GREEN HYDROGEN

INDIA'S OPPORTUNITY FOR A STRATEGIC SHIFT IN GLOBAL ENERGY TRADE

ALVAREZ & MARSAL

LEADERSHIP. ACTION. RESULTS.

Author's Note

Over the last two years, there has been a lot of excitement, accompanied by cynicism, about low-carbon hydrogen. The excitement has been spurred by increased focus on climate change along with sharp reductions in the cost of renewable energy over the last decade, which is a major cost driver of green hydrogen. The cynicism stems from the fact that low-carbon hydrogen costs much more when compared with alternative high carbon fuels (nearly two times as expensive), and that makes the case for investment less compelling. Against this backdrop, we need to look at low-carbon hydrogen in the context of what it offers: It is the most visible pathway that we have to bridge the gap to net-zero emissions. We need to see the economics of hydrogen in the context of the price of carbon and what the technology road-maps promise in coming years. Current forecasts suggest that low-carbon hydrogen costs will achieve parity with alternatives by the end of this decade or in the first half of the next decade. These estimates justify commitment by governments across the globe.

For India, green hydrogen could define an inflection point in our energy journey. Thanks to our vast renewable energy resources and a favorable ecosystem, India for the first time could be a supplier of scale in the global energy trade. Over the next two decades, hydrogen could fundamentally change the contours of our energy supply chain, which will have implications not only for our economy but also our geopolitics. India should, therefore, weigh in on this with the utmost seriousness and be prepared to take bold measures to capitalize on this opportunity.

In this paper, we analyze the competitiveness of various global regions to produce green hydrogen. While there are other forms of low-carbon hydrogen, the focus of this paper is on the green version, which is produced using the electrolysis route with renewable energy. This is expected to be one of the dominant routes for low-carbon hydrogen production. The paper analyzes 10 countries for their competitiveness in the sector and gives recommendations for what India must do to scale up. We hope this paper creates excitement for green hydrogen and momentum to act among stakeholders.

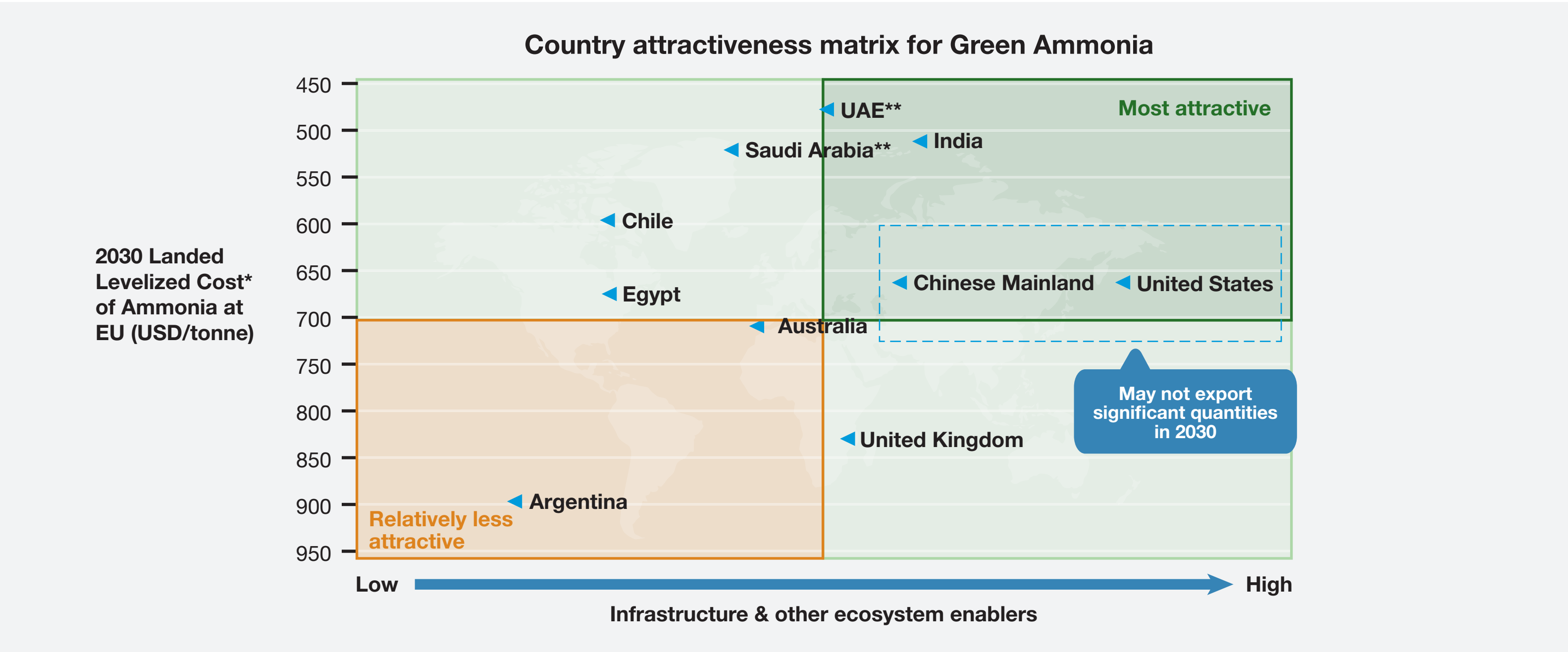
Santosh Kamath
Managing Director, Energy Transition
Alvarez & Marsal

An Opportunity for India

Hydrogen will be an important lever in the global journey toward a net-zero carbon footprint and is expected to be equivalent to 10–20 per cent of the world's energy mix by 2050, both as energy carrier and feedstock. That is a significant quantum and could create an economic opportunity of nearly USD 0.5 trillion. Countries rich in renewable energy resources like solar and wind are well-placed to take advantage of this opportunity. These include India, Egypt, Latin America (Chile and Argentina) as well as countries such as Saudi Arabia, the UAE, the Chinese mainland, Australia and the United States. Energy supply chains would be substantially impacted by this new energy vector.

The four factors that determine a nation's competitiveness for green hydrogen are (i) renewable energy resources, (ii) manufacturing, engineering and construction competitiveness, (iii) the electricity ecosystem and (iv) cost of capital. Direct green hydrogen transportation across long distances is cost prohibitive and it is expected to be converted to ammonia and transported in the form of ammonia. Our analysis of green ammonia prices and factors of competitiveness across 10 high-potential countries shows the following:

Figure 1: Country attractiveness matrix for green ammonia trade[1]



Source: Alvarez and Marsal analysis

*LCOH: Levelized Cost of Hydrogen, LCOA: Levelized Cost of Ammonia. Levelized costs denote a single price which will be paid during the entire tenure of the contract/project.

**For Saudi Arabia and the UAE we have considered solar wind hybrid for calculations. Only solar based green hydrogen production is expected to be 10-15 cents/kg higher in price.

The UAE, India and Saudi Arabia seem well placed in global green hydrogen competitiveness and therefore could partake a significant share of global trade. In the 2030 timeframe, low-carbon hydrogen, while relatively nascent in its lifecycle, could still yield a USD 24–36-billion trade opportunity for the world. The early adopters of hydrogen on the demand side, i.e., imports in global trade flows, are the EU, Japan and South Korea. Together, they are expected to create an import demand of nearly 12 million tonnes of hydrogen or equivalent in green ammonia terms.

[1] The landed levelized costs of ammonia in the EU are inclusive of shipping freight to Europe. Shipping prices are levied based on existing shipping fuel used by the industry. If green methanol is used for shipping of green ammonia, then the landed prices are expected to increase by 3–10 per cent of the prices denoted in the graph.

In terms of relative competitiveness for exports, our analysis shows that the countries rank as follows:

Table 1: Green hydrogen and green ammonia price at production location

Country	2023		2030	
	LCOH*	LCOA*	LCOH*	LCOA*
	USD/kg	USD/tonne	USD/kg	USD/tonne
UAE	2.7	629	1.7	436
India**	3.2	727	1.8	467
Saudi Arabia	2.9	686	1.8	475
Chile	3.4	783	2.1	541
Chinese Mainland	3.1	719	2.4	588
Egypt	3.8	918	2.3	641
United States	3.9	876	2.5	610
Australia	4.5	962	2.7	635
Argentina	5.2	1220	3.1	838
United Kingdom	5.0	1077	3.5	809

Source: Alvarez & Marsal analysis

*LCOH: Levelized Cost of Hydrogen, LCOA: Levelized Cost of Ammonia. Levelized costs denote a single price which will be paid during the entire tenure of the contract/project.

**Assuming rupee depreciation of 2.8%, without which the ammonia LCOA is expected to be higher by USD 130-140 /tonne.

The government has already announced a National Green Hydrogen Mission (NGHM) with an outlay of INR 19,744 crore (USD 2.3 billion). Incentives have been announced for hydrogen production and electrolyzer manufacturing. In order to capture this opportunity, India needs to move quickly on certain measures as discussed below.

Key Enablers for a Green Hydrogen Economy

In addition to the initiatives already in place, the following policies can work as enablers for a green hydrogen economy:

1. Set up a program to create green hydrogen demand of one million tonnes per annum by 2027. Identify end-use sectors for offtake and create a mandate accompanied by a viability gap funding plan so that the impact on end-use sectors is softened. If we assume a viability gap of USD 1/kg the program would require an annual outlay of USD 1 billion.

2. De-risk projects through credible offtake guarantees. The Solar Energy Corporation of India's (SECI) model of creating a credible offtaker counterparty has worked well in the case of solar and wind auctions to reduce the cost of capital and attract investments. The same may be adopted for hydrogen where an offtake guarantee program can significantly help reduce costs. Along with other cost reduction measures such as indirect tax exemptions, this model can help reduce costs by 10–15 percent.

3 Consider decoupling of the renewable energy (RE) supply transaction from the hydrogen production and sale-purchase transaction through a credible intermediary. Further to the point above on offtake guarantee, the intermediary can also play the role of decoupling the RE transaction from the hydrogen transaction. It purchases RE hybrid power through auctions and provides the same to hydrogen producers. The benefits of such a decoupling model are that it de-risks the RE capacity, enabling easier financing and participation of a greater number of players in the RE part of the chain, while simultaneously reducing the capital investment needed for hydrogen producers. Of course, the intermediary does end up owning some of the risks, but this is one way to help reduce financing costs and reduce overall costs.

4 Keep the process simple and execute speedily. This will contribute to the ease of doing business and help to get the investments grounded sooner without losing momentum.

For India, the case to aggressively support green hydrogen is strong. By moving early, we can stake a claim to a larger share of the global energy trade, substitute some of our imports, especially LNG, and spur domestic GDP growth. By 2030, this could lead to USD 3–5 billion of exports and USD 7–15 billion of import substitution, opening the doors to a much larger opportunity in the decades ahead.

India needs to be bold and to plan a large outlay for this program. India could need an outlay of USD 4–12 billion cumulatively in the run up to 2030, depending on how quickly costs fall. While this figure is large in absolute terms, it is small in the context of our economy and our oil import bill, which is estimated at a staggering USD 1.0 –1.4 trillion over the same period — a small price to pay now for longer-term climate impact and economic advantages.

1. Hydrogen, an important bridge to decarbonization, will serve 10–20 percent of the world's energy demand by 2050

Since the beginning of the industrial age, temperatures have risen by 1.2 degrees Celsius. Extreme climate events have become more frequent in recent decades. Greenhouse gas emissions are rising at an alarming rate, reaching about 53 billion tonnes[i] CO2e per year in 2021. This urgently needs to be contained to limit global warming and prevent significant damage to life on earth.

The dominant source of all emissions is energy production, which contributes nearly 66 percent[i]. The world today still depends largely on fossils to produce energy. In 2021, fossil fuel-based energy production comprised nearly 82 percent[ii] of all energy production. Only 20 percent[ii] was in the form of electricity, for which renewable sources of production can be used more easily, albeit with challenges in scaling up. The proportion of electricity produced by renewable sources is expected to rise to nearly 52 percent[iii] by 2050 in a net-zero scenario. However, there is still going to be a large part of the energy use which is expected to be met through methods other than electricity. This is where hydrogen can play an important role. Hydrogen is expected to constitute 10–20 percent[iv] of all primary energy use in 2050 in a net-zero scenario.

1.1 Hydrogen use is already prevalent in certain sectors, but produced mainly using fossils; this needs to shift to cleaner methods of production

As per the International Energy Agency, or IEA, global hydrogen demand stood at 95 million tonnes[v] per annum in the year 2022. Refineries and fertilizers are the major users of hydrogen, contributing to 65–70 percent[vi] of the total hydrogen demand. Hydrogen is used as a catalyst and desulphurization agent in refineries and as a feedstock for ammonia-based fertilizers.

Currently hydrogen is produced primarily using fossil fuels, predominantly natural gas. The natural gas-based hydrogen production takes place through a process called steam methane reforming (SMR). This process leads to 9–10 kilograms of CO2 emissions per kilogram of hydrogen produced. The hydrogen produced from the use of fossil fuels like natural gas is called grey hydrogen.

Two methods are used prominently to produce low-carbon hydrogen: (i) Usage of carbon capture in the existing fossil fuel-based production process, which creates blue hydrogen. This process reduces CO2 emissions by 70–90 percent;[vii] and (ii) Production of hydrogen through electrolysis of water using renewable electricity, which produces green hydrogen.

1.2 Apart from substituting existing grey hydrogen, low-carbon hydrogen will enable decarbonization of hard-to-abate sectors like steel, transport and manufacturing

While renewable energy like solar and wind has proven to be quite an effective green source for electricity so far, when it comes to heavy-duty sectors like steel manufacturing, heavy-duty transport and high temperature manufacturing processes, electrification routes may not always be efficient or even feasible. For such industries, green or low-carbon hydrogen appears to be the most viable pathway to decarbonization, due to hydrogen's properties as a reductant in chemical reactions and as a high energy density fuel. For example, in steel manufacturing, it can replace coal or coke to reduce iron from its ore. Similarly, it can help in decarbonization of sectors like shipping and aviation through usage of sustainable fuels manufactured from green hydrogen.

1.3 Hydrogen demand is expected to grow 5x by 2050 under the net-zero scenario

As per IEA's net-zero scenarios, the world would require 528 million tonnes[viii] of green hydrogen by 2050. This means a 5x growth in hydrogen demand and even at USD 1/kg pricing, it will be a USD 0.5 trillion industry by 2050.

1.4 Hydrogen supply chains will see significant shifts as the supply centers move to regions of high renewable energy potential

While the supply chain today largely originates in gas producing and exporting nations, in the future the balance could shift to those with high renewable energy potential. These geographies include India, North Africa (Egypt and Morocco), Latin America (Chile and Argentina) as well as Saudi Arabia, Australia and the U.S., which have both gas resources as well as abundant renewable energy.

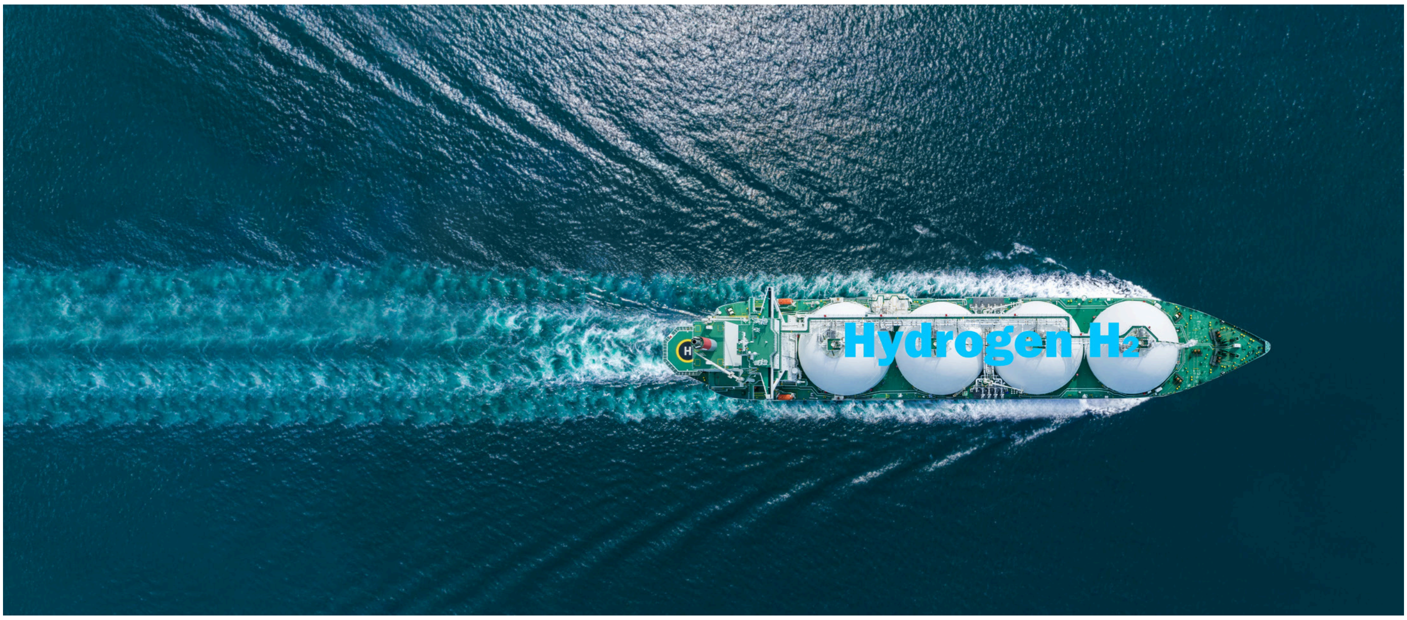
2. Global hydrogen trade is expected to be in the range of USD 24–36 billion by 2030

Many major countries across the world have established targets for production and consumption of low-carbon or green hydrogen.

Figure 2: Key green hydrogen export and import-focused countries based on 2030 announced targets or projects[2]

Export Focused Countries		Import Focused Countries	No clear indication whether these countries will be importer or exporter		
1. Argentina	7. Mauntania	1. Belgium	1. Brazil	6. Italy	11. Romania
2. Australia	8. Oman	2. France	2. Canada	7. Netherland	12. Spain
3. Chile	9. Saudi Arabia	3. Germany	3. Chinese Mainland	8. Norway	13. Sweden
4. Egypt	10. UAE	4. Japan	4. Denmark	9. Poland	14. USA
5. India	11. UK	5. South Korea	5. Finland	10. Portugal	
6. Kazakhstan					

Source: Country strategy documents, IEA project database



Chile, Argentina, Australia, Egypt, India, Saudi Arabia, Kazakhstan, the UAE and Oman are expected to produce green hydrogen for exports.[3] We have also included the UK as an exporter due to Scotland's potential for exporting green hydrogen based on offshore wind resources.

The EU, Japan and South Korea are expected to import as per their declared roadmaps. The U.S. and the Chinese mainland are expected to produce hydrogen mainly for their internal consumption as per the targets taken up in their strategy documents and, hence, are not included in the trade flow analysis.

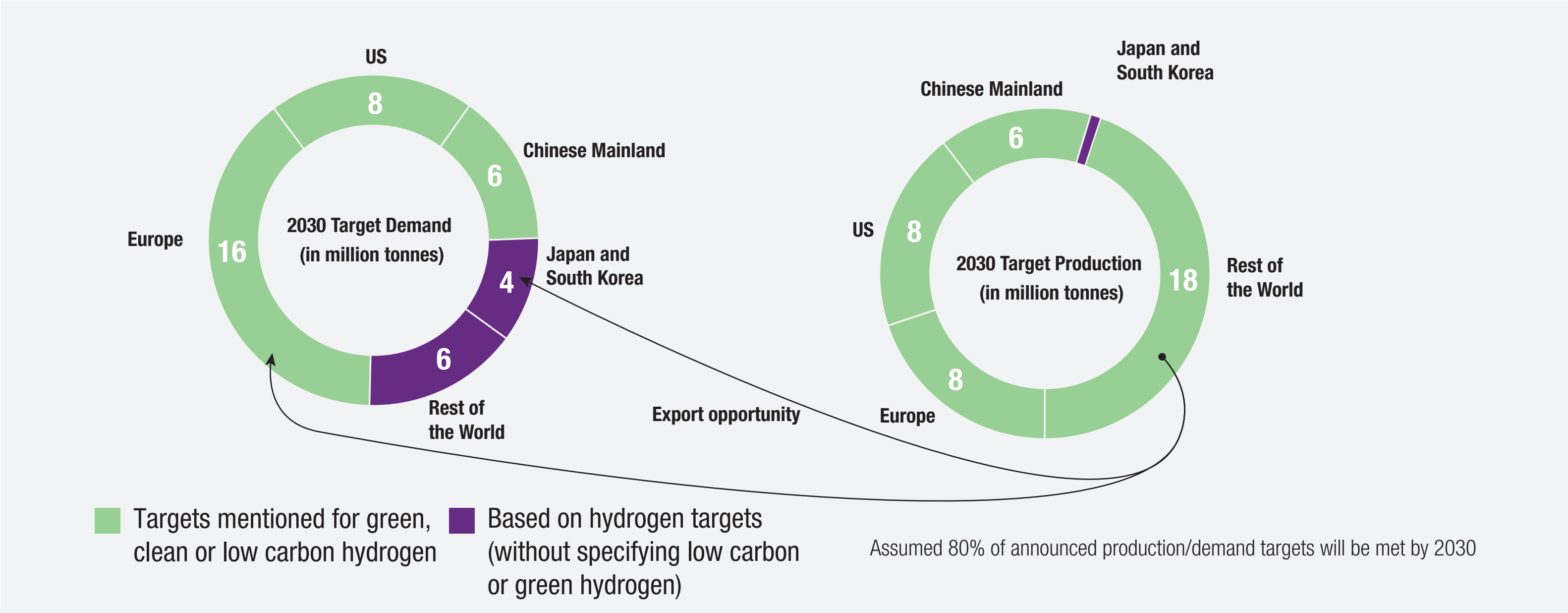
[2] For some countries like Australia, announced projects were considered for analysis as there were no clear targets specified by the country.

[3] Country-announced targets and major projects are analyzed to classify them as potential export-focused countries and import-focused countries. Countries that are expected to consume or produce less than 2 million tonnes of green hydrogen are not classified as exporters or importers under this study, except Oman and the UAE which are classified as export-focused based on announced projects and/or their country's ambition.

The EU has envisioned 20 million tonnes of green hydrogen consumption under its REPowerEU plan, which includes a plan to import 10 million tonnes of green hydrogen from other countries in 2030. Other than the EU, Japan and South Korea are expected to be major importing countries of low-carbon or green hydrogen, as per their announced target consumption and limited national potential for producing low-carbon hydrogen economically. Europe, Japan and South Korea are expected to import 12 million tonnes of low-carbon or green hydrogen by 2030, which creates a significant trade opportunity of USD 24–36 billion annually for supplying countries.[4]

The U.S. and the Chinese mainland are expected to have over 14 million tonnes of low-carbon and clean hydrogen demand by 2030. Since both of these countries have significant internal demand, most of the low-carbon hydrogen produced by them is expected to be consumed domestically. Hence, the U.S. and the Chinese mainland may not play a significant role in the hydrogen export market by 2030.

Figure 3: Clean and low-carbon hydrogen trade opportunity[5]



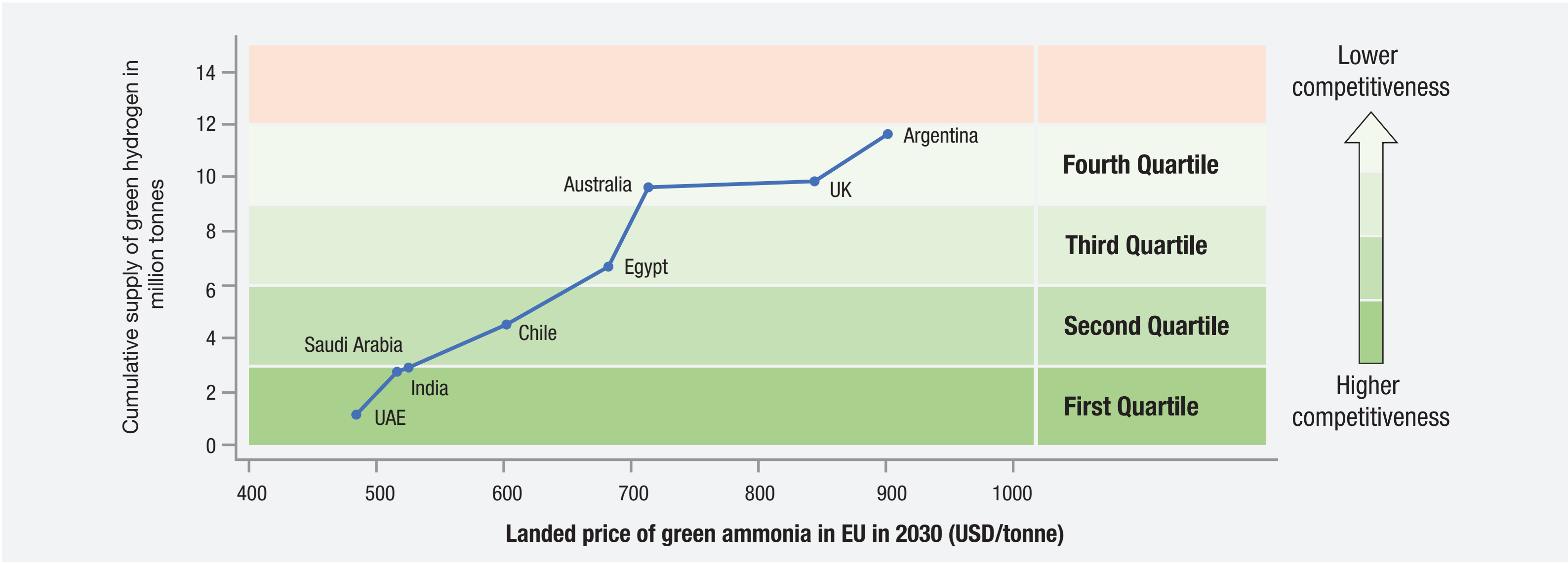
Source: Country strategy documents, IEA project database, assuming capacity equivalent to 80 percent of the quantum of projects announced will materialize

The green hydrogen supplier countries will play an important role in bridging the supply gap for importer countries. Since the cost of making hydrogen will differ from country to country, the competitive positioning of these renewable energy-rich countries will determine the potential trade deals for exports. Because transporting pure hydrogen is difficult due to its extremely light weight, most exports are expected in the form of green ammonia.

Our analysis suggests that the UAE, India and Saudi Arabia can provide low-carbon hydrogen at the lowest cost and are, therefore, expected to be competitively placed for supply to Europe, Japan and South Korea.

[4] Assuming 80 percent of the targets materialize by 2030
[5] Assuming 80 percent of the targets materialize by 2030

Figure 4: The UAE, India and Saudi Arabia are expected to offer attractive green ammonia prices for exports[6]



Source: Alvarez and Marsal analysis

The following sections of the paper analyze the relative competitiveness of these geographies to cater to the import demand. All prices mentioned in the subsequent sections are in 2023 constant USD prices.

[6] The ammonia prices are inclusive of shipping freight to Europe. The shipping prices are levied based on existing shipping fuel used by the industry. If green methanol is used as fuel for shipping of green ammonia, the landed prices are expected to increase by 3–10 percent of the prices denoted in the graph.

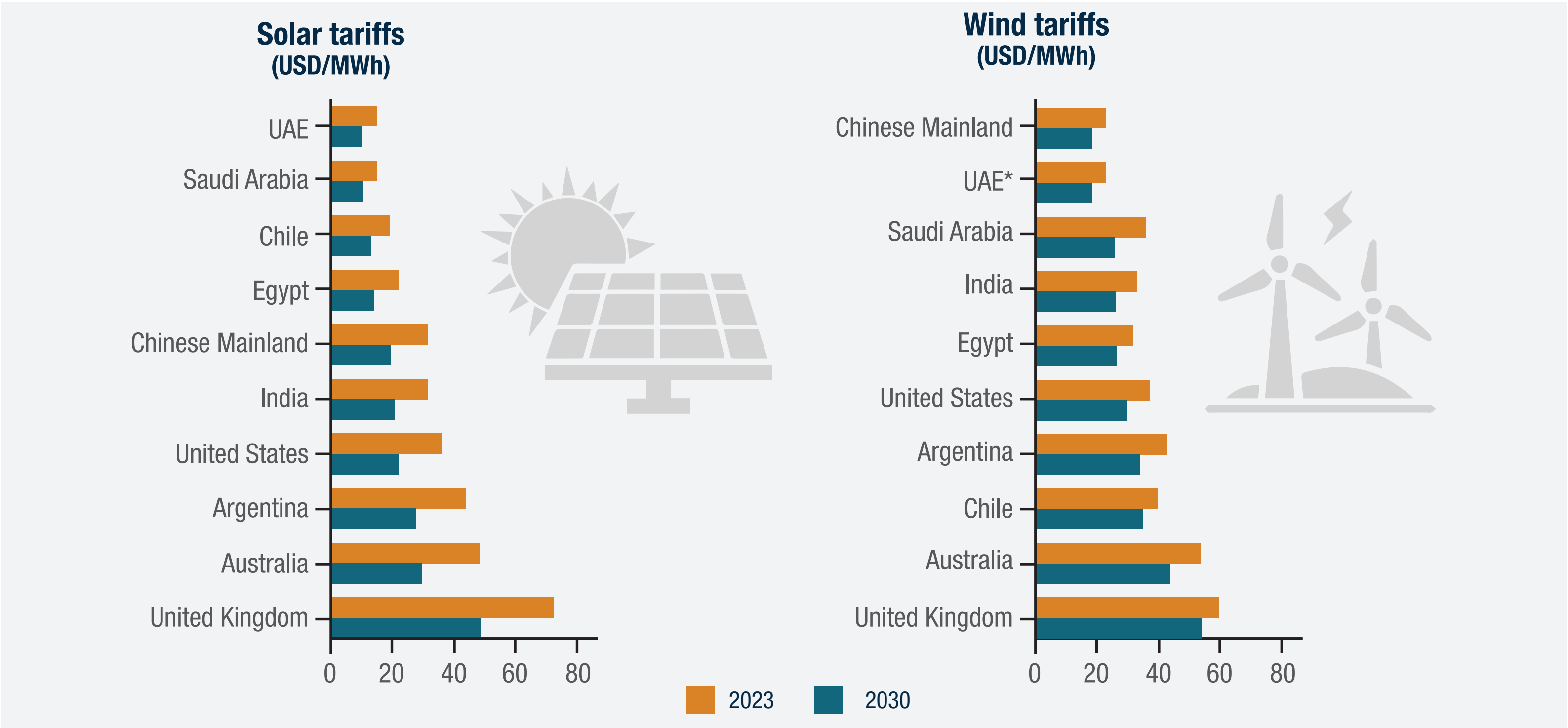
3. Factors determining relative global cost competitiveness

3.1 Renewable Energy Resources: Renewable energy (including electricity transmission costs) contributes 65–85 percent to the overall cost of hydrogen

Renewable energy is the key input for producing green hydrogen through the electrolysis route. The favorable cost trends of the two prominent renewable energy sources — solar and wind — along with decreasing electrolyzer costs will set the roadmap for future cost curves of hydrogen.

The UAE, Saudi Arabia, Egypt, Chile, Chinese mainland and India are expected to have less than 20 USD/MWh solar tariffs in 2030. Chinese mainland, Saudi Arabia, Egypt, the U.S. and India are expected to have less than 30 USD/MWh wind tariffs in 2030.

Figure 5: 2023 and 2030 solar and wind tariffs for different countries



Source: Secondary research, Alvarez & Marsal analysis
*Assumed to be similar to Saudi Arabia.

3.2 Local Manufacturing: The Chinese mainland and India will have manufacturing cost leadership for electrolyzers

An electrolyzer system is the equipment required for green hydrogen production. The electrolyzer system comprises the stack and the balance of plant (BOP). The stack primarily consists of electrodes, electrolytes and a membrane, whereas the BOP consists of power supply equipment, a water circulation system, and hydrogen processing and cooling systems.

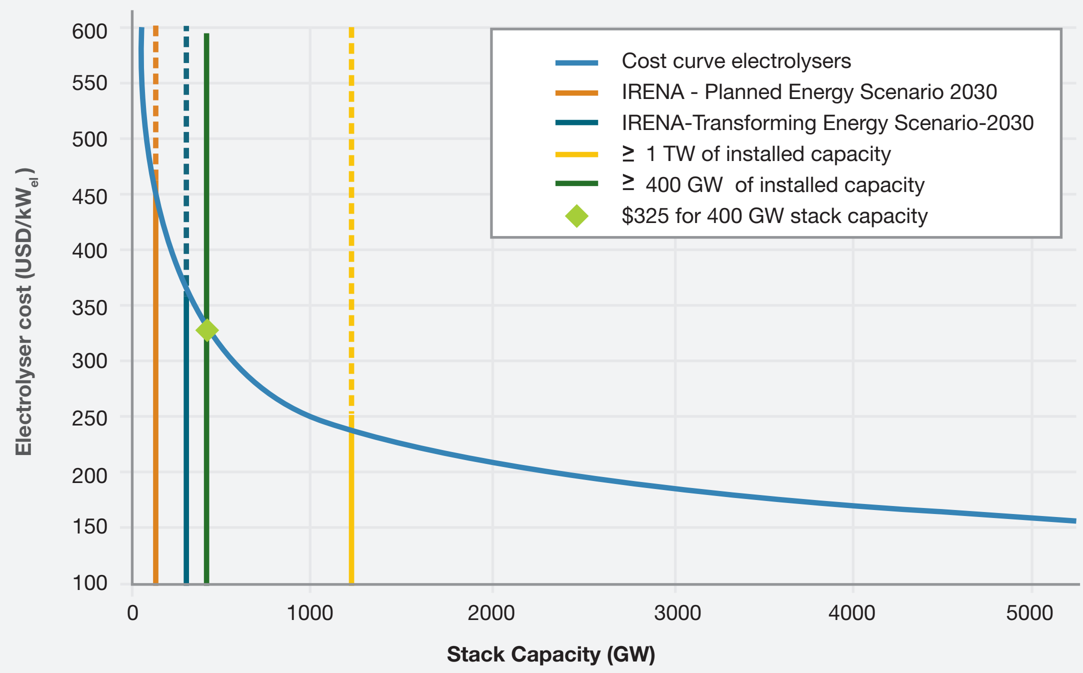
We expect significant learning curve benefits in electrolyzer costs as the world scales up production from current installations of less than 1 gigawatt (GW)[ix] to nearly 400 GW in 2030. The overall learning curve comprises two underlying learning curves:

i. A global learning curve in manufacturing of electrolyzer systems, which plays out at a global level, driven by technology-led gains and economies of scale for some critical parts of the global supply chain.

ii. Country-specific learning curves and cost advantages which will be driven by (a) local experience in designing, integration and deployment of the system on the ground and (b) cost decline owing to development of local supply chains and ecosystems.

For application of the global learning curve, the International Renewable Energy Agency or IRENA's learning curves were used in our analysis to arrive at an electrolyzer system cost of USD 325/kW corresponding to 400 GW[7] of global electrolyzer deployment.

Figure 6: Learning curve for electrolyzers



Source: IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5°C Climate Goal, International Renewable Energy Agency, Abu Dhabi and Alvarez and Marsal analysis

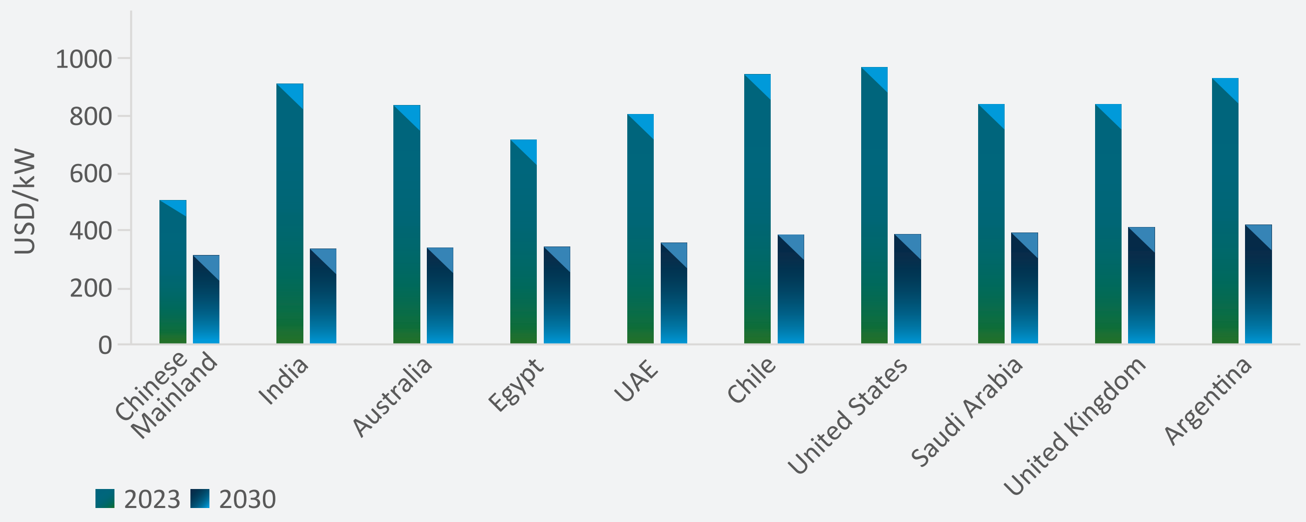
The country-specific learning curve has been applied based on the expected deployment of electrolyzers by 2030 in various countries.

Currently, the U.S., Europe and the Chinese mainland are the major manufacturers of electrolyzers. Countries other than these will have to import electrolyzers and are expected to incur additional logistics and other selling costs. In 2030, India is expected to be an important player in the electrolyzer manufacturing ecosystem, and the electrolyzers sourced from India and the Chinese mainland are expected to be the most competitively sourced electrolyzers across different countries.

At a baseline level, the electrolyzer costs (alkaline technology) inclusive of indirect taxes have been estimated in the range of USD 450-945/kW in 2023. Owing to learning curve effects, the capex is expected to be in the range of USD 310–440/kW in 2030 across different countries. This factors in the global as well as the country-specific learning curves.

[7]Expected electrolyzer deployed capacity across major countries if they achieve 80 percent of their announced consumption/production targets by 2030.

Figure 7: Electrolyzer capex (alkaline technology) inclusive of taxes and duties for 2023 and 2030



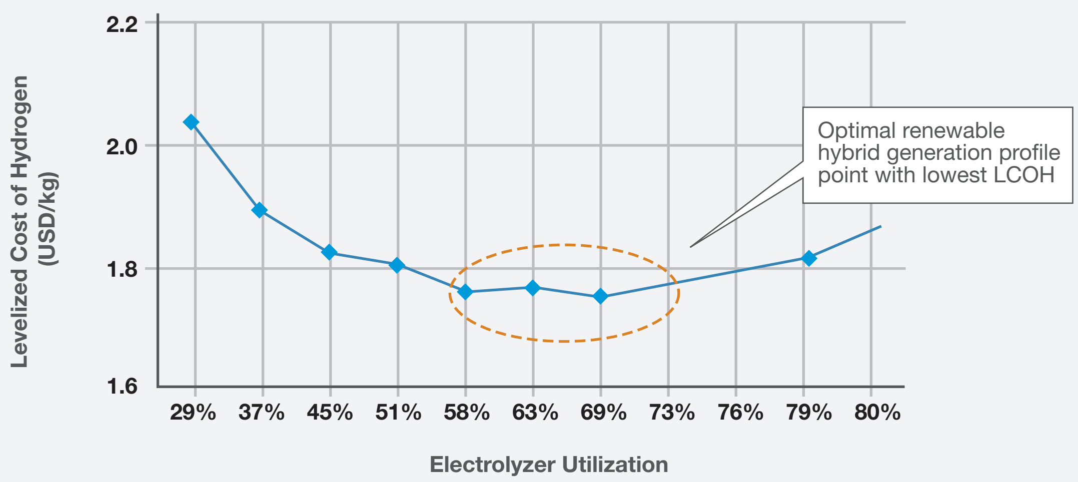
Source: Alvarez & Marsal analysis

3.3 Power grid ecosystem: Hybridizing and optimizing the solar and wind configuration are expected to lower the green hydrogen production costs

Sizing and integrating solar and wind supply in an optimal manner will lead to the lowest cost of producing hydrogen. The size of the electricity grid in the country and the presence of a power market also impacts this optimization. A larger electricity grid will enable tapping the best locations for producing solar and wind energy, while depth in the power markets will help monetize excess power when the generation exceeds the electrolyzer's capacity.

In our models, the RE configuration was optimized for each of the countries individually to arrive at the RE tariff and generation that leads to the lowest cost of hydrogen.

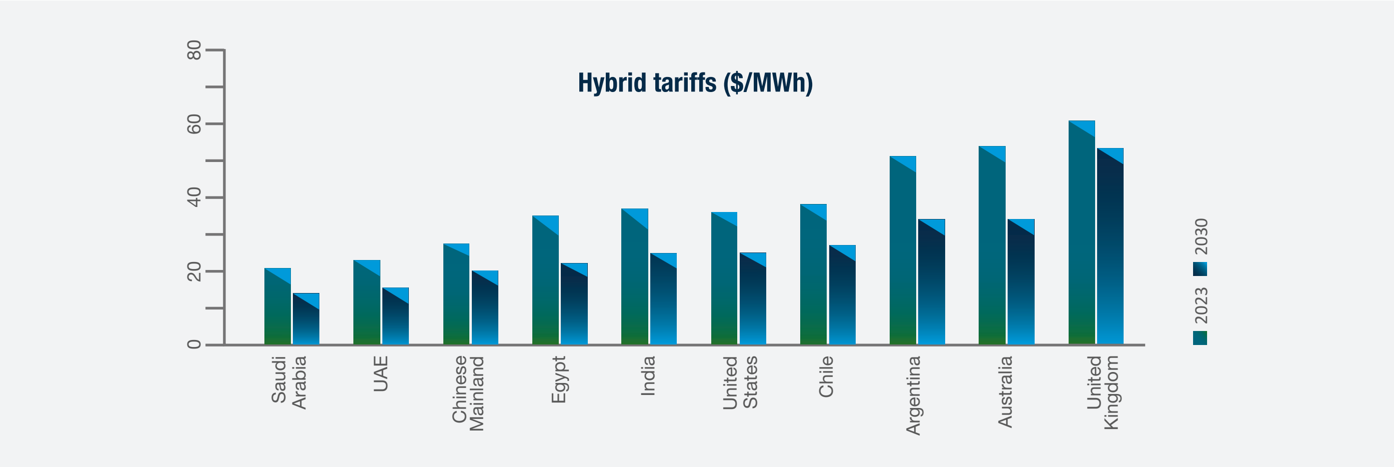
Figure 8: Lowest cost of hydrogen in 2030 is observed around 60–70 percent electrolyzer utilization for India



Source: Renewables.ninja, Alvarez & Marsal analysis

Following this optimization, the UAE and Saudi Arabia hybrid tariffs for 2030 are expected to be less than USD 20/MWh. Similarly, 2030 hybrid tariffs for the Chinese mainland, Egypt, Chile, India and the U.S are expected to be in the USD 20–30/MWh range.

Figure 9: Hybrid tariffs (country-wise)



Source: Secondary research, Renewables. ninja, Alvarez & Marsal analysis

3.4 Financing costs and currency depreciation

Green hydrogen production is a capex-heavy process with 70–90 percent of the hydrogen cost attributed to renewable energy and electrolyzer capital expenditure. Therefore, the cost of financing plays an important role in the final cost of green hydrogen. Countries with a lower cost of financing such as the UK and Australia are expected to have an advantage, and countries like Egypt and Argentina are expected to be at a disadvantage owing to higher country risk, leading to higher costs of financing.

Some countries like India and Chile may benefit from depreciating exchange rates that make importing from these countries in USD cheaper with the passage of time. The impact of a depreciating exchange rate can be as high as 17 percent[8] reduction in levelized cost in USD terms for countries like India.

[8] Indian Rupee (INR) is assumed to depreciate at 2.8 percent year-on-year with respect to the U.S. Dollar (USD). The Chilean Peso is assumed to depreciate at 1.36 percent year-on-year with respect to USD.

4. Role of the UAE, India, Saudi Arabia, Chile, Australia and Egypt in 2030 global hydrogen trade

4.1 The UAE, India and Saudi Arabia expected to produce green hydrogen at less than USD 2/kg

The UAE is expected to produce the cheapest green hydrogen and green ammonia in 2030 across the 10 countries analyzed. India is expected to be second, driven by cheap renewable energy, low electrolyzer costs and a depreciating currency advantage. Even with high solar and wind resources, costs in Egypt and Argentina are higher owing to higher financing costs for the projects.

Table 2: Green hydrogen and green ammonia price at production location

Country	2023		2030	
	LCOH*	LCOA*	LCOH*	LCOA*
	USD/kg	USD/tonne	USD/kg	USD/tonne
UAE	2.7	629	1.7	436
India**	3.2	727	1.8	467
Saudi Arabia	2.9	686	1.8	475
Chile	3.4	783	2.1	541
Chinese Mainland	3.1	719	2.4	588
Egypt	3.8	918	2.3	641
United States	3.9	876	2.5	610
Australia	4.5	962	2.7	635
Argentina	5.2	1220	3.1	838
United Kingdom	5.0	1077	3.5	809

Source: Alvarez & Marsal analysis

*LCOH: Levelized Cost of Hydrogen, LCOA: Levelized Cost of Ammonia. Levelized costs denote a single price which will be paid during the entire tenure of the contract/project.

**Assuming rupee depreciation of 2.8%, without which the ammonia LCOA is expected to be higher by USD 130-140 /tonne.

The U.S. is expected to produce green hydrogen and green ammonia at USD 2.5/kg and USD 610/tonne, respectively, in 2030. This is before considering the benefits of the Inflation Reduction Act (IRA) which can be availed by the project developers. The IRA incentive of USD 3/kg for 10 years leads to a USD ~2/kg and USD ~1.7/kg reduction in LCOH in 2023 and 2030 respectively. This leads to an LCOA of USD 530/tonne in 2023 and USD 318/tonne in 2030.

4.2 India well-positioned on infrastructure and other enablers

Since green hydrogen and green ammonia are expected to be traded under long-term contracts, infrastructure and other enablers will be important factors to be considered by the importing countries while forging a trade deal. Countries with existing experience in renewable energy, the hydrogen supply chain, adequate infrastructure, high political stability and good trade relations may be preferred for import of green hydrogen and ammonia. The following framework scores 10 countries on their infrastructure and other ecosystem enablers to identify those that are favorably positioned.

Table 3: Infrastructure and other ecosystem enablers scoring

	Renewable Energy Ecosystem	Size of Power Grid (including Transmission)	Current H2 Usage	Manufacturing Ecosystem	Petrochemicals and Gas Consumption	Port Infrastructure	Ease of Doing Business	Trade Relationships (with EU and Japan)	Final Score
United States	▲	▲	▲	▲	▲	▲	▲	▲	3.0
Chinese Mainland	▲	▲	▲	▲	▲	►	►	►	2.6
UK	►	►	▲	►	►	▲	▲	►	2.4
India	▲	▲	▲	►	►	►	►	►	2.3
UAE	▼	▼	▼	►	►	▲	▲	►	2.0
Australia	►	►	▼	▼	▼	►	▲	►	1.8
Saudi Arabia	▼	►	►	▼	►	►	►	►	1.7
Chile	▼	▼	▼	▼	▼	►	►	▼	1.3
Egypt	▼	►	►	▼	▼	►	▼	▼	1.3
Argentina	▼	▼	▼	▼	▼	▼	▼	▼	1.0

▲ High ► Medium ▼ Low

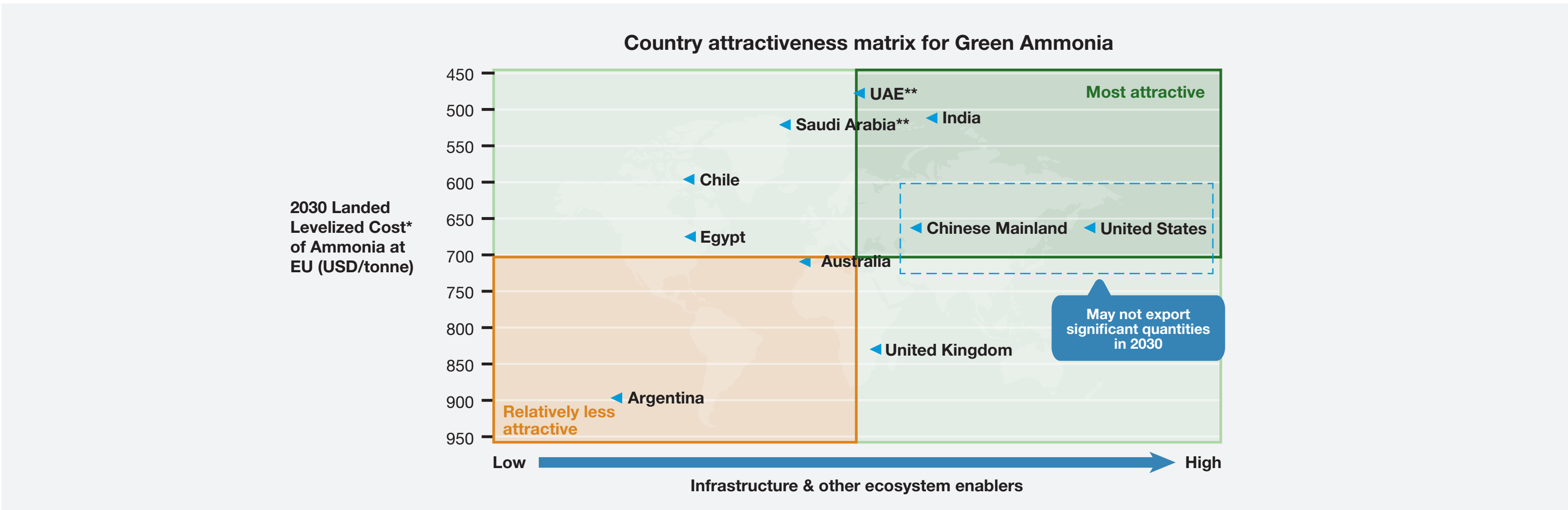
Source: Alvarez & Marsal analysis

The U.S., the Chinese mainland and India have significant renewable energy deployment and large electricity grids. Both of these factors are conducive for green hydrogen development. The U.S., the Chinese mainland, India and the UK have experience in handling hydrogen in existing industries along with a strong engineering and manufacturing ecosystem. Countries with existing port infrastructure and trade relations with the EU and Japan are expected to leverage them for exports. Political stability and the ease of doing business are also important factors when countries or regions look for trade partners. The U.S., the UK, the UAE and Australia score well on this parameter.

4.3 India likely to emerge as green ammonia supplier with one of the lowest costs by 2030

India, the U.S. and the Chinese mainland have favorable economics for exports as well as a high score on infra-structure and other enablers and, hence, are placed in the most attractive quadrant. However, the U.S. and the Chinese mainland are not expected to be major exporters due to their large internal needs, which leaves India as the most preferred partner for trade with the EU, Japan and South Korea. Saudi Arabia and the UAE, with economics close to India, are expected to be close competitors. Chile, Egypt and Australia are expected to follow these three as preferred countries for green hydrogen or green ammonia trade.

Figure 10: Country attractiveness matrix for green ammonia trade[9]



Source: Alvarez and Marsal analysis

*LCOH: Levelized Cost of Hydrogen, LCOA: Levelized Cost of Ammonia. Levelized costs denote a single price which will be paid during the entire tenure of the contract/project.

**For Saudi Arabia and the UAE we have considered solar wind hybrid for calculations. Only solar based green hydrogen production is expected to be 10-15 cents/kg higher in price.

For capturing the green hydrogen or green ammonia trade opportunity and leverage its attractive position, India will have to take certain steps. The next section focuses on the steps India needs to take to realize the potential trade opportunity.

[9] The landed levelized costs of ammonia in the EU are inclusive of shipping freight to Europe. The shipping prices are levied based on existing shipping fuel used by the industry. If green methanol is used as fuel for shipping of green ammonia, then the landed prices are expected to increase by 3–10 percent of the prices denoted in the graph.

5. Policy recommendations

India is positioning itself to capitalize on the hydrogen revolution, with the Indian government taking steps to establish the hydrogen ecosystem in the country with a significant INR 19,744-crore (USD 2.3 billion)[x] support program. This includes generation-based incentives (GBI) of INR 13,050 crore (USD 1.57 billion) for hydrogen production and production-linked incentives (PLI) of INR 4,440 crore (USD 533 million) for electrolyzer manufacturing.

The current announced measures by the government have played an important role to create initial momentum, with many players having announced projects. To get the projects moving on the ground, we make the following specific recommendations:

5.1 Create initial domestic demand for one million tonnes of hydrogen by 2027

Creation of firm demand is the single most important need for the low-carbon hydrogen industry at present. The government can identify end-use sectors that are most amenable to offtake hydrogen and work out a financial support plan to bridge any viability gaps. This could be done in a transparent manner through public-private partnership models to design projects. Some of the sectors that should be targeted are refineries, fertilizers, steel and heavy-duty transport.

5.2 Help reduce costs of producing hydrogen through supply-side interventions

The government can help reduce cost of producing green hydrogen in three areas:

1. De-risking projects through credible offtake guarantees: The SECI model of creating a credible offtaker intermediary has worked well in the case of solar and wind auctions to reduce the cost of capital and attract investments. The same model may be adopted for hydrogen, where an offtake guarantee program can significantly help to reduce costs. A model on the lines of Germany's H2Global, which focuses on import of green hydrogen with a provision for viability gap funding, can be developed for domestic demand creation in India.

2. Contract for Differences (CfD) model to enable round-the-clock renewables: A unique CfD model can be designed to enable round-the-clock renewables, especially for interstate supply of power to electrolyzers. Under this model, the temporal mismatches between RE generation and electrolyzer consumption are addressed by buying and selling power in the power exchange. The CfD will fund the difference between the buy price and sell price, so that the electrolyzer gets a predictable, stable cost of renewable power. Given that wind capacities available for the hydrogen sector may be constrained, this model will also enable greater use of solar power in the mix, since the CfD allows to convert it into round-the-clock power in the power exchange. This concept needs some discussion among stakeholders.

3. Reducing taxes on equipment: The government must address the impact of indirect taxes on equipment. Measures to reduce or refund the taxes can help to save 6–10 percent in the final cost of hydrogen.

Current Policy Measures

1. Generation-based incentive or GBI for hydrogen production: GBI will be offered on 0.45 million tonnes of hydrogen production. A subsidy of INR 50,40,30/kg (USD 0.60, 0.48, 0.36/kg) for the first, second and third years will be offered under the scheme.[xi]

2. PLI for electrolyzer manufacturing: PLI is being offered for 1,500 MW of annual electrolyzer production capacity. The incentive starts from INR 4,440/kW (USD 53/kW) in the first year and tapers to INR 1,480/kW (USD 18/kW) in the fifth year of operations.[xii]

3. Demand creation through procurement tenders by Solar Energy Corporation of India Limited (SECI): SECI is aggregating green hydrogen and green ammonia demand from refineries and fertilizer industries. It is expected to come up with centralized tenders for procurement of green hydrogen and green ammonia.

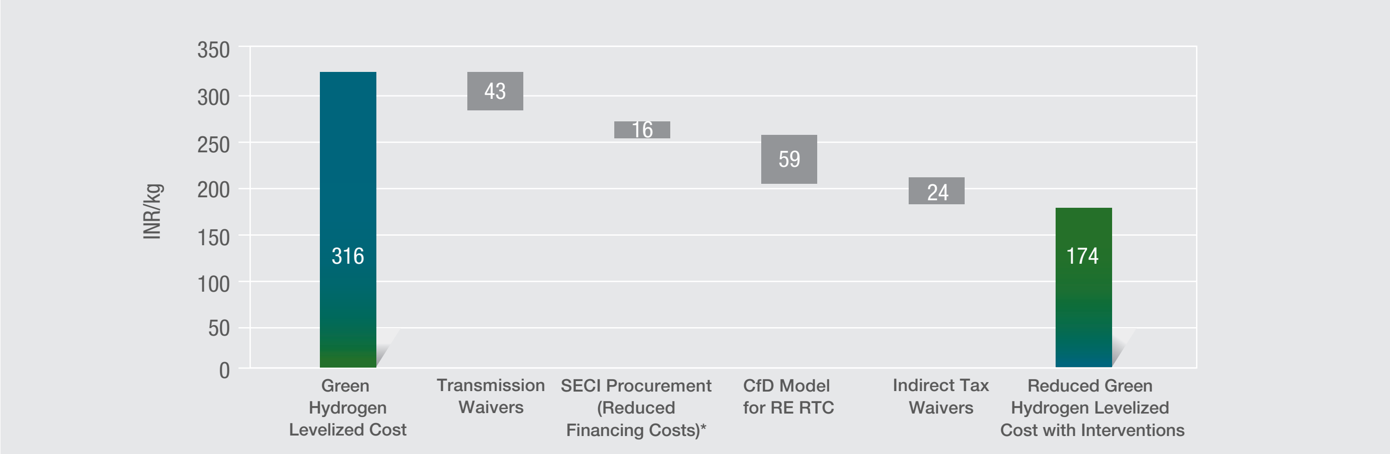
4. Transmission waivers: there is a 100% waiver of interstate transmission charges for 25 years on green hydrogen and ammonia projects commissioned until December 31, 2030.[xiii]

5. Exemption from cross-subsidy surcharge for third-party purchases of green power for production of green hydrogen and green ammonia.

6. Creation of hydrogen valleys: The Department of Science and Technology (DST) is leading the initiative for development of Hydrogen Valley Industrial Clusters. DST is running a process for allocating an INR 90-crore (USD 10 million) grant.[xiv]

7. INR 455 crore (USD ~55 million) has been allocated for research development and deployment and for setting up pilot plants for production and utilization of hydrogen in the iron and steel-making process.[xv]

Figure 11: Estimated green hydrogen levelized cost (in INR/kg) after impact of cost reduction levers



Source: Alvarez and Marsal analysis

*Reduced financial costs will be driven by SECI guarantees and procurements.

Implementation of these cost reduction strategies could lead to a substantial reduction of approximately 45 percent in green hydrogen levelized costs, bolstering financial viability. These measures, while expensive, may be provided to the first one million tonnes of hydrogen capacity, to compensate early movers for the higher risks and higher costs they incur as compared to late movers in a reducing cost curve environment.

5.3 Decoupling of renewable energy and hydrogen production systems

For additional de-risking of the projects, decoupling of the renewable energy supply transaction from the hydrogen production and sale-purchase transaction through a credible intermediary can be considered. In addition to the point above on offtake guarantee, here the intermediary further plays the role of decoupling the RE transaction from the hydrogen transaction. It purchases RE hybrid power through auctions and provides the same to hydrogen producers. The benefits of such a decoupling model are that it de-risks the RE capacity, enabling easier financing and more players participating in the RE part of the chain, while simultaneously reducing the capital investment needed for hydrogen producers.

5.4 Simplify processes and move with speed

Often when it comes to implementation of these programs, companies encounter process friction due to a large number of checks and balances. These elements slow down decision making and eventually delay the program rollout. While the processes intend to target the incentives fairly and efficiently, there is merit in keeping the policy simple and focusing on ease of implementation.

5.5 At a state level, improve ease of doing business through land allocation, transmission connectivity and state-level banking of energy

Many states have announced policies for green hydrogen, given the potential to attract investments and create jobs. Particularly, these projects are very land-intensive and, therefore, favorable policies to allocate land and government support in land acquisition are needed. This will be critical to achieve such a program scale. For achieving the government target of five million tonnes of green hydrogen production, India needs to allocate nearly 2.6–4.2 lakh acres of land.

This must be further supported by the timely grant of transmission connectivity. State-level policies to reduce the cost of renewable energy through cost-effective banking of power will also help to facilitate speed of execution and reduce the cost of producing hydrogen.

5.6 Private sector should think long-term and build trusted relationships

Private suppliers and customers need to work in partnership in a transparent manner so that there is clear understanding of costs on both sides, appreciation of the risks involved, level of readiness and timelines to implement the projects. This will be necessary to build trust and enter into equitable contracts for both buyers and sellers. Hydrogen will be a long-term play, and it is important to lay the right foundation to create long-lasting partnerships.

6. Why is a large financial commitment beneficial?

Establishing the green hydrogen supply chain early would give India a head start in terms of two specific long-term economic advantages: First, it will help us rapidly scale up and reduce costs, securing India a substantial market share in global supply markets. Second, it will enable the domestic end-use sectors to switch early, safeguarding their long-term competitiveness. For example, our steel and auto sectors that face the looming specter of decarbonization pressures will be able to prepare early when supported by a robust domestic hydrogen supply chain.

To achieve the monumental scale required, it is imperative that India’s hydrogen sector garners substantial support — an estimated USD 4–12 billion until 2030. This is driven by the need to level the playing field against global suppliers who enjoy government subsidies and to enable domestic end-use sectors to transition affordably. By offering this bridge support, the end-use sectors that operate in competitive markets will be able to adopt sustainable alternatives sooner.

The benefits of such a program can be substantial — assuming a 10-15 percent share of global trade in hydrogen can provide USD 3–5 billion annually in export revenues by 2030. Import substitution in domestic sectors might save a substantial USD 7–16 billion in foreign exchange. The prospective impact on GDP by kickstarting the hydrogen economy — between 0.1–0.5 percent annually — holds the promise of elevating India's economic prowess. Such an endeavor will also position us well to ride the hydrogen wave expected in the next few decades.

While the quantum of support might look large, the broader context offers perspective. Over the next seven years, India's oil import bill is estimated at a staggering USD 1.0 –1.4 trillion. What we need to propel the hydrogen sector into orbit is only a fraction of this amount. The potential outcomes of India's strategic investment in green hydrogen are profound — economic resilience, stronger geopolitical presence and sustainable growth that transcends generations.

Sources

i. UN environment programme, “Emissions Gap Report 2022,” 27 October 2022. https://www.unep.org/resources/emissions-gap-report-2022.

ii. BP, “Statistical Review of World Energy,” 2022. https://www.bp.com/content/dam/bp/business-sites/en/-global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf.

iii. International Energy Agency, “World Energy Outlook 2022,” 2022. https://www.iea.org/reports/world-energy-outlook-2022.

iv. Energy Transmission Commission, “Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy.” April 2021. https://energy-transitions.org/wp-content/uploads/2021/04/ETC-Global-Hydrogen-Report.pdf.

v. International Energy Agency, “Global Hydrogen Review 2023,” 2023. https://www.iea.org/reports/global-hydrogen-review-2023.

vi. International Energy Agency. https://www.iea.org/.

vii. Hellonext, “Green, Blue and Grey Hydrogen: the main differences.” https://www.hellon-ext.world/green-blue-and-grey-hydrogen-the-main-differences/.

viii. International Energy Agency, “Net zero by 2050: A roadmap for the global energy sector.” https://iea.blob.core.windows.net/assets/dee-bef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf.

ix. International Energy Agency, ”Electrolyzer.” https://www.iea.org/energy-system/low-emission-fuels/electrolysers.

x. Ministry of New and Renewable Energy, “National green hydrogen mission,” Jan 04, 2023. https://pib.gov.in/PressReleasePage.aspx?PRID=1888547

xi. Ministry of New and Renewable Energy, https://mnre.gov.in/img/documents/uploads/-file_f-1687963916599.pdf.

xii. Ministry of New and Renewable Energy ,https://mnre.gov.in/img/documents/uploads/-file_f-1687964057675.pdf.

xiii. Ministry of Power, Order No. 12/07/2023 -RCM. https://pib.gov.in/PressReleaseIframePage.aspx-?PRID=1928128#:~:text=The%20ISTS%20waiver%20of%20Green,2025%20to%2031%20Dec%202030.&text=In%20a%20major%20decision%2C%20the,to%20Green%20Hydrogen%2FGreen%20Ammonia%20.

xiv. Department of Science and Technology Ministry of Science and Technology, “Call for proposals on Hydrogen Valley Platform in India,” 2023. https://dst.gov.in/sites/default/files/Call%20for%20Propos-als.pdf.

xv. Ministry of Steel, File No. S-20015/5/2021 – TECH (E12147). https://steel.gov.in/sites/default/files/Letter%20R%26D%20Proposals%20Green%20Hydrogen%20Mission.pdf.

SANTOSH KAMATH
Managing Director

skamath@alvarezandmarsal.com

KEY CONTRIBUTORS:

ABHISHEK KOCHAR
Senior Director

RAVI CHANDRAKAR
Director

SIMARJEET SINGH
Senior Manager

BHAVANA GADDAM
Manager

RAUNAK MEENA
Manager

ABOUT ALVAREZ & MARSAL

Companies, investors and government entities around the world turn to Alvarez & Marsal (A&M) for leadership, action and results. Privately held since its founding in 1983, A&M is a leading global professional services firm that provides advisory, business performance improvement and turnaround management services. When conventional approaches are not enough to create transformation and drive change, clients seek our deep expertise and ability to deliver practical solutions to their unique problems.

With over 10,000 people providing services across six continents, we deliver tangible results for corporates, boards, private equity firms, law firms and government agencies facing complex challenges. Our senior leaders, and their teams, leverage A&M's restructuring heritage to help companies act decisively, catapult growth and accelerate results. We are experienced operators, world-class consultants, former regulators and industry authorities with a shared commitment to telling clients what's really needed for turning change into a strategic business asset, managing risk and unlocking value at every stage of growth.

To learn more, visit: **AlvarezandMarsal.com**

Follow A&M on:

ALVAREZ & MARSAL
LEADERSHIP. **ACTION. RESULTS.**℠