with some of the largest ports in the world and therefore are uniquely situated to deploy green port infrastructure and clean bunkering fuels at scale, Quad partners agreed to establish two-to-three Quad low-emission or zero-emission shipping corridors by 2030. These could provide a perfect backdrop for further collaboration to build demand for green hydrogen in the sector.

In addition, opportunities exist where the U.S. and India can further collaborate in the maritime sector to ensure adequate development and deployment of green hydrogen and send clear policy signals to green hydrogen investors and producers that there will be growing demand for their products. In particular, the U.S. and India can support setting IPCC-derived Paris-aligned targets for decarbonization of the maritime sector, through the IMO's revised GHG strategy, to be adopted in July 2023. This would send a strong, global demand signal for zero-emissions fuels such as ammonia, and indirectly for the green hydrogen needed to produce them. Currently the U.S. supports this position at the IMO,[36] while India has instead supported adoption of a target that would "peak . . . emissions from international shipping as soon as possible [as well as to aim net zero GHG emissions preferably around mid-century and before the end of this century.]."[37]

India and the U.S. lead on using lifecycle "Well-to-Wake" accounting for assessing emissions from shipping.

In order to unlock investment in zero-emissions fuels, it is imperative that both national and international targets and policies for shipping take into account the full lifecycle emissions for different fuels, requiring “Well-to-Wake” accounting, in the parlance of the IMO rather than “Tank-to-Wake” accounting, which only looks at emissions produced when fuel is actually burned on board. Relying on Tank-to-Wake accounting would drive counterproductive changes in maritime fuel by making hydrogen produced with fossil fuels appear competitive with green hydrogen and derived fuels, thereby potentially harming demand for green hydrogen as well as failing to deliver on emissions reductions.

By supporting the use of lifecycle, “Well-to-Wake” accounting in assessing emissions from shipping, the U.S. and India could ensure that the fuel transition in the sector does drive both emissions reductions and production of zero emissions fuels. Other potential areas for U.S.-India collaboration such as a jointly developed certification system for green fuels and a common taxonomy, or a mutually acceptable Measurement, Verification, and Reporting protocol that provides guarantees of origin for green fuels would greatly benefit this effort, by helping to ensure the emissions intensity of green fuels.

Establish viable markets and trading systems for green hydrogen and derivatives

The biggest challenge for developers of green hydrogen in India, and also generally across the developing world, is a lack of demand. This is due to the high cost of green hydrogen, which cannot compete with fossil fuels directly on an energy basis. In addition to increasing demand through the strategies above, the cost of green hydrogen can come down significantly if lower-cost financing is available. The U.S. is in a position to support the growth of green hydrogen by both providing offtake guarantees as well as financing, thereby creating a virtuous loop in deploying projects. The engagement can be strengthened with support for manufacturing of electrolyzers such that India can supply low-cost electrolyzers at scale to the U.S. markets or deploy them for green hydrogen production in India for export to the U.S. Developing such market structures and trade mechanisms can create scale and significantly reduce the cost of green hydrogen production through offtake certainty (guaranteed demand for electrolyzers and/or green hydrogen or derivatives) and consequently lower cost of finance for project developers. Offtake can be achieved either through exchange of green attributes (similar to carbon credits where only certificates are exchanged), marine bunkering of green ammonia at Indian ports, or through sustainable aviation fuel in the aviation sector.

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