IH2A
INDIA HYDROGEN ALLIANCE

# INDIA GREEN HYDROGEN EQUIPMENT & SERVICES MARKET OPPORTUNITY 2030

## Green Hydrogen Industry Whitepaper

India Hydrogen Alliance, IH2A

October 19 2023

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## EXECUTIVE SUMMARY

This industry white paper has been prepared in anticipation of the significant green hydrogen CAPEX plans that will precede actual production and end-use offtake of green hydrogen or its derivatives. It offers a preliminary view, based on industry inputs gathered by India Hydrogen Alliance (IH2A). The key takeaways from this white paper are that:

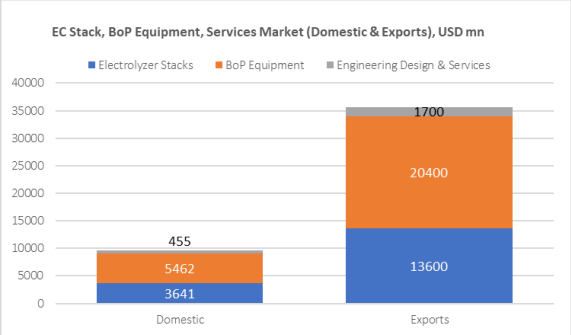
There exists a potential USD 45-50 bn Green Hydrogen Economy and Market Creation Opportunity for India between 2024-2030, for green hydrogen equipment and services exports i.e. hydrogen systems engineering design, Electrolyser (EC) stack manufacturing, Balance of Plant (BoP) equipment manufacturing, building on India's global competitive advantage on specialist engineering design and equipment manufacturing skills for domestic and global markets. *The USD 45-50 bn estimate is based on a conservative projection. This is separate from the market for Green Hydrogen and its derivatives, which will emerge as demand offtake and supplies are matched.*

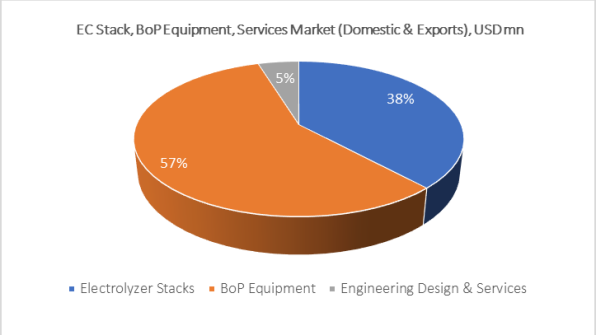
The paper assumes hypothetical development of about 135 green hydrogen projects domestically by 2030, and deployment of 6.8 GW pa Electrolyser Capacity, producing and delivering at least 1 Mmt green hydrogen to domestic offtake for industrial use (refinery and steel in compressed gaseous form), fertilizer feedstock (as green ammonia) and heavy-duty transport (as liquid hydrogen). The 135 green hydrogen projects could vary in scale, ranging from 10 MW, 20 MW, 50 MW to 100 MW projects using Alkaline and PEM technologies (see Part A for assumptions on project scales, by EC technology and end-use offtake), together with BoP Equipment (representing 60% of costs of green hydrogen plants) represent a domestic green hydrogen equipment market worth USD 9 bn. Part A of this report focusses on assumed domestic green hydrogen projects pipeline and deployed systems/ equipment that may be built in the 2024-2030 timeframe. The BoP equipment scope beyond the EC boundary could be even greater for industrial and ammonia plants *(see b. in Assumptions section). An optimistic view would add an additional 3.4 GW electrolyser capacity to add an additional USD 4.5 bn to the domestic market during the same period.*

The paper further assumes that locally manufactured EC stacks and BOP equipment will be globally competitive in Asia-Pac, Middle East (ME) and Africa markets (EC stack components, compressors, transformers, rectifiers, storage equipment, water purification, air separation units, liquification units, BoP components) – representing a larger exports market for green hydrogen equipment. Taking an approach similar to the one for the domestic market, the paper estimates green hydrogen equipment exports potential to be worth at least USD 34 bn, with 540 assumed projects in APAC, ME and Africa region (270 in APAC, and 135 each in ME and Africa), between 2024-2030. This hydrogen systems and equipment exports market is likely to precede export of green hydrogen molecules during this period. This is detailed in Part B, which also emphasizes India's competitive advantages on engineering design and manufacturing – a critical bottleneck in project development and deployments globally. This syncs well with the government's ambition for exports (albeit through equipment and services in this case). *NOTE: BoP equipment scope beyond EC boundary could be greater for industrial and ammonia plants.*

An additional USD 2.1 bn in specialist talent/service exports for engineering design, project development and EPC services, has been estimated based on 5% OPEX on deployed project CAPEX investments. This covers new technical, commercial and policy/regulatory skillsets and jobs, estimated at 162,000 direct and indirect jobs. This is covered in part C of this report.

Potential USD 50 bn Green Hydrogen Equipment & Services Market (Domestic and Exports), 2030




KEY ASSUMPTIONS:

a) This report assumes that India has potential to manufacture green hydrogen systems and equipment for projects to deliver at least 1 Mmt Green H2 for Domestic Consumption, and to export H2 Systems, Equipment and Skills to Asia, Middle East and Africa by 2030, to create a Global Green Hydrogen Engineering and Manufacturing Hub in India. It is also assumed that there is also a desire to build distinct competitive advantage in equipment manufacturing and services within the global green hydrogen economy. NOTE: *Electrolyser efficiencies have been assumed to remain constant until 2030 estimating production volumes in this report, although ideally they should increase and lead to higher production.*

b) There will be variations in costs among ammonia plants, industrial setups, and transportation facilities; and there is a scope of BoP equipment beyond EC boundaries, increasing the potential BoP equipment opportunity.

RISK FACTORS

a) Actual project development will determine both hydrogen systems and equipment deployment – number of estimated projects (135 projects as a combination of different scales at 10, 20, 50 and 100 MW by electrolyser capacity; OR a combination of different capacities to create large hydrogen hubs of 100 MW or higher) will determine actual green hydrogen market development.

b) BoP equipment is estimated to be 60% of cost of a H2 production plant- domestic manufacturing of compressors, storage tanks, gas separation units, pipelines, evacuation infrastructure – are important for driving down equipment CAPEX. Safety certification and globally harmonized standardization of such equipment will ensure that India can emerge as a global manufacturing hub for Green H2 equipment, beyond current push for domestic Electrolyser manufacturing.

c) Developing specialist green hydrogen engineering systems and global competency plays to India's competitive advantage – but for this to be achieved both a) and b) are necessary conditions. Without them, India is unlikely to become a global green hydrogen engineering services hub.

d) Accelerated efforts to form a National Green Hydrogen Development Corporation, on public-private partnership, to enable project development, building global manufacturing competitive strengths for EC, BoP equipment and Services; and enable hydrogen price discovery for offtake is critical. Such a National Green Hydrogen Development Corporation would also ensure that public and private players are collaborating closely on development of the green hydrogen economy.

KEY TAKAWAYS & IMPLICATIONS FOR STAKEHOLDERS – POLICY MAKERS, INDUSTRY & INVESTORS

1) This is consolidated H2 equipment and services market potential of USD 45-50 bn, over and above offtake market for green H2 molecules - a green-field opportunity for India-made green hydrogen systems, equipment, and engineering services exports for deployment in India, Asia-Pac, Middle

East and Africa. The USD 50 bn is assumed to be split USD 17 bn for Electrolyser Stacks, USD 26-31 bn for BoP Equipment (Compressors, Storage Tanks, Transformers, Rectifiers, Liquefaction Units, Air Separation Units, Dispensing Units, Power Systems, Sensors and Instrumentation, and Pipeline/ Evacuation Infrastructure), and USD 2 bn for specialist Engineering Services.

2) This indicates potential to create 15-20 Green Hydrogen Equipment Manufacturing Companies in India, with estimated revenues of USD 2bn+ each, from public and private sector side. This value-creation opportunity exists for engineering design, equipment manufacturing, EPC and services companies.
3) Participation of anchor global and Indian investors in H2 equipment manufacturing will be critical to developing this projected USD 45-50 bn Green H2 Equipment and Services market. This should be a separate workgroup within the Green Hydrogen Mission Secretariat, working with Ministries of Commerce (DPIT), Heavy Industry, Power and Environment (for accelerating industrial decarbonization).

For preparation of this white paper, IH2A engaged with representatives from 36 companies operating across the H2 value-chain in India and globally, covering member and non-member companies, investors, government stakeholders and energy-transition experts. 18 existing equipment manufacturing companies were engaged with and their inputs sought.

ACKNOWLEDGMENTS

IH2A would like to thank the Ministry of New and Renewable Energy, Government of India, for their remarks during the stakeholder meeting and participation from the industry for their inputs into the white paper. The inputs were sought directly as well as through a multi-stakeholder e-consultation organised on September 20 2023.

- Private industry participants (36 companies) - Chart Howden, Reliance Industries, JSW Steel, Hero Future Energies, bp, John Cockerill, Nel, L&T, Air Liquide, Shell, Cummins, Welspun Energy, Torrent Power, Skeiron Green Energy, Siemens Energy, Toyota Kirloskar, Tubacex, Bureau Veritas, Sumitomo, Ceres, Plug Power, Thermax, Newtrace, Technip Energies, Thyssenkrupp Nucera, H2e, Ador Power, Kirloskar, KPIT, Nikkiso Cosmodyne, McDermott, Tata Consulting Engineers, Arup, Mitsui Orient Lines, and FTI Consulting.
- Government participants and representatives - Ministry of New and Renewable Energy (MNRE), Ministry of External Affairs (MEA) and NITI Aayog

# PART A: Domestic Green Field H2 Projects & Equipment (ECs & BoP)

We started with projecting the number of greenfield green hydrogen projects, of varying scale, that would cumulatively deliver at least 1 Mmt of green hydrogen per annum. We assumed three use-cases (industrial use, ammonia use and heavy-duty transport) using Alkaline (AK) and PEM electrolyser technologies. Below is an indicative illustration of number of green-field projects to be built over 2024-2030, with assumptions skewed towards larger (50-100 MW+) plants for Industrial Offtake (for Compressed Gasous Hydrogen) and Green Ammonia Offtake (Fertilizer) Offtake.

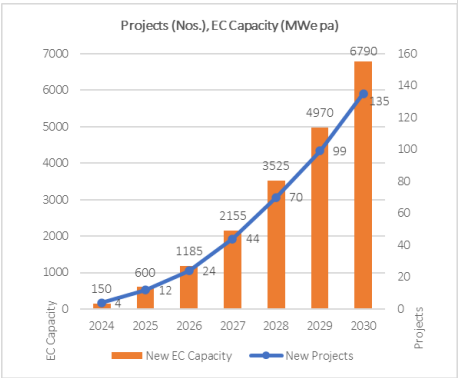
| | | | No. of projects commissioned | | | | | | | | EC capacity installed | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Commercial Scale Green H2 Projects** | **TECH** | **EC-CAP/MW** | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOTAL | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOTAL |
| CGH2 Projects for Industrial Offtake (Steel, Refinery & Cement) - 25, 50, 100 MW | | | | | | | | | | | | | | | | | | |
| MAK - Medium 25 MW Industrial Offtake Projects & Captive Production Projects | AK | 25 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | **7** | 25 | 25 | 25 | 25 | 25 | 25 | 25 | **175** |
| MPEM - Medium 25 MW Ind Offtake Projects & Captive Production Projects | PEM | 25 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | **5** | 0 | 0 | 0 | 25 | 25 | 25 | 50 | **125** |
| LAK - Large 50 MW Industrial Offtake Projects & Captive Production Projects | AK | 50 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | **15** | 50 | 50 | 100 | 100 | 150 | 150 | 150 | **750** |
| LPEM - Large 50 MW Industrial Offtake Projects & Captive Production Projects | PEM | 50 | 0 | 1 | 1 | 2 | 3 | 3 | 4 | **14** | 0 | 50 | 50 | 100 | 150 | 150 | 200 | **700** |
| VLPEM - Very Large 100 MW Ind Offtake Projects & Captive Production Projects | PEM | 100 | 0 | 1 | 1 | 2 | 3 | 3 | 4 | **14** | 0 | 100 | 100 | 200 | 300 | 300 | 400 | **1400** |
| **TOTAL** | | | **2** | **4** | **5** | **8** | **11** | **11** | **14** | **55** | **75** | **225** | **275** | **450** | **650** | **650** | **825** | **3150** |
| H2 Projects for Ammonia Production for Fertilizer and Exports - 25, 50, 100 MW | | | | | | | | | | | | | | | | | | |
| MAK - Medium 25 MW Fertilizer Offtake Projects | AK | 25 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | **7** | 25 | 25 | 25 | 25 | 25 | 25 | 25 | **175** |
| MPEM - Medium 25 MW Fertilizer Offtake Projects | PEM | 25 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | **5** | 0 | 0 | 0 | 25 | 25 | 25 | 50 | **125** |
| LAK - Large 50 MW Export-Oriented Projects | AK | 50 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | **15** | 50 | 50 | 100 | 100 | 150 | 150 | 150 | **750** |
| LPEM - Large 50 MW Export-Oriented Projects | PEM | 50 | 0 | 1 | 1 | 2 | 3 | 3 | 4 | **14** | 0 | 50 | 50 | 100 | 150 | 150 | 200 | **700** |
| VLPEM - Very Large 100 MW Ind. Offtake Projects & Captive Production Projects | PEM | 100 | 0 | 1 | 1 | 2 | 3 | 3 | 4 | **14** | 0 | 100 | 100 | 200 | 300 | 300 | 400 | **1400** |
| **TOTAL** | | | **2** | **4** | **5** | **8** | **11** | **11** | **14** | **55** | **75** | **225** | **275** | **450** | **650** | **650** | **825** | **3150** |
| LH2 Projects for Transport Use Case - 10, 25, 50 MW | | | | | | | | | | | | | | | | | | |
| SAK - Small 10 MW Heavy Duty Transport Offtake Projects | AK | 10 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | **9** | 0 | 0 | 10 | 20 | 20 | 20 | 20 | **90** |
| MAK - Medium 25 MW Heavy Duty Transport Offtake Projects | AK | 25 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | **7** | 0 | 0 | 25 | 25 | 25 | 50 | 50 | **175** |
| MPEM - Medium 25 MW Heavy Duty Transport Offtake Projects | PEM | 25 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | **6** | 0 | 0 | 0 | 25 | 25 | 50 | 50 | **150** |
| LAK - Large 50 MW Heavy Duty Transport Offtake Projects | AK | 50 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | **2** | 0 | 0 | 0 | 0 | 0 | 25 | 25 | **50** |
| LPEM - Large 50 MW Heavy Duty Transport Offtake Projects | PEM | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **1** | 0 | 0 | 0 | 0 | 0 | 0 | 25 | **25** |
| **TOTAL** | | | **0** | **0** | **2** | **4** | **4** | **7** | **8** | **25** | **0** | **0** | **35** | **70** | **70** | **145** | **170** | **490** |
| **GRAND TOTAL (Greenfield Projects achieving Technical and Financial Close)** | | | **4** | **8** | **12** | **20** | **26** | **29** | **36** | **135** | **150** | **450** | **585** | **970** | **1370** | **1445** | **1820** | **6790** |

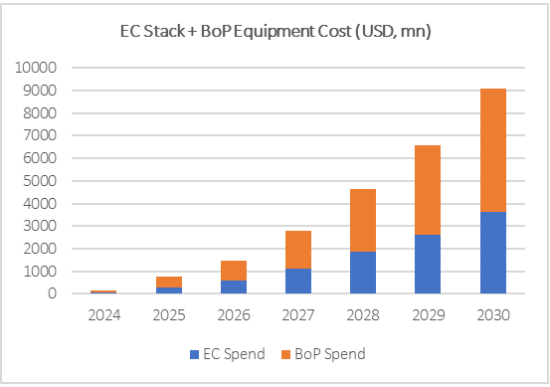
135 such green hydrogen projects would have to be built over next seven years, to create an EC installed base of 6.8 GW Electrolyser Capacity, at a cost of USD 3.6 bn (estimated at USD 0.4 mn/MW for AK ECs and USD 0.6 mn/MW for PEM ECs) and Installed BoP Equipment worth USD 5.5 bn, by 2030. BoP equipment covers Compressors, Storage Tanks, Transformers, Rectifiers, Air Separation Units, Water Purification, Pipelines/ Evacuation Infrastructure, for estimated green hydrogen projects.

| | | EC Stack Costs, USD mn | | | | | | | | BoP Equipment Costs, USD mn | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Commercial Scale Green H2 Projects** | **TECH** | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOTAL | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | TOTAL |
| CGH2 Projects for Industrial Offtake (Steel, Refinery & Cement) - 25, 50, 100 MW | | | | | | | | | | | | | | | | | |
| MAK - Medium 25 MW Industrial Offtake Projects & Captive Production Projects | AK | 10 | 10 | 10 | 10 | 10 | 10 | 10 | **70** | 15 | 15 | 15 | 15 | 15 | 15 | 15 | **105** |
| MPEM - Medium 25 MW Ind Offtake Projects & Captive Production Projects | PEM | 0 | 0 | 0 | 15 | 15 | 15 | 30 | **75** | 0 | 0 | 0 | 23 | 23 | 23 | 45 | **113** |
| LAK - Large 50 MW Industrial Offtake Projects & Captive Production Projects | AK | 20 | 20 | 40 | 40 | 60 | 60 | 60 | **300** | 30 | 30 | 60 | 60 | 90 | 90 | 90 | **450** |
| LPEM - Large 50 MW Industrial Offtake Projects & Captive Production Projects | PEM | 0 | 30 | 30 | 60 | 90 | 90 | 120 | **420** | 0 | 45 | 45 | 90 | 135 | 135 | 180 | **630** |
| VLPEM - Very Large 100 MW Ind Offtake Projects & Captive Production Projects | PEM | 0 | 60 | 60 | 120 | 180 | 180 | 240 | **840** | 0 | 90 | 90 | 180 | 270 | 270 | 360 | **1260** |
| **TOTAL** | | **30** | **120** | **140** | **245** | **355** | **355** | **460** | **1705** | **45** | **180** | **210** | **368** | **533** | **533** | **690** | **2558** |
| H2 Projects for Ammonia Production for Fertilizer and Exports - 25, 50, 100 MW | | | | | | | | | | | | | | | | | |
| MAK - Medium 25 MW Fertilizer Offtake Projects | AK | 10 | 10 | 10 | 10 | 10 | 10 | 10 | **70** | 15 | 15 | 15 | 15 | 15 | 15 | 15 | **105** |
| MPEM - Medium 25 MW Fertilizer Offtake Projects | PEM | 0 | 0 | 0 | 15 | 15 | 15 | 30 | **75** | 0 | 0 | 0 | 23 | 23 | 23 | 45 | **113** |
| LAK - Large 50 MW Export-Oriented Projects | AK | 20 | 20 | 40 | 40 | 60 | 60 | 60 | **300** | 30 | 30 | 60 | 60 | 90 | 90 | 90 | **450** |
| LPEM - Large 50 MW Export-Oriented Projects | PEM | 0 | 30 | 30 | 60 | 90 | 90 | 120 | **420** | 0 | 45 | 45 | 90 | 135 | 135 | 180 | **630** |
| VLPEM - Very Large 100 MW Ind. Offtake Projects & Captive Production Projects | PEM | 0 | 60 | 60 | 120 | 180 | 180 | 240 | **840** | 0 | 90 | 90 | 180 | 270 | 270 | 360 | **1260** |
| **TOTAL** | | **30** | **120** | **140** | **245** | **355** | **355** | **460** | **1705** | **45** | **180** | **210** | **368** | **533** | **533** | **690** | **2558** |
| LH2 Projects for Transport Use Case - 10, 25, 50 MW | | | | | | | | | | | | | | | | | |
| SAK - Small 10 MW Heavy Duty Transport Offtake Projects | AK | 0 | 0 | 4 | 8 | 8 | 8 | 8 | **36** | 0 | 0 | 6 | 12 | 12 | 12 | 12 | **42** |
| MAK - Medium 25 MW Heavy Duty Transport Offtake Projects | AK | 0 | 0 | 10 | 10 | 10 | 20 | 20 | **70** | 0 | 0 | 15 | 15 | 15 | 30 | 30 | **75** |
| MPEM - Medium 25 MW Heavy Duty Transport Offtake Projects | PEM | 0 | 0 | 0 | 15 | 15 | 30 | 30 | **90** | 0 | 0 | 0 | 23 | 23 | 45 | 45 | **90** |
| LAK - Large 50 MW Heavy Duty Transport Offtake Projects | AK | 0 | 0 | 0 | 0 | 0 | 10 | 10 | **20** | 0 | 0 | 0 | 0 | 0 | 15 | 15 | **15** |
| LPEM - Large 50 MW Heavy Duty Transport Offtake Projects | PEM | 0 | 0 | 0 | 0 | 0 | 0 | 15 | **15** | 0 | 0 | 0 | 0 | 0 | 0 | 22.5 | **0** |
| **TOTAL** | | **0** | **0** | **14** | **33** | **33** | **68** | **83** | **231** | **0** | **0** | **21** | **50** | **49.5** | **102** | **125** | **346.5** |
| **GRAND TOTAL (Greenfield Projects achieving Technical and Financial Close)** | | **60** | **240** | **294** | **523** | **743** | **778** | **1003** | **3641** | **90** | **360** | **441** | **785** | **1115** | **1167** | **1505** | **5462** |

This installed green hydrogen project base - 135 projects of varying scales for the three separate use-cases – is likely to yield 1 Mmt per annum of Green Hydrogen.

| | | H2 Production - 150 Mtpa/MW (est.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Commercial Scale Green H2 Projects** | **TECH** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **TOTAL** |
| CGH2 Projects for Industrial Offtake (Steel, Refinery & Cement) - 25, 50, 100 MW | | | | | | | | | |
| MAK - Medium 25 MW Industrial Offtake Projects & Captive Production Projects | AK | 3750 | 3750 | 3750 | 3750 | 3750 | 3750 | 3750 | **26250** |
| MPEM - Medium 25 MW Ind Offtake Projects & Captive Production Projects | PEM | 0 | 0 | 0 | 3750 | 3750 | 3750 | 7500 | **18750** |
| LAK - Large 50 MW Industrial Offtake Projects & Captive Production Projects | AK | 7500 | 7500 | 15000 | 15000 | 22500 | 22500 | 22500 | **112500** |
| LPEM - Large 50 MW Industrial Offtake Projects & Captive Production Projects | PEM | 0 | 7500 | 7500 | 15000 | 22500 | 22500 | 30000 | **105000** |
| VLPEM - Very Large 100 MW Ind Offtake Projects & Captive Production Projects | PEM | 0 | 15000 | 15000 | 30000 | 45000 | 45000 | 60000 | **210000** |
| **TOTAL** | | **11250** | **33750** | **41250** | **67500** | **97500** | **97500** | **123750** | **472500** |
| H2 Projects for Ammonia Production for Fertilizer and Exports - 25, 50, 100 MW | | | | | | | | | |
| MAK - Medium 25 MW Fertilizer Offtake Projects | AK | 3750 | 3750 | 3750 | 3750 | 3750 | 3750 | 3750 | **26250** |
| MPEM - Medium 25 MW Fertilizer Offtake Projects | PEM | 0 | 0 | 0 | 3750 | 3750 | 3750 | 7500 | **18750** |
| LAK - Large 50 MW Export-Oriented Projects | AK | 7500 | 7500 | 15000 | 15000 | 22500 | 22500 | 22500 | **112500** |
| LPEM - Large 50 MW Export-Oriented Projects | PEM | 0 | 7500 | 7500 | 15000 | 22500 | 22500 | 30000 | **105000** |
| VLPEM - Very Large 100 MW Ind. Offtake Projects & Captive Production Projects | PEM | 0 | 15000 | 15000 | 30000 | 45000 | 45000 | 60000 | **210000** |
| **TOTAL** | | **11250** | **33750** | **41250** | **67500** | **97500** | **97500** | **123750** | **472500** |
| LH2 Projects for Transport Use Case - 10, 25, 50 MW | | | | | | | | | |
| SAK - Small 10 MW Heavy Duty Transport Offtake Projects | AK | 0 | 0 | 1500 | 3000 | 3000 | 3000 | 3000 | **13500** |
| MAK - Medium 25 MW Heavy Duty Transport Offtake Projects | AK | 0 | 0 | 3750 | 3750 | 3750 | 7500 | 7500 | **26250** |
| MPEM - Medium 25 MW Heavy Duty Transport Offtake Projects | PEM | 0 | 0 | 0 | 3750 | 3750 | 7500 | 7500 | **22500** |
| LAK - Large 50 MW Heavy Duty Transport Offtake Projects | AK | 0 | 0 | 0 | 0 | 0 | 3750 | 3750 | **7500** |
| LPEM - Large 50 MW Heavy Duty Transport Offtake Projects | PEM | 0 | 0 | 0 | 0 | 0 | 0 | 3750 | **3750** |
| **TOTAL** | | **0** | **0** | **5250** | **10500** | **10500** | **21750** | **25500** | **73500** |
| | | | | | | | | | |
| **GRAND TOTAL (Greenfield Projects achieving Technical and Financial Close)** | | **22500** | **67500** | **87750** | **145500** | **205500** | **216750** | **273000** | **1018500** |




A predictable pipeline of Indian projects will provide reassurance to global manufacturers to create local factories for hydrogen equipment manufacturing (both EC stacks and BoP equipment). *Increasing domestic production beyond 1 Mmt per annum, will require more projects and associated CAPEX investment for EC and BoP equipment.*

## CRITICAL ENABLERS/ KEY HURDLES

*1)* EC & BoP Equipment Manufacturing Supply Chain Development in India will happen if global investment decisions favouring India are taken. Global EC and BoP Equipment manufacturers want clarity about local demand creation and project development before they make a global supply chain investment decision. The proposed National Green Hydrogen Development Corporation can play a important role to ensure actual project deployment. *Stakeholder Views: A central coordinating body will be important as collaboration is required from consumers, producers, governments etc. Each region and project location has its own challenges - a central coordinator can design/plan and implement if India wants to be a global supply hub.*

2) Green Hydrogen Hubs, aggregating capacities higher than 150-200 MW/hub, can provide a faster pathway for large project build out- these should be prioritized over smaller-scale projects.

*3)* India can identify 2-3 Regional Manufacturing Hubs for Green Hydrogen Equipment (EC Stacks, BoP equipment), and attract global investors and manufacturing companies. This would be in addition to current incentives for EC Manufacturing. *Industry Stakeholder Views: Projected numbers are conservative and achievable. Localisation of technologies will be faster if demand aggregation is accelerated.*

## PART B: Global H2 Projects & Equipment (EC + BoP)

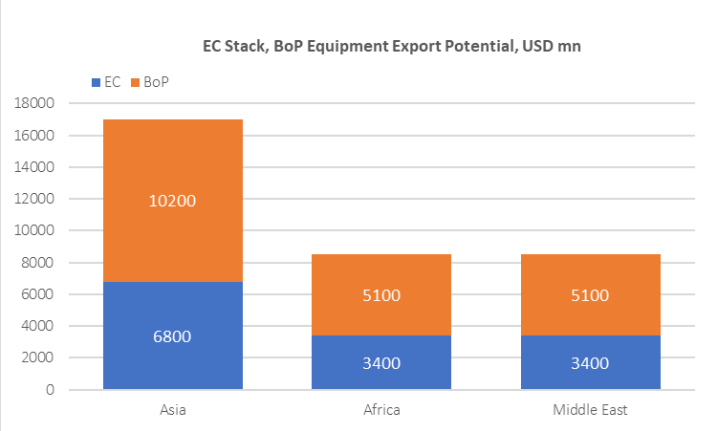
The paper assumes that other key regions in Asia, Middle East and Africa will undertake similar CAPEX for green hydrogen project development, and overall project development will proceed for both Alkaline and PEM technologies, with small, medium and large-scale deployments. If India completes Part A successfully and build a Global Base/Hub for EC Stack and BoP Equipment Manufacturing in India, it can use the domestic manufacturing base to cater to the EC Stack and BoP Equipment needs, through equipment exports in the above three regions.

Splitting by region, the paper assumes that green hydrogen projects in Asia will develop at a higher rate (270, as compared to 135 in India) in the 2024-30 period, while Middle East and Africa projects will develop at the same rate as India:

- Asia (ex-India, ex-China) – 270 projects/ 13.6 GW EC Installed Capacity
- Africa – 135 projects/ 6.8 GW EC Installed Capacity
- Middle East – 135 projects/ 6.8 GW EC Installed Capacity

Collectively, these represents greenfield build-out opportunity of 27.2 GW EC Installations (AK, PEM), worth USD 13.6 bn, and USD 20.4 bn in BoP Equipment (Compressors, Storage Tanks, Liquification Units, Pipelines), for potential Equipment Export market worth USD 34 bn by 2030. This would represent an estimated 10% of the global EC installations (270-350 GW, IEA estimates) by 2030.

While competition for Alkaline ECs (assumed at 50%) may be high, India can focus on a larger share of PEM EC exports (estimated at average rate of USD 0.5 mn/MW). BoP Equipment exports would cover Compressors, Storage Tanks, Transformers, Rectifiers, Liquefaction Units, Air Separation Units, Dispensing Units, Power Systems, Sensors, Instrumentation, and Pipeline/ Evacuation Infrastructure.




### CRITICAL ENABLERS/ KEY HURDLES

1) India should sign global project development & strategic supply chain partnerships to secure the acceptability and competitiveness of India-made H2 systems and equipment for local projects.
2) Moving beyond the Indian Standard for green hydrogen, India can establish standards for hydrogen systems and equipment; and set up global testing and certification facilities in India.
3) India can leverage its low-cost manufacturing base to build global hub manufacturing capabilities in hydrogen systems engineering design and manufacturing. Attracting early investors to expand domestic H2 manufacturing, for ECs and BoP equipment, will reap significant export revenue for India, and establish India as a supply chain leader. *Industry Stakeholder Views: The export potential is significant, and the numbers presented are achievable. Equipment suppliers are worried about domestic demand creation and project development in the country, and looking at how the government can help support that so that we can avoid equipment dumping from other countries.*

## PART C: Green Hydrogen Skills & Competencies- Technical, Commercial & Policy

The paper has mapped the different job roles in every green hydrogen project, and identified the following 40 new job specifications:

| NEW H2 JOB ROLES - H2 SKILLING & COMPETENCIES | | |
|---|---|---|
| **TECHNICAL** | **COMMERCIAL** | **SAFETY & POLICY/ REGULATORY** |
| Engineering Design | Project Development | Policy Design & Public Finance |
| Materials Sciences | Commercial Assessments | H2 Pricing & Market Development |
| Electrolyzer Stacks Systems | O&M/ EPC Contracting | H2 Supply Side Policies |
| BoP Design and Engineering | Project Investment | H2 Subsidies – CAPEX |
| EC Manufacturing | Project Financing & Investments | H2 Subsidies – Demand Side |
| RE – Power Systems & Integration | Project Econ. Modelling | H2 Demand Side Policies |
| Storage Systems - CGH2, Ammonia & LH2 | Project Underwriting/ Insurance | Project Development Support |
| Liquification Systems | Project Lending & Debt | Technical – Certification & Standards |
| Cryogenic LH2 Handling | Equity Investment & Structuring | Safety & Certification |
| EPC & Systems Maintenance | Legal – Offtake, Construction, Operations | H2 Standards |
| Stationary FC Systems | Project EPC | |
| Mobile FC Systems | Vendor Negotiations | |
| H2 Pipelines – Design/ Mainten. | Industrial Procurement | |
| Industrial Systems Integration | | |
| Project Development & Management | | |
| Instrumentation | | |
| Testing and Standardization | | |
| Safety & Audit | | |
| Incident Response & Risk | | |
| Environmental Impact & Risk | | |
| Evacuation & Dispensing Systems | | |
| Technical Assessments | | |

Aggregated for 135 domestic projects and 540 global projects, this translates to 27,000 new direct, green hydrogen job opportunities will be created between 2024-30 (5400 new domestic job opportunities and 21600 new global job opportunities), based on project development alone. Assuming a multiple of 5 for indirect jobs (135,000), green hydrogen project development is likely to create **162,000 new job opportunities, direct and indirect, over 2024-30.** These are specialist skills that can be developed in a single jurisdiction, and transferable temporarily to the project sites, during project development. This is easily replicated as Indian engineers currently work with this model in large engineering projects.

Sizing the service market, covering technical and commercial-related skills for project development, the paper has estimated **the aggregated Green Hydrogen Services market to be worth USD 2.1 bn**, calculated as 5% OPEX of estimated USD 43 bn CAPEX in part A and B, which **can be addressed by India as Service Exports, based on the strengths of its strong local engineering talent base.**

### CRITICAL ENABLERS/ KEY HURDLES

a) Engineering Design and Project Development, EPC and O&M experience in green hydrogen projects is a scarce capability. India should focus on a concerted Green Hydrogen engineering talent development that can be deployed for projects in India and globally.

b) This will require close collaboration between industry, engineering and research institutes and global partners (both government and global equipment players). This collaboration should also focus on building global testing and certification capabilities in the country.

DISCLAIMER

This white paper has been developed proactively by India Hydrogen Alliance after discussions with multiple stakeholders from the industry, potential offtake organisation, equipment manufacturers, investors, technical agencies and the government. The takeaways from the paper are intended to support evidence-based decision making, for better green hydrogen commercialisation, and building India as a global green hydrogen leader. The takeaways are intended to supplement other government and private sector efforts to develop the green hydrogen economy in India.

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