Advancing Energy Transition and Circular Economy in Building Up Capabilities to Net Zero/Carbon Neutrality: Advocacy and Stakeholder Management in Accelerating Green Hydrogen

APEC Policy Partnership on Science, Technology and Innovation

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Produced by
Project Overseer
Professor Ts Dr Shahrina Md Nordin ACM, FASc, FEI
Senior Director, Partnership & Ecosystem Building
Universiti Teknologi PETRONAS,
32610 Seri Iskandar, Perak, Malaysia

Authors
Farah Amelia Shahirah Roslan, Farah Nursyahirah Ismail, Associate Professor Dr Amjad Shamim, Dr Syaza Izyanni Ahmad, Dr Hayyiratul Fatimah Md Zaid, Professor Dr Shameem Rafik-Galea

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

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ABBREVIATIONS

AEM	Anion Exchange Membrane
AEMEL	Anion Exchange Membrane Electrolyser
AEMURFC	Anion Exchange Membrane Unitized Regenerative Fuel Cell
AI	Artificial Intelligence
APEC	Asia-Pacific Economic Cooperation
ARENA	Australian Renewable Energy Agency
BAU	Business-as-Usual
BEV	Battery electric vehicles
BM	Biomass
BOP	Balance of Plant
BRIN	National Research and Innovation Agency Indonesia
CAD	Canadian Dollar
CAPEX	Capital expenditure
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
CEFC	Clean Energy Finance Corporation
CHP	Combined Heat and Power
CO_2	Carbon dioxide
EDS	Emission Division Scenario
EJ	Exa joule
EMEA	Europe, the Middle East and Africa
EV	Electric vehicles
EWG	Energy Working Group
FCEV	Fuel cell electric vehicle

FCV	Fuel cell vehicle
FGD	Focus Group Discussion
FH2R	Fukushima Hydrogen Energy Research Field
GH	Green hydrogen
GHG	Greenhouse gas
Gt	Giga tonnes
GTh	Geothermal
GW	Giga watt
H_2	Hydrogen
ha	Hectare
HaaS	Hydrogen-as-a-Service
HESC	Hydrogen Energy Supply Chain
HETR	Hydrogen Economy Technology Roadmap
HPS	Hydrogen Portfolio Standard
HRDWG	Human Resources Development Working Group
HRS	Hydrogen Refuelling Station
IEA	International Energy Agency
IEC	International Electrotechnical Commission
Ir	Iridium
IRA	Inflation Reduction Act
ISO	International Organisation for Standardisation
ISSL	Institute of Sustainable and Smart Living
IT	Information technology
JETI	Just Energy Transition Initiative
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour

LCOH	Levelised cost of hydrogen
LH_2	Liquid hydrogen
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LULUCF	Land use, land-use change and forestry
m	Million
MCH	Methylcyclohexane
MEC	Microbial electrolysis cells
MFC	Microbial fuel cells
MHIA	Malaysia Hydrogen Industry Alliance
MOSTI	Ministry of Science, Technology and Innovation
Mt	Million tonnes
Mtpa	Million tonnes per annum
MVP	Most valuable player
MYR	Malaysian Ringgit
$NaBH_4$	Sodium borohydride
$NaBO_2$	Sodium borate
NCD	Nationally Determined Contribution
NEDO	New Energy and Industrial Technology Development Organization
NETR	National Energy Transition Roadmap
Nm^3	Normal cubic meter
NMB	NanoMalaysia Berhad
O&G	Oil and gas
O&M	Operations and maintenance
OPEX	Operating Expense
PEC	Photoelectrochemical cells
PEM	Proton Exchange Membrane

PEMEL	Proton Exchange Membrane Electrolyser
PEMFC	Proton Exchange Membrane Fuel Cell
PEMURFC	Proton Exchange Membrane Unitized Regenerative Fuel Cell
PGM	Platinum group metal
PLN	Perusahaan Listrik Negara (Indonesia State Electricity Corporation)
POX	Partial oxidation
PPSTI	Policy Partnership on Science, Technology and Innovation
Pt	Platinum
PV	Photovoltaic
R&D	Research and development
RE	Renewable energy
SLO	Social licence to operate
SMR	Steam Methane Reforming
SOEC	Solid Oxide Electrolyser Cell
SOEL	Solid Oxide Electrolyser
SOFC	Solid Oxide Fuel Cell
SOURFC	Solid Oxide Unitized Regenerative Fuel Cell
STEM	Science, Technology, Engineering and Mathematics
TAFE	Technical and Further Education
TNB	Tenaga Nasional Berhad
TNBR	Tenaga Nasional Berhad Research
tr	trillion
TVET	Technical and Vocational Education and Training
US	United States
URFC	Unitized regenerative fuel cells
USD	United States dollar
UTP	Universiti Teknologi PETRONAS

W	Watt
WGS	Water-Gas Shift
wt%	Weight percentage

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Green hydrogen is increasingly recognised as one of the significant option of APEC's transition toward low-carbon development, energy security and sustainable economic growth. In line with the Putrajaya Vision 2040 and the Aotearoa Plan of Action, this APEC-funded initiative, PPSTI_101_2024: Advancing Energy Transition and Circular Economy in Building Up Capabilities to Net Zero/Carbon Neutrality, was undertaken to assess regional readiness, identify capability gaps and develop strategic pathways, recognising that APEC economies differ in resource endowments, infrastructure starting points, energy prices, industrial structures and transition pathways, in order to support green hydrogen deployment across the region.

The project applied a multi-phase methodology, beginning with a comprehensive desktop study of global and regional hydrogen trends, followed by a cross-economy survey involving 141 respondents from government, industry and academia. Five expert interviews were conducted to deepen contextual understanding of technological, regulatory and market challenges. These insights shaped the agenda of a two-day technical seminar held on 15-16 October 2025 in Kuala Lumpur, which convened policymakers, industry leaders, researchers and practitioners from 11 APEC economies. The project concluded with a Focus Group Discussion (FGD) involving 80 participants, providing a platform to validate findings and jointly formulate actionable strategies.

Across all activities, several cross-cutting challenges were identified: high hydrogen production costs, fragmented standards and certification systems, limited demand mechanisms, financing constraints, gaps in hydrogen-ready infrastructure and the need for skilled human capital. Participants also emphasised the importance of social licence to operate, community inclusion and regional cooperation to ensure equitable and successful deployment. At the same time, emerging opportunities were noted in electrolyser innovation, renewable integration, hydrogen hubs, industrial symbiosis and cross-border collaboration to build a competitive APEC hydrogen market.

The project synthesised these insights into ten strategic recommendations. These include accelerating technology innovation and scale-up; harmonising policy, standards and regulatory frameworks; expanding financing pathways; building a multidisciplinary hydrogen workforce; strengthening regional collaboration and knowledge-sharing; promoting community inclusion and transparent engagement; improving ecosystem governance; enhancing market confidence through demand-side mechanisms; and strengthening regional data integration and institutional capacity through an APEC Hydrogen Data Hub and Network Secretariat.

Together, these recommendations form a comprehensive, actionable roadmap to guide APEC economies in advancing green hydrogen as a promising pathway of sustainable growth, decarbonisation and resilience in selected sectors and contexts. By leveraging coordinated action, shared capabilities and regional partnerships, APEC economies are well-positioned to unlock new industrial opportunities, generate quality jobs and accelerate progress toward net-zero ambitions, inclusive and low-carbon future aligned with the Putrajaya Vision 2040 and the Aotearoa Plan of Action.

1.0 INTRODUCTION AND BACKGROUND OF STUDY

1.1 Global Context: The Urgency of Low-Carbon Transition

The global energy landscape is undergoing rapid transformation as economies intensify efforts to reduce greenhouse-gas emissions and achieve mid-century net-zero commitments (International Energy Agency, 2023). According to the IEA's Net Zero Roadmap and related analysis, achieving climate targets will require deep changes in the global energy system, including decarbonisation of power generation, industrial processes and transport energy use (International Energy Agency, 2023). Fossil-fuel dependence is increasingly incompatible with long-term sustainability, prompting accelerated investment in renewable energy and clean technology innovation.

Hydrogen has emerged as a versatile energy carrier with applications across industry, transport and power systems. It is produced through multiple pathways that are commonly classified by colour to indicate their carbon footprint:

- Grey hydrogen: produced from natural gas through steam methane reforming, with carbon emissions released to the atmosphere.

- Blue hydrogen: produced from fossil fuels with carbon capture, utilisation, or storage that reduces the emissions impact.

- Green hydrogen: produced via electrolysis powered by renewable energy such as solar, wind, or hydropower, resulting in near-zero emissions.

- Turquoise hydrogen: produced through methane pyrolysis, generating solid carbon instead of carbon dioxide.

- Pink hydrogen: produced using nuclear-powered electrolysis.

- Brown or black hydrogen: produced from coal gasification and associated with very high carbon emissions.

Among these pathways, green hydrogen is widely regarded as a sustainable long-term option because it supports deep decarbonisation with minimal lifecycle emissions (International Renewable Energy Agency, 2020; Hydrogen Council, 2021). Green hydrogen provides a viable alternative for hard-to-abate sectors such as steelmaking, ammonia production, petrochemicals, maritime transport and heavy mobility. Its flexibility as an energy carrier and industrial feedstock enables sector coupling, renewable integration and long-duration energy storage.

International hydrogen strategies published by the European Union, Australia; Canada; Japan; Republic of Korea; Mexico; and the United States project that hydrogen could supply up to 10 to 12 % of global final energy demand by 2050, with estimates varying across scenarios (International Energy Agency, 2019; DNV, 2023). These developments reflect growing recognition of hydrogen, particularly green hydrogen, as a cornerstone of sustainable energy systems and circular-economy transitions.

1.2 APEC Context: Strategic Importance of Green Hydrogen

The Asia-Pacific region accounts for nearly 40 % of global energy consumption (APEC Energy Demand Overview, 2023) and remains one of the fastest-growing economic blocs (International Energy Agency, 2023). Increasing demand, strong reliance on fossil-based systems and heightened vulnerability to climate impacts underscore the need for accelerated transition toward clean and diversified energy options.

APEC's strategic direction is anchored in the Putrajaya Vision 2040, which emphasises innovation, sustainability and inclusive economic growth. The Aotearoa Plan of Action encourages member economies to expand renewable energy, advance circular-economy practices and promote low-carbon technologies. The PPSTI Strategic Plan 2016 to 2025 further prioritises science, technology, innovation and human-capital development.

Green hydrogen aligns with these priorities by strengthening clean energy systems, improving regional energy security and supporting long-term industrial transformation. Several APEC economies including Australia; People's Republic of China; Japan; and Republic of Korea have progressed with domestic hydrogen strategies and demonstration projects. Others are in early stages of planning feasibility assessments, pilot deployments and regulatory development. Across the region, GH is increasingly explored as a strategic option for decarbonising industry and heavy mobility, enabling cross-border renewable-energy trade and positioning APEC as a competitive hub for emerging hydrogen markets.

APEC economies exhibit significant diversity in energy resources, infrastructure maturity and economic structures. Renewable-rich economies such as Australia and Chile are well-positioned for large-scale green hydrogen production, while others may prioritise alternative pathways including electrification, bioenergy or carbon capture solutions. These variations necessitate flexible, context-specific strategies that consider cost competitiveness, infrastructure readiness and system integration trade-offs.

1.3 Alignment to APEC Goals and Priorities

The initiative titled "Advancing Energy Transition and Circular Economy in Building Up Capabilities to Net Zero or Carbon Neutrality: Advocacy and Stakeholder Management in Accelerating Green Hydrogen" (PPSTI_101_2024) directly supports APEC's long-term strategic direction.

This project contributes to:

- The Putrajaya Vision 2040 focuses on innovation, sustainability and economic integration
- The Aotearoa Plan of Action through commitments to renewable energy uptake, low-carbon systems and circular-economy practices

- The PPSTI Strategic Plan 2016 to 2025 by strengthening science-based innovation and human-capital development

- Peru 2024 APEC Priorities which highlight sustainable and circular economic growth

The project also strengthens collaboration across relevant APEC fora including the Policy Partnership on Science, Technology and Innovation (PPSTI), the Energy Working Group (EWG) and the Human Resources Development Working Group (HRDWG).

1.4 Problem Statement

While interest in green hydrogen (GH) continues to expand globally, the scaling of GH across the APEC region faces several key challenges:

1. Technological and Cost Challenges

    - High production costs due to expensive electrolysers, renewable intermittency and significant capital expenditure

    - Limited availability of commercially proven electrolyser technologies suited to diverse climatic and energy contexts

2. Infrastructure and Logistics Gaps

    - Insufficient storage and transport infrastructure such as pipelines, ammonia terminals, liquefaction facilities and hydrogen carriers

    - Limited development of hydrogen hubs, industrial clusters and integrated supply chains

3. Regulatory and Standards Fragmentation

    - Absence of harmonised safety standards and certification frameworks

    - Regulatory uncertainty affecting investor confidence and project bankability

4. Market and Financial Barriers

    - Weak demand signals and limited offtake guarantees

    - Need for blended-finance models, de-risking mechanisms and cross-border investment pathways

5. Social Licence and Human-Capital Constraints

    - Public misconceptions regarding hydrogen safety and environmental impact

    - Shortages of skilled professionals trained in hydrogen systems, storage, integration and safety

The feasibility and competitiveness of GH differ significantly across member economies due to variation in renewable resource quality, electricity pricing, existing infrastructure, market size, industrial demand, and system-integration requirements. The differences in readiness indicate the need for coordinated action, shared policy frameworks, stronger capability-building programmes and improved knowledge-sharing systems.

1.5 Objectives of the Project

This project emphasises the urgency of low-carbon transition for sustainability through accelerated energy transition and circular economy. It aims to advance the capabilities of APEC economies in GH capacity, accelerating technological innovation and policy enforcement through science advocacy and stakeholder engagement. The specific objectives are to:

1. Share the latest advancements in high-efficiency, low-cost GH production technologies;

2. Strengthen understanding of the GH ecosystem, including storage, market assessment for hydrogen energy applications and safety protocols for transportation;

3. Assess the economic viability of production costs in establishing a clean-energy economy; and

4. Enhance the GH network across industry, academia, policymakers and stakeholders within APEC.

1.6 Purpose of the Report

This Final Report consolidates the findings and outputs of the APEC PPSTI_101_2024 project, integrating evidence from the pre-seminar survey and desktop study, expert interviews and the two-day technical seminar held in October 2025 at Concorde Hotel Kuala Lumpur. It provides a comprehensive synthesis of research insights, stakeholder deliberations and focus-group recommendations to support policy formulation, technological advancement and collaborative implementation.

The report aims to serve as a reference framework for APEC policymakers and stakeholders to design effective strategies, investment mechanisms and cooperation models for advancing the green-hydrogen economy toward net-zero carbon neutrality.

2.0 METHODOLOGY

The APEC PPSTI_101_2024 project applied a multi-phase, mixed-method and triangulation-based approach to examine green hydrogen readiness, capability gaps and opportunities across APEC economies. The methodology integrates quantitative, qualitative and consultative techniques to ensure robust evidence, stakeholder validation and policy relevance.

2.1 Research Framework

Four complementary phases were designed to build progressively on each phases, moving from baseline evidence generation to expert deep-dive analysis, stakeholder engagement and final validation. This phased approach enabled the integration of technical, economic, governance and ecosystem perspectives, while ensuring that findings were continuously refined and validated through stakeholder interaction.

Table 1: Implementation Workflow for APEC PPSTI_101_2024 Project

Phase	Activities	Timeline	Key Output
Phase I – Pre-Seminar	Desktop study, survey dissemination, data analysis	June–August 2025	Pre-Seminar Report (August 2025)
Phase II – Expert Consultation	Conduct and analyse 5 expert interviews	Sep 2025	Interview Summary Matrix
Phase III – Seminar Delivery	2-day seminar with 10 APEC economies	15–16 October 2025	Seminar Report (October 2025)
Phase IV – Validation & Integration	Focus Group Discussion, synthesis, drafting of final recommendations	October–December 2025	Final APEC Publication (June 2026)

The project followed a four-phase implementation workflow, as detailed below:

1. **Pre-Seminar Research (Baseline Phase)**

   A desktop study and a cross-economy survey were conducted from June to August 2025 to establish baseline trends and challenges.

2. **Expert Interviews (Deep-Dive Phase)**

   Five semi-structured interviews with specialists from academia, industry and government explored priority issues in technology, policy and ecosystem development.

3. **Seminar Implementation (Engagement Phase)**

   A two-day seminar held on 15 and 16 October 2025 at Concorde Hotel Kuala Lumpur convened policymakers, industry experts and academics for knowledge exchange and validation of findings.

4. **Focus Group Discussion (Validation and Strategy Phase)**

   A structured FGD at the end of the seminar enabled participants to co-develop recommendations across four thematic clusters: Production Technologies, Ecosystem Development, Economic Viability and Network Building.

2.1.1 Analytical Approach

A triangulation matrix was applied to organise and integrate findings. Convergence across data sources strengthened validity, while divergent results were cross-checked through literature review to maintain analytical rigor. The integration of these sources produced a region-wide Green Hydrogen Outlook 2025, highlighting actionable pathways for capability building.

Table 2: Triangulation of Data Sources and Analytical Purposes

Data Source	Analysis Type	Integration Purpose
Survey	Quantitative (descriptive statistics, mean ranking)	Establish baseline perceptions across economies
Desktop Study	Documentary synthesis	Identify policy, technology and cost trends
Expert Interviews	Thematic analysis	Deepen contextual understanding and policy relevance
FGD	Consensus mapping	Validate findings and co-develop recommendations

The project utilised three forms of triangulation to strengthen validity:

1. **Methodological triangulation**

   Multiple data-collection techniques were used, including a desktop study, survey, expert interviews, seminar discussions and a Focus Group Discussion (FGD).

2. **Data-source triangulation**

   Information was gathered from representatives of government agencies, energy companies, academic institutions, research organisations and policy bodies across 11 APEC economies.

3. **Stakeholder triangulation**

   Contributions from public sector, private sector, academia and civil society ensured a balanced and inclusive evidence base.

2.1.2 Limitations and Scope

The research analysis was constrained by:

- Unequal data availability across economies
- Varying maturity levels of hydrogen strategies
- Differences in domestic definitions and reporting standards
- Limited representation from some economies with emerging hydrogen sectors
- The report does not assume a uniform transition model across APEC economies

Despite these limitations, triangulation across four independent data sources ensured balanced insights representing both developed and emerging APEC members.

2.2 Data Collection Methods

2.2.1 Desktop Study

A comprehensive review of over 150 academic papers, policy documents and domestic hydrogen roadmaps was conducted. Findings informed the survey and interview instruments. The review assessed:

- Green hydrogen cost structures and technology readiness
- Policy and regulatory frameworks
- Market trends and deployment pathways
- Best practices from frontrunner economies such as Australia; Chile; Japan; Republic of Korea

2.2.2 Survey Questionnaire

A purposive sampling technique was employed for this study. The selection of a purposive sampling method was to focus on APEC economies' perception on GH production capabilities, consumers' acceptance, research and development (R&D) drive and policies. Therefore, this technique is the best fit as it allows us to collect data from specific groups rather than a general group.

The number of participants is determined by the responses of each member economies on the survey. The total number of responses collected from the data is 141 responses. The highest number of responses were from Indonesia (8.5%); Japan (4.3%); Malaysia (66%); Thailand (5%);and Viet Nam (1.5%).

2.2.2.1 Measurement of Items and Scales

A structured close-ended questionnaire was employed on a five-point Likert scale. The data on the respondents' demographics and current trends and analysis of GH in APEC members economies were also collected to determine the background of the respondents and on how do they perceive the current trends of GH.

2.2.2.2 Data Analysis Procedure

Before conducting the data analysis, there are a few steps that should be taken in order to avoid problematic data. These steps consist of data selection, coding and screening. Thus, the raw data should be arranged and coded based on the values set during the statistical analysis. Hence, a descriptive statistic of each variable would be conducted to provide a brief description of the response by looking at the frequency, means and standard deviation.

After gaining the results of the descriptive statistics, data screening was conducted to observe if there are any missing data present in the collection. Missing data may occur as certain respondents may decide to omit, refuse or have little understanding regarding certain questions within the questionnaires. To address this, certain actions such as deletion, distribution or replacement may be carried out after obtaining the results from the normality test. However, as this study employs a non-probability sampling technique, the data would be considered non-normal. Hence, the usage of SmartPLS helps to mitigate this issue due to its ability to address non-normal data.

2.2.2.3 Analysis

There are two softwares used to analyse the quantitative data for this study, namely SPSS and SmartPLS. SPSS is used at the initial stage of the study to conduct descriptive statistics and reliability tests. Although SPSS being capable to conduct multiple regression analysis, it falls short in terms of handling non-normal data. Thus, this explains why SPSS is championed in the early stages of the research compared to SmartPLS.

However, as SPSS fails in addressing non-normal data, SmartPLS is then employed. This is because the data used is a structural equation modelling (SEM) and it is often used to assess and analyse relationships between both observed and latest variables. Despite being similar with linear regression, it differs in terms of SEM being more impactful in observing the linear causal relationships and accounts for measurement error simultaneously. Thus, with SmartPLS's capability in addressing non-normal data distribution, complex structural equation models can be applied onto it and both reflective and formative construct can be used to predict behaviour more efficiently.

2.2.2.4 Reliability and Validity test

Prior to the dissemination of the questionnaire, the questionnaire undergoes both validity and reliability test. The validity test is carried out to ensure that the questionnaire is considered valid and relevant by both practitioners and academicians as well. This sees that the validity test was sent to multiple parties such as industry players and lecturers with the specialisation of GH. Finally, the questionnaire was sent to APEC to ensure that the questions are considered relevant and prudent by APEC. Once the reviews and corrections made by the recommendation of all parties, the questionnaire would then be finalised and would be disseminated for the reliability test.

The reliability test is then carried out to ensure that the instruments used for this research is considered reliable. Therefore, this sees that the instrument is being used to evaluate itself. The reliability test is measured by the Cronbach Alpha based on the sections of the questionnaire. The scores of the Cronbach Alpha are tabulated below. Based on the reliability scores of the instrument, it shows that the variables are considered reliable and valid due to most of the Cronbach Alpha is higher than 0.8. Therefore, this shows that the instrument is considered valid and ready for general dissemination.

Table 3: Reliable score of each variable for the study

Variable	**Cronbach Alpha**
Perceived Cost of Green Hydrogen	0.550
Perceived Environmental Benefit	0.886
Awareness of Green Hydrogen	0.876
Trust in Green Hydrogen Safety Standards	0.806
Perceived Government Support	0.699
Perceived Industry Commitment	0.691
Technological Readiness of Green Hydrogen	0.791
Perceived Economic Viability	0.884
Public Acceptance of Green Hydrogen	0.899
Adoption of Green Hydrogen	0.933
Clarity of Green Hydrogen Communication	0.940
Perceived Credibility of Green Hydrogen Messaging	0.924
Supply Chain Reliability	0.892
Policy Support	0.921
Investment in Green Hydrogen	0.926
Infrastructure Availability	0.929
Distribution/Transportation Efficiency	0.949

The reliability coefficient (Crombach Alpha score) is as follows:
0.80 < r11 1.00 very high reliability
0.60 < r11 0.80 high reliability
0.40 < r11 0.60 moderate reliability
0.20 < r11 0.40 low reliability.
-1.00 r11 0.20 very low reliability (not reliable).

2.2.3 Expert Interviews

This study adopted a qualitative interview-based approach to examine the technological, economic, governance and social dimensions shaping green hydrogen development across selected APEC economies. Semi-structured expert interviews were used to capture in-depth insights from stakeholders directly involved in hydrogen research, policy formulation and applied deployment.

2.2.3.1 Participant selection

Five experts were purposively selected based on their direct professional involvement in green hydrogen-related activities, ensuring representation across key stakeholder groups, including government, academia and applied research. Participants were drawn from Australia; Malaysia; and Peru, reflecting economies at different stages of hydrogen ecosystem development. Selection criteria prioritised participants with demonstrated experience in hydrogen technology, policy, infrastructure, or sectoral applications relevant to APEC priorities.

2.2.3.2 Data Collection

Interviews were conducted between August and October 2025 using a semi-structured interview guide aligned with the objectives of the APEC initiative “Advancing Energy Transition and Circular Economy in Building Up Capabilities to Net Zero/Carbon Neutrality: Advocacy and Stakeholder Management in Accelerating Green Hydrogen.” Interviews were conducted online, recorded with participant consent and transcribed for analysis. Each interview lasted approximately 45–60 minutes.

2.2.3.3 Data analysis

The interview transcripts were analysed using thematic analysis, following an iterative and inductive process. Initial familiarisation involved repeated reading of transcripts to identify recurring patterns, key issues and areas of convergence and divergence across participants. Codes were then developed and refined through constant comparison, resulting in a structured set of themes and sub-themes reflecting technical, economic, governance, workforce and social dimensions of green hydrogen deployment.

2.2.4 Focus Group Discussion (FGD)

The FGD served as a final validation platform, consolidating collective insights into structured recommendations. On Day 2 of the seminar, participants were organised into four thematic groups:

1. Production Technologies
2. Hydrogen Ecosystem
3. Economic Viability
4. Network Building

2.3 Ethical Considerations

All survey, interview and FGD participants provided informed consent. Personal data were anonymised and handled in accordance with APEC publication protocols and Universiti Teknologi PETRONAS (UTP) research-integrity guidelines.

3.0 RESEARCH FINDINGS: QUANTITATIVE SURVEY ANALYSIS

This chapter presents the quantitative survey analysis on perceptions and statistical relationships related to green hydrogen adoption across APEC economies. While the survey provides insights into key technological, economic and human-centric determinants, the policy and implementation implications may vary depending on domestic cost structures, infrastructure readiness and broader transition conditions. These results highlight the importance of interpreting the quantitative findings within the broader diversity of conditions across APEC economies.

3.1 The Role of Human Factors in Green Hydrogen Adoption

The adoption of green hydrogen in the APEC region reflects a convergence of technological, economic and human-centric determinants. While the necessary technology for decarbonisation and sustainable energy is available and the need for such solutions is widely recognised, progress remains slow. This is not solely due to tangible barriers such as cost or infrastructure, but is also deeply affected by public perception, the credibility of information and the level of trust in safety standards. These human factors often outweigh traditional barriers, underscoring the importance of addressing psychological and social dimensions in the transition to green hydrogen.

3.2 Public Acceptance: Statistical Evidence

Table 4: Drivers of Public Acceptance

No	Variable	β	Std. Error	t / p-value
H1	Awareness of Green Hydrogen → Public Acceptance	-0.123	0.063	t=-1.956; p=0.053
H2	Perceived Environmental Benefit → Public Acceptance	0.558	0.076	t=7.319; p=0.001
H3	Trust in Green Hydrogen Safety Standards → Public Acceptance	0.234	0.072	t=3.223; p=0.002
H4	Clarity of Green Hydrogen Communication → Public Acceptance	0.054	0.067	t=0.811; p=0.419
H5	Policy Support → Public Acceptance	0.337	0.076	t=4.450; p=0.001

Public acceptance is most strongly and positively associated with perceived environmental benefits ($\beta = 0.558$, $p < 0.001$), indicating that confidence in the environmental upside markedly raises willingness to accept green hydrogen. Trust in safety standards also shows a significant positive effect ($\beta = 0.234$, $p = 0.002$), underscoring the role of credible safety governance. Policy support contributes meaningfully ($\beta = 0.337$, $p < 0.001$), reinforcing that enabling policies help translate interest into acceptance. In contrast, awareness alone has a slight negative, non-significant effect (β = −0.123, p ≈ 0.053) and clarity of communication is non-significant (β = 0.054, p = 0.419), suggesting that information quality must be paired with credibility and perceived benefits to be effective.

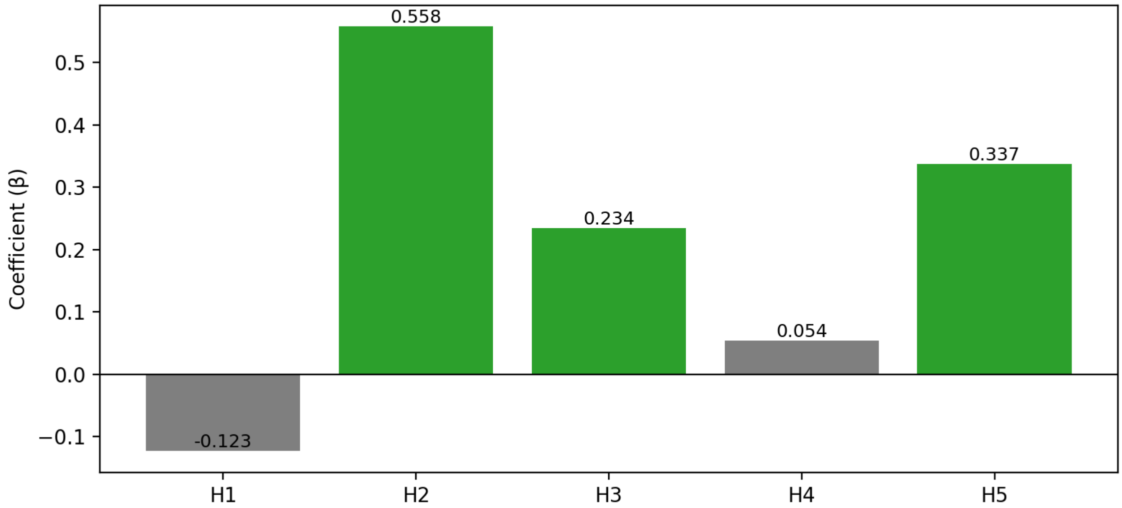


Figure 1: Coefficients for Public Acceptance Drivers

Note: Bars in green indicate $p < 0.05$ (statistically significant).

3.3 Perceived Economic Viability: Statistical Evidence

Table 5: Drivers of Perceived Economic Viability

No	Variable	β	Std. Error	t / p-value
H6	Perceived Cost of Green Hydrogen → Perceived Economic Viability	0.173	0.085	t=2.029; p=0.010
H7	Technological Readiness of Green Hydrogen → Perceived Economic Viability	0.317	0.090	t=3.508; p=0.044
H8	Perceived Government Support → Perceived Economic Viability	0.104	0.091	t=1.152; p=0.001
H9	Perceived Industry Commitment → Perceived Economic Viability	0.525	0.078	t=6.695; p=0.001
H10	Policy Support → Perceived Economic Viability	0.342	0.079	t=4.326; p=0.001
H11	Infrastructure Availability → Perceived Economic Viability	0.374	0.070	t=5.352; p=0.001
H12	Supply Chain Reliability → Perceived Economic Viability	0.481	0.078	t=6.155; p=0.001

Perceived economic viability is chiefly shaped by institutional and logistical enablers. The most influential factor is industry commitment ($\beta = 0.525$, $p < 0.001$), signalling that visible leadership and investment from industry substantially improve perceptions of viability. Reliable supply chains ($\beta = 0.481$, $p < 0.001$) and adequate infrastructure ($\beta = 0.374$, $p < 0.001$) further strengthen viability by reducing operational risk and friction. Policy support also exerts a notable positive effect ($\beta = 0.342$, $p < 0.001$). Technological readiness ($\beta = 0.317$, $p = 0.044$) and perceived cost ($\beta = 0.173$, $p = 0.010$) maintain smaller, yet positive roles.

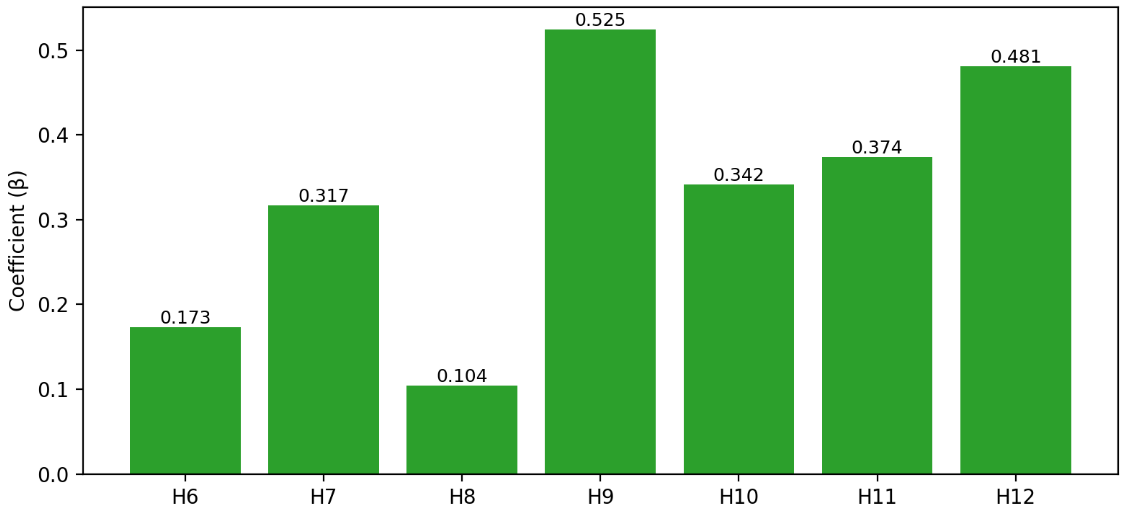


Figure 2: Coefficients for Economic Viability Drivers

Note: Bars in green indicate $p < 0.05$ (statistically significant).

3.4 Adoption of Green Hydrogen: Statistical Evidence

Table 6: Drivers of Adoption

No	Variable	β	Std. Error	t / p-value
H13	Perceived Credibility of Green Hydrogen Messaging → Adoption of Green Hydrogen	0.578	0.077	t=7.508; p=0.000
H14	Perceived Economic Viability → Adoption of Green Hydrogen	0.930	0.690	t=1.338; p=0.183
H15	Public Acceptance of Green Hydrogen → Adoption of Green Hydrogen	0.807	0.720	t=11.217; p=0.000
H16	Distribution/Transportation Efficiency → Adoption of Green Hydrogen	0.365	0.074	t=4.915; p=0.000

Actual adoption hinges foremost on public acceptance (β = 0.807, $p < 0.001$), affirming that social license is decisive in moving from concept to implementation. The perceived credibility of messaging exerts a strong, significant influence (β = 0.578, $p < 0.001$), which highlights the premium on trustworthy, transparent communication. Distribution and transportation efficiency also contributes (β = 0.365, $p < 0.001$), reflecting the importance of logistical readiness. Perceived economic viability, despite its conceptual relevance, does not show a significant direct effect on adoption in this model (β = 0.930, $p = 0.183$).

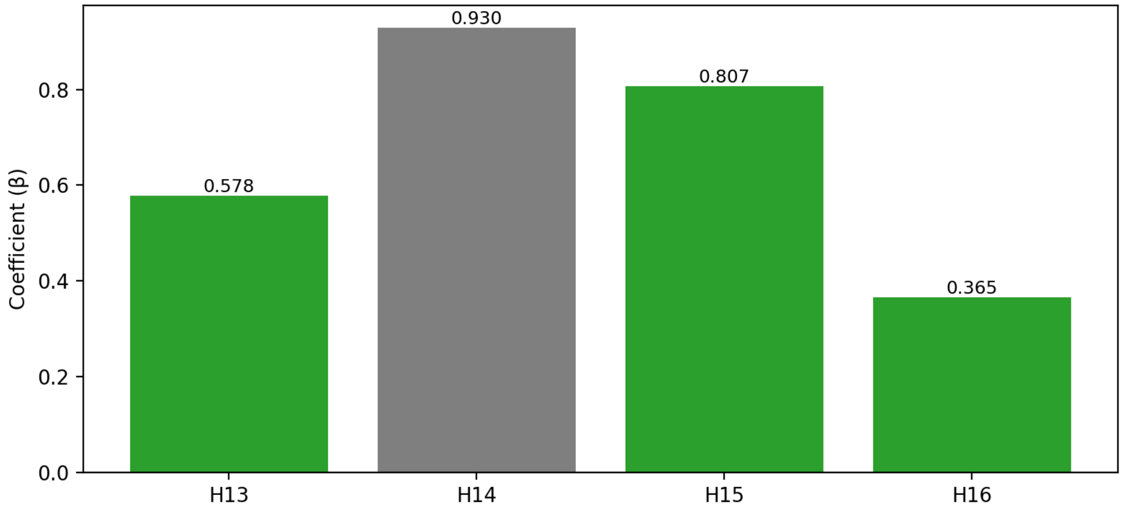


Figure 3: Coefficients for Adoption Drivers

Note: Bars in green indicate $p < 0.05$ (statistically significant).

3.5 Policy Implications for APEC Economies

Policy support emerges as a statistically significant lever both for public acceptance and for perceived economic viability. For APEC economies, a practical policy playbook should combine targeted incentives (e.g., production tax credits, contracts for difference and accelerated depreciation for GH assets) with enabling regulation (e.g., streamlined permitting, shared infrastructure corridors and harmonised safety codes). Multi-year, stable policy signals help derisk long-lived investments and reduce the cost of capital, magnifying industry commitment and supply chain reliability.

3.6 Sector-Specific Pathways for Adoption

High-impact sectors differ across APEC members, but priority applications include ammonia and fertiliser production (where GH feeds into green ammonia), steel decarbonisation via direct-reduced iron, heavy transport (long-haul trucks, buses, maritime bunkering) and power-to-X fuels for aviation. Policymakers can catalyse demand by creating offtake frameworks, such as long-term purchase agreements tied to emissions intensity thresholds and by standardising guarantees of origin to ensure traceability and credibility in messaging.

To further contextualise sectoral suitability, Table *7* presents a prioritisation of green hydrogen applications across key sectors in APEC economies. The ranking reflects the relative technical feasibility, economic competitiveness and alignment with decarbonisation needs across different use cases. As shown in Table 7, green hydrogen demonstrates the strongest value proposition in hard-to-abate sectors such as ammonia production and steel manufacturing, where direct electrification is not readily viable.

Table 7: Priority Ranking of Green Hydrogen Applications in APEC

Priority Level	**Application Sector**	**Rationale**
High	Ammonia / fertiliser	Existing hydrogen demand, easier substitution
High	Steel (DRI)	Hard-to-abate, high emissions reduction potential
Medium	Heavy transport (trucks, maritime)	Suitable for long-range, high utilisation
Medium	Power storage	Useful for long-duration storage but cost-sensitive
Low (near-term)	Passenger vehicles	BEVs more cost-competitive
Low (near-term)	Residential heating	Electrification more efficient

These rankings indicate that green hydrogen deployment is most effective in sectors where direct electrification is technically or economically constrained, reinforcing its role as a complementary solution within a broader decarbonisation portfolio. This prioritisation aligns with current global evidence and stakeholder insights from the study, indicating that green hydrogen is most effective in sectors where electrification faces technical, economic or operational limitations, while alternative solutions remain more efficient in others.

3.7 Regional Cooperation and Cross-Border Value Chains

APEC's diversity in renewable resources and industrial bases enables complementary specialisation: economies rich in solar and wind can focus on low-cost GH production, while manufacturing hubs advance electrolyser components, storage systems and fuel cell technologies. Regional corridors for GH and derivatives (ammonia, methanol, e-fuels) can be developed through shared port infrastructure, harmonised safety certification and common logistics standards, improving distribution/transportation efficiency and reinforcing adoption.

3.8 Financing Mechanisms and Risk Mitigation

Mobilising investment at scale requires blended finance structures that combine public guarantees with private capital such as credit enhancement, revenue stabilisation mechanisms and sovereign risk sharing for cross-border projects. Green banks or dedicated APEC facilities can provide concessional financing for early-stage infrastructure, while standardised project documentation reduces transaction costs and accelerates bankability, aligning with the strong statistical role of industry commitment and supply chain reliability.

3.9 Safety, Standards and Certification

Trust in safety standards significantly boosts acceptance. Establishing an APEC-aligned safety and certification framework on covering production sites, storage, transport (pipelines, trucking, maritime) and end-use systems, will create uniform expectations and reduce perceived risk. Mutual recognition agreements between regulators can expedite deployment, while transparent incident reporting and third-party audits reinforce credibility in public messaging.

3.10 Public Engagement and Credible Messaging

Given the strong role of messaging credibility, engagement strategies should deploy trusted messengers (scientific bodies, standards organisations and respected industry associations) and combine quantitative environmental claims with locally relevant co-benefits of air quality, jobs and energy security. Demonstration projects with open data and community oversight can convert awareness into trust, aligning social license with adoption.

3.11 Supply Chain Reliability and Infrastructure Readiness

Developing diversified, resilient supply chains for electrolysers, storage vessels and power electronics is essential. APEC members can map critical components, identify single-point vulnerabilities and create contingency inventories. Infrastructure planning should integrate GH with existing energy networks, repurpose assets where feasible and adopt modular build-out strategies to minimise time-to-market and enhance distribution efficiency.

3.12 Key Drivers of Market Readiness

A comprehensive set of variables shapes the readiness of the market for green hydrogen. These include perceived cost, technological readiness, government and industry support, stakeholder collaboration, infrastructure availability, policy support, public awareness, environmental benefits and trust in safety standards. Statistical analysis demonstrates that perceived environmental benefits exert the strongest positive influence on public acceptance, followed by trust in safety standards and supportive policy frameworks. Interestingly, awareness of green hydrogen alone, without accompanying trust or perceived benefit, does not guarantee acceptance and may even have a slight negative effect. The clarity of communication, while important, is not a significant driver unless it is coupled with credibility and trust.

3.13 Economic Viability and Institutional Commitment

Economic viability emerges as a multifaceted construct, heavily dependent on industry commitment, the reliability of supply chains, the adequacy of infrastructure and the presence of supportive policies. Among these, industry commitment stands out as the most influential factor, closely followed by supply chain reliability and infrastructure. While technological readiness and cost considerations remain relevant, their impact is somewhat secondary to the broader institutional and logistical context.

3.14 Determinants of Adoption

The actual adoption of green hydrogen is most strongly driven by public acceptance. The perceived credibility of messaging and the efficiency of distribution and transportation systems also play substantial roles. These findings underscore the necessity of building public trust and ensuring that information about green hydrogen is both credible and transparent. Efficient logistics and supply chains are essential to make green hydrogen a practical and accessible solution.

3.15 Social Acceptance and Trust

Social acceptance and trust are central to the successful adoption of green hydrogen. It is not sufficient to simply inform the public; there must be a concerted effort to build confidence through credible communication and robust safety standards. People are more likely to embrace green hydrogen if they are convinced of its environmental benefits and trust the safety measures in place. Awareness campaigns must be designed to foster genuine understanding and trust rather than just disseminate information.

3.16 Economic and Institutional Drivers

The perception of economic viability is shaped by visible industry commitment, reliable supply chains and adequate infrastructure. Policy support acts as a catalyst, enabling these factors to coalesce into a favourable environment for green hydrogen. Industry leadership and policy incentives are essential for scaling up initiatives and moving beyond pilot projects to widespread adoption.

3.17 Technological and Logistical Readiness

Efficient production, transport and distribution of green hydrogen underpin its practical viability. Investments in infrastructure and supply chain systems are critical, as they directly influence both economic perceptions and the actual feasibility of adoption. While not the most dominant factors, technological and logistical readiness remain important for the sector's growth.

3.18 Communication and Credibility

The credibility of messaging about green hydrogen significantly influences adoption rates. Transparent, trustworthy communication, supported by independent validation and real-world success stories, can bridge the gap between awareness and acceptance. Stakeholders must prioritise not just the content of their messages, but also the channels and messengers through which information is delivered.

3.19 Strategic Recommendations

A coordinated approach that brings together policy support, technological advancement and stakeholder engagement is essential. Emphasising the environmental and safety benefits of green hydrogen, prioritising infrastructure investment and leveraging credible sources of information are recommended strategies for accelerating adoption. Policymakers, industry leaders and researchers must recognise that social and psychological factors are as critical as technical and economic ones. Building public trust, ensuring credible communication and fostering cross-sector collaboration are essential steps toward realising the full potential of green hydrogen in the region.

4.0 RESEARCH FINDINGS: DESKTOP STUDY

The objective of the desktop study is to complement survey findings with global insights, best practices and policy recommendations for advancing Green Hydrogen (GH) in APEC economies. This desktop study reviews existing literature, data and reports to gather background information and insights.

4.1 Situational Analysis of Green Hydrogen (GH) in APEC

4.1.1 GH Policies, Strategies, & Roadmaps

Many APEC economies have introduced domestic hydrogen strategies to align with decarbonisation targets, energy security goals and industrial innovation. These roadmaps typically outline timelines for technology deployment, infrastructure development and investment priorities. Examples include:

- Australia: Launched its economy-wide Hydrogen Strategy in 2019, emphasising export potential, particularly to East Asian markets. It supports regional hydrogen hubs and industry scaling.

  [Source: COAG Energy Council, 2019]

- China: Integrated hydrogen development into its 14th Five-Year Plan, with a focus on fuel cell vehicle rollout and domestic electrolyser production.

  [Source: IEA Hydrogen Projects Database]

- Japan: One of the earliest to adopt a domestic hydrogen strategy (2017), focusing on building a hydrogen society with mobility, power generation and supply chain development.

  [Source: METI, Japan Hydrogen Strategy 2017]

- Republic of Korea: Hydrogen Economy Roadmap (2019) sets targets for hydrogen vehicles, charging stations and power generation, aiming to become a global hydrogen leader.

  Source: Ministry of Trade, Industry and Energy

While other economies (e.g., Malaysia; Mexico; Thailand) are in earlier stages, many are drafting policies or supporting pilot projects.

4.1.2 Comparative Analysis of GH Adoption Rates

GH adoption rates vary widely across APEC economies, influenced by policy strength, energy prices, industrial readiness and renewable energy availability. These differences suggest that APEC economies are not moving along a single hydrogen pathway. For instance, Australia and Chile are leveraging abundant solar/wind resources for competitive GH production. As a result, GH may be more attractive in some economies as a production, export or industrial decarbonisation pathway, while in others it may remain limited to pilot projects, selected end uses, or complementary roles alongside other low-carbon technologies.

- High adoption:
  - Australia: Strong in GH production and export agreements.
  - Japan; and Republic of Korea: High deployment of fuel cell vehicles and power generation projects.
- Moderate adoption:
  - China: Rapidly scaling hydrogen infrastructure, though focus remains on blue hydrogen and fuel cells for trucks.
- Lower adoption or early-stage:
  - Peru; The Republic of the Philippines; and Viet Nam: Early in roadmap development; mostly involved in pilot studies or feasibility assessments.

[Source: IEA Global Hydrogen Review 2023; Hydrogen Council Reports 2023]

4.1.3 Case Studies of Successful GH Projects

Some projects serve as reference points for success:

- Australia – Export Projects: Projects such as the Asian Renewable Energy Hub and partnerships with Japan; and Republic of Korea position Australia as a GH exporter.

  [Source: ARENA, CEFC, Australian Hydrogen Council]

- Chile – Atacama Desert Hydrogen Hub: Leveraging high solar radiation, Chile aims to be a low-cost GH exporter to Asia-Pacific. [Source: McKinsey Hydrogen Insights, 2023]

- China – Electrolyser Manufacturing: China leads in low-cost alkaline electrolyser production, crucial for GH scalability. Companies like Longi and PERIC are exporting globally.

- Japan – Hydrogen Mobility & Refuelling Infrastructure: Japan has over 150 hydrogen refuelling stations and is piloting hydrogen-powered trains and buses. Tokyo Olympics 2020 was a showcase for hydrogen-fuelled mobility.

  [Source: Japan Hydrogen Association, 2021]

These case studies highlight the role of public-private partnerships, strategic funding and infrastructure readiness.

4.1.4 Consumers' Acceptance & Market Readiness

Market readiness is progressing slowly in developing APEC economies due to infrastructure costs, regulatory uncertainty and technology lock-in. Market readiness involves not only technical deployment but also demand-side engagement, infrastructure support and public perception:

- Challenges:
  - Limited public awareness about GH benefits
  - Safety concerns about hydrogen handling
  - Lack of end-user applications in domestic heating, industry, or mobility in many APEC economies
- Progress:
  - Incentives for hydrogen-powered vehicles in Japan and Republic of Korea
  - Public-private programs for industrial hydrogen in Australia and China
  - Increasing attention to consumer education and engagement (e.g., via demonstration projects)

[Sources: DNV Energy Transition Outlook 2023; World Bank – Hydrogen in Developing Economies (2022)]

4.1.5 Conclusion: Situational Analysis of GH in APEC

The APEC region presents a diverse hydrogen landscape, with frontrunners like Australia; People's Republic of China; Japan; and Republic of Korea leading policy development, infrastructure investment and market adoption. However, many member economies are still at early or pilot stages, facing challenges related to cost, policy coherence and consumer readiness. Despite this variation, momentum is growing across the region, supported by domestic roadmaps, international collaboration and increasing private sector participation.

To accelerate GH deployment, APEC economies must:

- Strengthen domestic strategies and regulatory clarity
- Enhance infrastructure and public engagement
- Promote regional cooperation and knowledge sharing

Overall, the situational analysis highlights that APEC economies are pursuing multiple energy-transition pathways, with GH appearing more attractive in some economies and sectors than others. Its role is likely to depend on domestic resource endowments, infrastructure readiness, industrial structures, market demand and policy priorities. While momentum is growing across the region, the pace and form of deployment will vary, with some economies advancing production and export ambitions, and others focusing on selective applications, pilot development, or alternative decarbonisation routes.

4.2 Best Practices & Technological Innovations in Green Hydrogen (GH)

4.2.1 Advances in GH Production Efficiency & Cost Reduction

GH production is undergoing rapid innovation to improve efficiency and lower costs, primarily through:

- Electrolysis Technology Enhancements:
    - PEM (Proton Exchange Membrane) Electrolysers: Offer fast response times and higher purity hydrogen. Widely adopted in Japan; and Republic of Korea.
    - Alkaline Electrolysers: Mature and cost-effective technology, with China leading global production (e.g., Longi, Sungrow).
    - Solid Oxide Electrolysers (SOECs): Operate at high temperatures with potential for higher efficiency when integrated with industrial waste heat.
- Integration with Renewables:
    - Innovations in solar- and wind-coupled electrolysis systems are enabling "green" pathways with lower carbon footprints.
    - Australia's Hydrogen Energy Supply Chain (HESC) project integrates brown coal gasification with renewable offsets and aims to transition fully to green hydrogen.
- Cost Reduction Trends:
    - Global average cost of GH (2023) ranges from USD 3–6/kg, with targets of USD 1.5/kg by 2030.
    - Factors contributing to cost reduction include economies of scale, reduced electrolyser CAPEX and declining renewable energy prices.

[Sources: IEA (2023). Global Hydrogen Review; BloombergNEF (2022). Hydrogen Cost Outlook]

4.2.2 Infrastructure, Storage, & Transportation

Infrastructure development is critical to GH supply chains. These infrastructure options involve distinct cost, safety and system-integration trade-offs. Compressed and liquid hydrogen may be more suitable for some domestic mobility or industrial applications, while ammonia and other carriers may offer advantages for long-distance transport and export. Similarly, some economies may prioritise localised production and use to reduce transport costs, while others may favour larger hub-based models linked to industrial clusters or export corridors.

- Hydrogen Refuelling Stations:
  - Japan leads with over 160 stations, supporting FCVs (fuel cell vehicles) and public transport.
  - Republic of Korea is targeting 310 stations by 2030 under its Hydrogen Economy Roadmap.
- Storage Technologies:
  - Compressed Hydrogen: Common but energy-intensive.
  - Liquid Hydrogen: Higher density but requires cryogenic conditions; demonstrated in Japan's Suiso Frontier LH_2 carrier.
  - Ammonia as Carrier: Used for long-distance GH transport; decomposed at destination for hydrogen recovery (e.g., Australia-Japan corridor).
- Pipeline Integration & Grid Readiness:
  - People's Republic of China and Republic of Korea are exploring H_2-natural gas blending in pipelines.
  - Australia is piloting hydrogen-ready transmission networks.

The preferred approach will depend on domestic infrastructure starting points, end-use demand, geography, logistics cost and the scale at which hydrogen is expected to be deployed.

[Sources: Hydrogen Council (2023). Hydrogen Insights Report; DNV (2023). Hydrogen Forecast to 2050]

4.2.3 Research & Development (R&D) Trends

R&D is being accelerated by both government and private sectors in APEC economies:

- Innovation Clusters & Hydrogen Valleys:
  - Japan's Fukushima Hydrogen Energy Research Field (FH2R) integrates solar power with a 10 MW electrolyser.
  - Australia's Hydrogen Hubs in Gladstone and WA focus on co-locating renewable energy, hydrogen production and export infrastructure.
- Funding Mechanisms:
  - Australia's ARENA and CEFC provide grants and concessional finance.
  - Japan; and Republic of Korea use industrial innovation programs with public-private collaboration.
- Technology Breakthroughs:
  - Membrane technologies for high-efficiency electrolysis.
  - AI-assisted control systems for dynamic renewable-H_2 integration.
  - Modular electrolysers for decentralised hydrogen production.

[Source: CSIRO (2021). National Hydrogen R&D Roadmap; METI (2023); US DOE Hydrogen Program]

4.2.4 Sectoral Applications & Use Cases

GH is already moving beyond pilots into early operations such as smart cities (systems integration), road transport (FCEVs) and maritime (ferries/ports).

4.2.4.1 Smart Cities & GH Integration

The rise of GH technology has become a component of Smart Cities whereby it helps to create a sustainable infrastructure and energy system. Smart cities are defined as an urban model which uses technology, human capital and governance to achieve sustainability, efficiency and social inclusion. Therefore, this model is considered as one of the key goals for the cities of the future (Marchesani, 2023). To achieve the title of 'smart cities', a few criteria were highlighted and mentioned by Gracias, Parnell, Specking, Pohl & Buchanan (2023). These characteristics of a smart city are tabulated in Table 8.

Table 8: Characteristics of Smart Cities

Characteristic	Definition	Illustrative initiative	Example city
Connectivity	IoT networks collect and transmit data from sensors across the urban environment (Albino, Berardi & Dangelico, 2015; Gracias et al., 2023).	City-wide smart mobility/parking sensors	Singapore (Ferro-Escobar, Vacca-González & Gómez-Castillo, 2022)
Data-driven decision-making	Advanced analytics and AI enable more informed and responsive governance (Shahat Osman & Elragal, 2021).	"Sentilo"-style open sensor platforms (air quality, traffic, energy, noise, waste levels)	Barcelona, Spain (Tahar & Nawel, 2023)
Sustainable infrastructure	Energy-efficient buildings, renewable energy and intelligent transport (Moreno, 2023).	Integrated energy & mobility planning (e.g., NEOM Project)	NEOM, Saudi Arabia (Albarrak, Sowilam & Kawady, 2025)
Urban optimisation	Reduce resource use and ecological footprints; enhance living standards (Fabled Sky Research, 2020).	Smart sensors in public housing	Singapore (Woods, Lim & Kong, 2025)
Citizen engagement	Digital platforms enable communication and participation in planning/decisions (Cardullo & Kitchin, 2019; Barendregt, Bendor & van Eekelen, 2024).	Local e-participation portals	Gdynia, Poland (Przybyłowski, Kaszuba & Suchanek, 2024)
Smart mobility	Integrates public transit, bike-share and AVs; analyses mobility behaviour to improve services and optimise infrastructure (Ben-Gal et al., 2019; Fontes, Arantes, Figueiredo & Novais, 2022).	Parking-supply management; demand-responsive transit	Zurich, Switzerland (Oyadeyi & Oyadeyi, 2025)
Enhanced public services	Improves delivery of essential services (Nam & Pardo, 2011; Son et al., 2023).	Domestic "smarter city" initiatives	Multiple cities in China (Shan et al., 2021)

In smart-city programmes, GH complements electrification by (i) balancing variable renewables and providing resilient backup (fuel-cell CHP/microgrids), (ii) enabling fast-turnaround, low-emission municipal fleets (e.g., buses, waste, emergency) and (iii) supporting data-driven operations where electrolyser and storage dispatch can be optimised alongside grid conditions (e.g., demand peaks, outages). This positioning supports city-level sustainability targets while complementing grid-based electrification programs. However, the role of hydrogen in smart-city systems should be assessed alongside direct electrification, battery storage and other urban decarbonisation options, particularly where hydrogen infrastructure remains limited or system costs are high.

4.2.4.2 Road Transport (Fuel Cell Electric Vehicles, FCEVs)

Fuel cell electric vehicles (FCEVs) convert hydrogen to electricity to power an electric drivetrain. Compared with battery electric vehicles (BEVs), FCEVs offer fast refuelling (typically 3-5 minutes), consistent performance in cold climates and suitability for high-utilisation duty cycles such as fleets and longer ranges. While FCEVs offer operational advantages in selected fleet and high-utilisation contexts, their broader competitiveness relative to battery electric vehicles will depend on accessible H_2 refuelling networks and continued reductions in platinum-group metal loadings and overall system costs. Early commercial models (e.g., Toyota Mirai, Hyundai Nexo; modular concepts such as NamX) demonstrate feasibility where stations are available. Planning should prioritise hub-and-corridor stations (logistics depots, bus yards, highway nodes), align codes and standards and target incentives to duty cycles where FCEVs provide operational advantages.

[Source: Borup, Krause & Brouwer, 2021; Hydrogen Council, 2021; Hydrogen Council, 2023; ARENA, 2022; Glenk & Reichelstein, 2019]

4.2.4.3 Maritime (Hydrogen Ferries & Ports)

The maritime sector is carbon-intensive and GH offers zero tailpipe emissions when used in fuel cells. Early deployments (e.g., hydrogen ferries operating on coastal/urban routes in Norway and California) demonstrate technical feasibility, while key challenges, onboard storage, bunkering standards, safety procedures and delivered fuel cost are being addressed through port-side electrolysers, cryogenic storage and pilot bunkering systems. Coordinated port-energy planning (shore power, GH production/storage, safe bunkering) and updated safety codes, together with “green shipping corridor” initiatives, can de-risk first movers and enable broader adoption. However, in maritime applications, hydrogen-based solutions may be more relevant in selected routes or port ecosystems, whereas other low-carbon fuels or electrification may be more practical in different contexts.

[Source: Atilhan et al., 2021; DNV, 2022; IEA, 2023; CARB—Sea Change; Norled—MF Hydra]

4.2.5 Global Best Practices in GH Safety Standards

As GH scales up, safety and risk management become critical:

- Regulatory Benchmarks:
    - Japan; and Republic of Korea follow ISO/TC 197 standards for hydrogen technologies.
    - The EU’s HySafe and H2Tools safety databases offer incident records and guidelines.
- Risk Management & Safety Protocols:

- Leak detection, ventilation design and emergency shutdown systems are incorporated in project planning.
- Cross-border collaboration on safety codes is ongoing under the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE).

- Public Perception & Training:
  - Demonstration projects are used to build public trust (e.g., hydrogen buses, neighborhood-scale microgrids).
  - Japan has implemented educational programs targeting local governments and first responders.

[Source: IEA Hydrogen Safety Database; IPHE (2022); ISO/IEC Hydrogen Standards Summary]

4.2.6 Conclusion: Best Practices & Technological Innovations in APEC

The APEC region showcases a spectrum of innovation and best practices in GH technology, with frontrunners driving:

- Efficiency improvements in electrolyser systems
- Infrastructure development for transport and storage
- Strategic public-private R&D investments
- Advanced safety management and regulatory harmonisation

Economies like Australia; People's Republic of China; Japan; and Republic of Korea serve as innovation leaders, while others are rapidly building capacity through pilot projects and international cooperation. Continued scaling will depend on reducing production costs, establishing regional infrastructure and aligning safety standards. Across these use cases, hydrogen is likely to deliver the greatest value where electrification is technically difficult, operational requirements are demanding, or integration with industrial and logistics systems creates a clearer strategic fit.

To maximise benefits across APEC, shared R&D platforms, regional hydrogen hubs and knowledge transfer mechanisms should be encouraged. A harmonised innovation and safety framework can accelerate GH market maturity while ensuring safe and sustainable deployment.

4.3 Economic & Market Analysis of Green Hydrogen in APEC

4.3.1 GH's Role in the Transition to a Clean Energy Economy

Green hydrogen is increasingly recognised as one of the strategic pathway for achieving carbon neutrality, particularly in sectors where electrification is challenging, such as:

- Heavy Industry: GH can replace fossil fuels in steel production (e.g., hydrogen-based DRI), ammonia synthesis and refining.
- Transport: GH enables long-range decarbonisation through fuel cells in heavy-duty trucks, buses, trains and shipping.
- Power Grid Support: Acts as seasonal energy storage to balance intermittent renewables.

In APEC economies:

- Japan; and Republic of Korea have explicitly linked GH to domestic decarbonisation strategies.
- Australia; and Chile position GH as an export-oriented clean energy solution.
- China integrates GH into its dual-carbon goals (carbon peak before 2030 and neutrality by 2060).

[Source: IEA (2022). Global Hydrogen Review; Hydrogen Council (2023); McKinsey & Co. (2021). Hydrogen Decarbonization Pathways]

4.3.2 Global vs. Regional Hydrogen Production Costs

Hydrogen production costs vary significantly due to differences in:

- Renewable Energy Potential: Australia; Chile; and the People's Republic of China benefit from abundant low-cost solar/wind.
- Electrolyser Costs: China leads in affordable electrolyser manufacturing.
- Grid Electricity Prices: Economies with high retail electricity prices (e.g., Japan and Republic of Korea) face higher GH costs.
- Scale and Infrastructure: Larger integrated projects tend to have lower levelised costs due to economies of scale.

Table 9: Estimated GH Production Cost (2023) by Economy

Economy	Estimated GH Production Cost (2023)
Australia	USD 2.0 – 3.0/kg (solar PV powered)
China	USD 2.2 – 3.8/kg
Chile	USD 1.8 – 2.5/kg (solar-rich zones)
Japan	USD 5.0 – 7.0/kg (import-based)
Republic of Korea	USD 4.5 – 6.0/kg

The global target cost for widespread competitiveness with fossil hydrogen (grey hydrogen) is USD 1–2/kg, expected around 2030 with supportive policies and scaling.

[Source: BloombergNEF (2022). Hydrogen Cost Outlook; IRENA (2023). Green Hydrogen Supply Cost Estimation]

4.3.3 Investment Trends & Emerging Business Models

a) Private Sector Participation

Investment in hydrogen is surging across APEC economies:

Australia: Over AUD 500 million committed through Clean Energy Finance Corporation (CEFC) and Australian Renewable Energy Agency (ARENA).

- CEFC – Clean Energy Finance Corporation
    - A government-owned green bank that provides debt and equity financing for clean energy projects, including hydrogen, renewables, energy efficiency and low-emission technologies.
    - Website: https://www.cefc.com.au
- ARENA – Australian Renewable Energy Agency
    - A government agency that funds research, development and demonstration projects to accelerate the commercialisation of renewable energy technologies, including green hydrogen.
    - Website: https://arena.gov.au
    - China: Over 100 companies involved in hydrogen value chain; major cities like Shanghai and Beijing support hydrogen clusters.
    - Japan; and Republic of KoreaKorea: Major industrial players (e.g., Toyota, Hyundai, Kawasaki Heavy) are investing in mobility and infrastructure.

b) Government Incentives

- Australia: Offers grants for hydrogen hubs and R&D.

- Japan: Provides capital subsidies and R&D tax incentives.

- Republic of Korea: Has a hydrogen law mandating adoption targets and infrastructure development.

c) Emerging Business Models

- Hydrogen-as-a-Service (HaaS): Companies provide hydrogen supply, maintenance and usage systems as bundled services (e.g., refueling-as-a-service).

- Export-Oriented Production: Australia; and Chile developing supply chains for hydrogen or ammonia export to Asia.

- Hydrogen Clusters and Valleys: Integrating production, storage, end-use and infrastructure within industrial zones to achieve economies of scale and local demand matching.

Reference: DNV (2023). Hydrogen Forecast to 2050; Hydrogen Council & McKinsey (2021). Hydrogen Insights Report; APEC Energy Working Group (2022)

4.3.4 Conclusion: Economic & Market Analysis of GH in APEC

GH plays a pivotal economic role in supporting energy transition goals and unlocking new market opportunities, though adoption method remains uneven across member economies. Economies such as Australia; People's Republic of China; Japan; and Republic of Korea are leveraging GH for industrial decarbonisation, clean transport and regional exports. However, wide cost variation remains a major hurdle, influenced by local renewable energy availability, infrastructure maturity and policy support. A robust economic and market framework will be essential for transitioning GH from pilot projects to large-scale commercial success in the region.

Key takeaways:

- GH can drive economic diversification and industrial transformation in APEC.

- Cost competitiveness is within reach by 2030 with policy and technological support.

- Strategic investment and innovative business models are accelerating deployment, particularly in hydrogen hubs and integrated ecosystems.

To advance economically viable GH markets, APEC economies should:

- Coordinate regional cost reduction strategies.

- Encourage blended finance mechanisms.

- Foster demand-side markets through public procurement and offtake agreements.

- Promote cross-border trade in hydrogen and its derivatives.

4.4 Policy & Regulatory Frameworks for Green Hydrogen in APEC

4.4.1 Comparative Policy Effectiveness Across Economies

APEC economies display diverse levels of policy maturity in hydrogen development. Key success factors for effective GH policies include:

- Clear domestic roadmaps with measurable targets
    - Japan: First economy to adopt a Basic Hydrogen Strategy (2017), setting clear targets for FCVs, refuelling stations and power generation capacity.
    - Republic of Korea: Hydrogen Economy Roadmap (2019) links hydrogen deployment with job creation, vehicle penetration and energy security.
- Cross-sector coordination mechanisms
    - Inter-ministerial task forces or hydrogen councils (e.g., Australia's domestic Hydrogen Taskforce) are effective in aligning energy, transport and industry stakeholders.
- Transparent regulatory frameworks
    - Standardised permitting processes, safety regulations and environmental guidelines reduce investor uncertainty.

In contrast, some APEC economies still face fragmented governance, pilot-only strategies, or lack of inter-agency coordination, limiting GH scalability.

Reference: IEA (2023) Hydrogen Policy Database; APEC Energy Working Group (2022); IPHE (2021)

4.4.2 Government Incentives & Regulatory Barriers

a) Financial Incentives for GH Development

- Capital grants and subsidies:
    - Australia: AUD 525 million Hydrogen Hubs program supports infrastructure and commercialisation.
    - Japan: Subsidies for hydrogen vehicles, electrolysis equipment and international supply chains.
- R&D funding and tax incentives:

    - People's Republic of China and Republic of Korea fund domestic technology development, especially in fuel cells and electrolysers.
- Carbon pricing and feed-in tariffs:
    - Though still limited in hydrogen, future carbon taxes or credits could support GH competitiveness against grey hydrogen.

b) Regulatory Barriers Hindering GH Growth

- Lack of harmonised safety standards: Different safety and labelling protocols across borders create trade inefficiencies.
- Unclear certification schemes: Definitions of "green hydrogen" vary; without standardised GHG accounting, export credibility suffers.
- Slow permitting & planning approval: Infrastructure deployment, especially pipelines and refuelling stations, is delayed by lengthy procedures.

Reference: Hydrogen Council & WEF (2022); IRENA (2023). Global Hydrogen Regulatory Review; World Bank (2022). Enabling Policies for Green Hydrogen

4.4.3 Recommendations for Strengthening GH Policy Frameworks

To create a conducive policy environment across APEC, the following recommendations are emphasised:

a) Policy Push-Pull Design

Push policies (e.g., R&D grants, pilot funding) must be balanced with pull policies (e.g., public procurement, quotas) to ensure both supply and demand.

Example: Republic of Korea's Hydrogen Portfolio Standard (HPS) mandates electricity producers to use a portion of hydrogen-based power.

b) Harmonisation of Regulations

APEC should promote:

Common definitions of GH based on lifecycle emissions.

Mutual recognition of certification schemes (e.g., Guarantees of Origin or Hydrogen Certification Platforms).

Alignment of safety codes and infrastructure design standards (pipes, valves, storage tanks).

c) Cross-Border Collaboration

Bilateral and multilateral agreements can streamline hydrogen trade, infrastructure co-development and innovation sharing.

Example: Australia–Japan hydrogen corridor (HESC project); Chile–Republic of Korea hydrogen cooperation MOU.

Reference: IPHE Hydrogen Certification Paper (2023); DNV (2022); McKinsey & Hydrogen Council (2023)

4.4.4 Conclusion: Policy & Regulatory Frameworks for GH in APEC

Policy and regulatory frameworks are fundamental to enabling the rapid deployment and scaling of green hydrogen across APEC economies. While frontrunners like Australia; Chile; Japan; and Republic of Korea provide strong institutional support, many economies still face regulatory fragmentation, undefined certification systems and limited incentives.

Key findings:

- APEC economies benefit from diverse approaches but require stronger policy coherence and harmonisation.
- Financial and fiscal incentives must be matched with long-term regulatory stability and clarity.
- Regional collaboration will be crucial to unlock cross-border GH trade, safety standardisation and knowledge transfer.

To advance GH adoption in the APEC region, policymakers should:

- Align domestic strategies with emissions and energy transition goals.
- Establish common GH definitions and certification protocols.
- Incentivise both producers and end-users through balanced push-pull mechanisms.
- Develop regional hydrogen hubs with shared infrastructure and regulatory frameworks.

A robust and harmonised regulatory environment will be key to creating a secure, investable and scalable hydrogen economy across the APEC region.

5.0 RESEARCH FINDINGS: QUALITATIVE INTERVIEW ANALYSIS

This chapter presents the results of five in-depth expert interviews conducted to examine the technological, economic, policy and societal conditions shaping green hydrogen readiness across APEC economies. The study identified seven main themes and one contextual theme that collectively explain the opportunities and constraints influencing green hydrogen deployment. Drawing on perspectives from experts across research institutions, academia, industry and government, providing a multi-dimensional understanding of hydrogen development. The findings provides contextual insights based on stakeholder perspectives, rather than universal conclusions applicable to all APEC economies. The themes synthesise insights on technological innovation, ecosystem infrastructure, structural and economic constraints, governance readiness, capacity building, public acceptance and sectoral fit.

5.1 Overview of Interview Participants and Themes

Five expert interviews were conducted, representing key segments of the green hydrogen ecosystem. Participants were referenced as P1 to P5 throughout the report as listed in Table 10.

Table 10: Overview of Interview Participants

Code	Name	Economy	Affiliation	Role & Expertise
P1	Dr Rezal Khairi Ahmad	Malaysia	NanoMalaysia Berhad	Technology and policy specialist in hydrogen innovation, ecosystem development and commercialisation
P2	Prof Talal Yusaf	Australia	Aviation Australia	Academic and applied expert in hydrogen aviation, certification, safety and system integration
P3	Prof Rocio Salas	Peru	Centre of Green Hydrogen, Universidad Nacional de Ingeniería (UNI)	Research Professor specialising in hydrogen ecosystem development, skills building and climate-aligned export strategies
P4	Dr Ikhmal Hakim Hassan	Malaysia	Ministry of Science, Technology and Innovation (MOSTI)	Government policy officer focused on hydrogen governance, regulatory readiness and inter-agency coordination
P5	Prof Dr Mohammad Azmi Bustam @ Khalil	Malaysia	Universiti Teknologi PETRONAS (UTP)	Chemical engineering expert in electrolyser materials, diagnostics and operational durability

The diversity of perspectives across the five interviewees deeply informed the themes that follow.

- **Technological themes (Theme 1)** provided detailed insights on electrolyser performance, materials science and diagnostic tools.

- **Ecosystem and cost themes (Theme 2)** reflect the experiences regarding electricity pricing, storage challenges and integration barriers.
- **Structural and policy themes (Themes 3 and 4)** emphasised subsidy lock-in, governance fragmentation and regulatory gaps.
- **Capacity building (Theme 5)** synthesises workforce and institutional capability insights from all participants.
- **Public acceptance and safety (Theme 6)** incorporate experiences with public perception and risk communication.
- **Sectoral application priorities (Theme 7)** integrate industry and aviation perspectives.

This multidisciplinary allowed the analysis to move beyond single-issue barriers and highlight the interdependencies between technology, governance, economics and societal readiness.

5.2 Climate Imperative & Modernisation Narrative

Hydrogen development was consistently framed within broader domestic and regional narratives of climate urgency and economic modernisation. Although it is not an operational determinant, this contextual lens helps explain APEC economies' interest in green hydrogen and the strategic intentions underpinning their long-term plans.

Particularly, green hydrogen is widely viewed as essential for meeting climate commitments, especially for sectors where electrification is infeasible. At the same time, it represents an opportunity for economies to position themselves at the forefront of emerging clean energy industries, build industrial capabilities and diversify beyond fossil fuel dependence.

Table 11: Contextual Drivers Shaping Green Hydrogen Development

Sub-Theme	Summary Description	Interviewees
Climate Urgency Narrative	Climate risks and NDC commitments drive domestic interest in hydrogen.	P2, P3, P4
Hydrogen as a Decarbonisation Tool	Hydrogen is essential for sectors where electrification is insufficient.	P1, P2, P3, P4, P5
Economic Modernisation Narrative	Hydrogen supports new industries, competitiveness and post-fossil economic transition.	P1, P3, P4, P5

1. Climate Urgency as a Strategic Driver

Green hydrogen adoption is motivated by environmental pressures rather than immediate market demand.

Verbatims:

- "If this massive giant ice mountain starts to melt and islands start to disappear." — **P2**
- "Green hydrogen is seen as a vital component for Peru's climate change mitigation strategies." — **P3**
- "We are committed with the locally determined contribution (NDC) of carbon reduction, carbon intensity by 45% by 2030. So alternative fuels are needed to meet this NDC." — **P4**

2. Green Hydrogen as a Decarbonisation Lever Across High-Emission Sectors

Green hydrogen is framed as a necessary tool in sectors where electrification is insufficient.

Verbatims:

- "Green hydrogen is important energy vector to decarbonise the economy." — **P3**
- "So for long run I think we will have no option, ...will be able to see something tangible when it comes to hydrogen." — **P2**
- "The real winner is volume - electronics, fertiliser, food, steel, so on and so far. Hydrogen would play like one of those unsung hero behind the curtain." — **P1**
- "Green hydrogen can become an export product and a way to decarbonise hard-to-abate industry" — **P4**
- "It can be a strategic element for industrial decarbonisation and renewable energy" — **P5**

3. Hydrogen for Economic Modernisation and Competitiveness

Hydrogen R&D is linked to industrial upgrading, new markets and future economic resilience.

Verbatims:

- "..develop 6 green hydrogen hubs for catering, both local and international demand. Their findings projected that in the long term, a new hydrogen economy could generate about 74,000 daily jobs. Also, an additional minimum GDP of or up to 4,000 millions in the region." — **P3**
- "Research on the electrolyte that be able to provide high energy density for hydrogen emission reaction and also developing new diagnostic sensor system for electrolyser, health and lifespan prediction for electrolyser." — **P5**
- "Allow for smaller economy to produce subcomponents, localisation. To get us on board in the global supply value chain, only that way we are able to create a sustainable high economy across APEC." — **P1**
- "economies of scales and R&D should bring the cost down." — **P4**

This demonstrates that hydrogen development across APEC economies is motivated by macro-level narratives of climate urgency and modernisation, rather than solely by market readiness. These narratives form the strategic backdrop for Themes 1–7, influencing policy ambition, R&D priorities and long-term energy planning. Although it does not directly shape operational decisions, this climate-modernisation framing reinforces the legitimacy of hydrogen investments and lends coherence to domestic hydrogen strategies.

5.3 Technological Advancement & Innovation Boundaries

Participants consistently emphasised that the remaining technological bottlenecks are no longer about "inventing a better electrolyser," but about addressing material degradation, high catalyst costs, integration challenges in regulated sectors and the need for real-time diagnostics to ensure operational safety and reliability. This signals a broader shift in the hydrogen innovation landscape, where progress is increasingly driven by materials engineering, system integration and operational performance rather than electrochemical design.

Table 12: Technological Advancement and Innovation Boundaries in Green Hydrogen

Sub-Theme	Summary Description	Interviewees
Mature Electrolyser Technologies	PEM & alkaline widely deployable but low innovation potential; mature and saturated market.	P1, P2, P3
Emerging High-Efficiency Systems	High efficiency and long-term cost potential; materials durability remains the key barrier.	P1
Materials as the Main Bottleneck	Membrane degradation, catalyst costs and durability challenges determine true LCOH.	P1, P4, P5
Diagnostics and Predictive Monitoring	Monitoring needed for reliability, lifespan prediction and reducing operational risks.	P5
Integration Over Invention	Certification, compliance, system integration more challenging than electrolyser design.	P2

1. Mature Electrolyser Technologies but Limited in Innovation Potential

Although widely deployed, PEM and alkaline systems no longer offer transformative innovation potential.

Verbatims:

- "PEM and Alkaline is very much red ocean. I think we understand that the big boys and big girls are already in the high TRL, MRL for us to compete directly." — **P1**
- "..using our PEM (proton exchange membrane) electrolyser to produce a green hydrogen, especially for academic research." — **P3**
- "There are many technologies already been developed." — **P2**

2. Emerging High-Efficiency Technology as the Future Innovation Space

AEM and SOEC are seen as promising due to high efficiency potential, but only if material stability challenges are resolved.

Verbatims:

- “Solid oxide electrolyser has gained momentum because they're able to reduce the operating temperature, which also translate into high efficiency electrolyser operation.” — **P1**
- “Our internal foray has been at the anion exchange membrane because we believe it's an emerging tech where few players have invested” — **P1**

3. Materials are the Primary Barrier to Cost and Durability

Membrane strength, catalyst affordability and degradation behaviour directly determine hydrogen's economic viability.

Verbatims:

- “Hydrogen is costly at initial stage, but now become more cheaper compared to previous due to the latest technology development, a new catalyst, new membrane, new system.” — **P5**
- “We were looking into deploying some of those local biomass sources to substitute and traditional material into the membrane to create a local supply chain support for these new technologies” — **P1**
- “To lower cost electrolyser, we should use abundant materials with high volume manufacturing, durable catalysts and membranes. We need to have durable PEM, AEM, durable catalyst for PEM and AEM electrolysers.” — **P4**

4. Diagnostics and Predictive Monitoring are Essential for Operations

As hydrogen moves toward industrial environments, real-time monitoring becomes critical for risk management and economic stability.

Verbatims:

- “Currently developing new diagnostic sensor system for electrolyser, health and lifespan prediction for electrolyser.” — **P5**

5. Integration Challenges Outweigh Invention Needs in Several Sectors

Regulated industries face hurdles not in electrolyser design, but in system integration, certification, compliance and safety frameworks.

Verbatims:

- “Let us integrate our business. Let us work together like I can't fight … other economies who are really producing quality and the quantity of hydrogen.” — **P2**

5.4 Ecosystem Readiness: Infrastructure, Storage & Cost Structure

While hydrogen technologies continue to advance, experts emphasised that the surrounding ecosystem remains the primary bottleneck for scaling green hydrogen in APEC economies. Even the most efficient electrolyser cannot deliver affordable hydrogen without addressing persistent gaps in storage, electricity pricing, transport logistics, renewable intermittency and supply chain localisation.

The green hydrogen ecosystem is broadly perceived as underdeveloped, especially compared with other clean technologies. The hydrogen storage whether as gas, liquid, or solid was consistently identified as costly and technically demanding, particularly for long-distance transport. Because storage inflates cost, participants stressed that hydrogen production must be located near the point of use, especially in aviation and industrial contexts.

Furthermore, electricity cost emerged as the single largest determinant of green hydrogen's economic viability. Where renewable energy remains expensive or unstable, green hydrogen becomes uncompetitive regardless of electrolyser efficiency improvements. Experts repeatedly described high electricity tariffs as the root cause of elevated hydrogen prices.

Overall, experts stressed that without improving infrastructure, renewable supply, logistics and local manufacturing capabilities, green hydrogen will remain confined to niche or demonstration-scale applications, rather than scaling into a commercially viable clean energy pathway.

Table 13: Infrastructure, Storage and Cost Constraints Affecting Green Hydrogen Readiness

Sub-Theme	**Summary Description**	**Interviewees**
In-Situ Hydrogen Production Model	Transport costs make onsite or near-site production essential.	P1
Storage & Transport Challenges	Storage solutions remain expensive, complex and limiting.	P1, P2, P4, P5
Electricity Cost Barrier	Electricity price is the strongest driver of hydrogen cost.	P1, P4, P5
Renewable Intermittency & Grid Limits	Unstable renewable supply undermines feasibility.	P1, P2, P3, P4

1. In-Situ Hydrogen Production as a Practical Necessity

Localised production is seen as the only feasible near-term model due to transport cost escalation.

Verbatims:

- "The only way for us to make it cheap if you were to go down the path of electrolyser, you must produce and use in the same local area." — **P1**

2. Storage and Transport are Major Technical and Cost Barriers

Storage systems remain one of the weakest and most expensive links in the value chain.

Verbatims:

- "Energy storage is a problem. Where to, how to store bulk of hydrogen." — **P2**
- "Even you produce, but you don't have storage and you don't have distribution infrastructure, there will be another issue." — **P5**
- "The cost of hydrogen will balloon if you include additional storage and additional transportation." — **P1**
- "We need to use advanced carrier like solid hydrides, liquid carrier ammonia, LOHC (Liquid Organic Hydrogen Carriers), are key innovation to reduce compression, cooling costs." — **P4**

3. Electricity Cost Dominates Hydrogen Production Economics

High renewable electricity prices make green hydrogen unaffordable, even with efficient electrolysers.

Verbatims:

- "For challenge large scale production normally is about cost electricity." — **P5**
- "The biggest cost component is the electric charge, electricity 40%, electrolysers is 20%.." — **P1**
- "..the rest of the costing is on electricity. The problem is not CapEx. The problem is the OpEx (operating expenditure) of the hydrogen production." — **P4**

4. Renewable Intermittency and Grid Constraints Undermine Viability

Hydrogen requires consistent renewable supply, but most grids cannot support sustained load.

Verbatims:

- ".. developing green hydrogen economy in Peru, especially because Peru is rich in solar and wind resource." — **P3**
- "Our job is to use to power the electrolyser with our solar and our wind turbine and that's why it's a green." — **P2**
- "For us to get into the green hydrogen bandwagon, we need large solar farm to contribute." — **P1**
- "If we want the hydrogen to be green, we need to have a better energy management system that combined intermittent solar winds with steady batteries that will maximise electrolyser use." — **P4**

5.5 Structural & Economic Conditions Shaping Hydrogen Viability

The experts highlighted that hydrogen deployment is shaped not only by technology and infrastructure, but by deeper structural and economic conditions within each economy. These include fossil-fuel dependency, entrenched subsidy systems, limited market demand at current hydrogen prices and a lack of coordinated strategies. Experts stressed that without addressing these structural realities, hydrogen cannot progress from pilot projects to commercially viable markets.

A dominant theme was that many APEC economies remain fiscally tied to fossil fuels, making hydrogen adoption a strategic and economic challenge rather than technological. Subsidy regimes, particularly petrol and gas subsidies, distort price signals and make green hydrogen appear artificially expensive. Hydrogen remains economically disadvantaged in markets characterised by substantial fossil-fuel subsidies and high renewable electricity prices.

Experts also emphasised misalignment between production cost and buyer willingness, echoing a broader market readiness issue. Sectors such as aviation, mining and manufacturing require hydrogen at substantially lower price points before large-scale adoption becomes feasible.

Finally, they also described a strong need for coordinated strategies, as fragmented visions across ministries, agencies and sectors delay project execution and create uncertainty for investors. This lack of alignment is a structural barrier that undermines hydrogen's integration into domestic energy systems.

Table 14: Structural and Economic Conditions Shaping Green Hydrogen Viability

Sub-Theme	Summary Description	Interviewees
Fossil Dependence Constraint	Reliance on fossil-fuel revenue slows transition and shapes policy decisions.	P1, P4
Subsidy Lock-In	Subsidised fossil fuels distort market competitiveness and hinder hydrogen adoption.	P1, P4
Hydrogen Price Misalignment	Production costs exceed what buyers are willing to pay, limiting adoption.	P1, P2
Domestic Manufacturing Limitations	Dependency on imports increases cost and weakens competitiveness.	P1, P4
Need for Coordinated Strategies	Fragmented governance slows implementation and weakens investor confidence.	P4, P5

1. Fossil-Fuel Dependence as a Structural Constraint

Economies that rely on oil and gas revenue face inherent transition challenges.

Verbatims:

- “The primary income still comes from Petronas. Even the with oil and gas.” — **P1**
- “Breakthrough in cost reduction, storage, technology and system integration so that Malaysia hydrogen project can compete with the traditional fuels.” — **P4**

2. Subsidy Lock-In Distorts Market Signals

Subsidised petrol, diesel and natural gas make hydrogen less competitive, regardless of technological progress.

Verbatims:

- “People are hung up on fossil fuels. It is heavily subsidised.”— **P1**
- “So that Malaysia hydrogen project can compete with the traditional fuels.” — **P4**

3. Hydrogen Price Misalignment Creates Market Resistance

Industries are unwilling to pay current hydrogen prices, even when motivated by decarbonisation goals.

Verbatims:

- “Right now, it can go up to USD 20 per kilogram. ..market readiness when it comes to buying or purchasing hydrogen before they can resell is right now they will need to pay USD 6-8.” — **P1**
- “You need to reduce the cost of producing hydrogen. Now they're talking about USD 6-7 per equivalent of kilogram. Let's target 2.” — **P2**

4. Limited Domestic Manufacturing Capacity Weakens Competitiveness

Domestic industry gaps create dependency on foreign suppliers and expose economies to external cost structures.

Verbatims:

- “China have invested heavily in producing alkaline water electrolyser because it's cheap. It's an old technology, but relatively efficient at economy of scale and they are deploying at mass both in China and they are offering those solution, especially for in situ generation.” — **P1**
- “The homegrown electrolyser in Malaysia, that only contribute to 30% of the CapEx.” — **P4**

5. Need for Coordinated Strategies to Align Stakeholders

Fragmented decision-making across ministries and agencies slows development.

Verbatims:

- “We have the vision on the road map but investor need clearer rules, a faster permit and cheaper dedicated clean power.” — **P4**
- “How they can be streamlined because they were involved of regulatory requirement.” — **P5**

5.6 Governance, Standards & Strategic Policy Direction

According to the experts, the governance and regulatory alignment are among the most influential determinants of hydrogen readiness in APEC economies. While many economies have published domestic hydrogen strategies, the real progress depends on operational clarity, institutional coordination and the development of standards, certification systems and definitions that give industry confidence.

A recurring theme in the interview was policy fragmentation, where multiple ministries or agencies share overlapping mandates without clear leadership. This creates uncertainty, slows project approvals and discourages investment. Interviewees emphasised that hydrogen requires a “whole-of-government” approach, yet most economies remain characterised by uncoordinated or compartmentalised governance structures.

Moreover, significant gaps were also identified in regulatory frameworks, definitions and certification systems, particularly regarding the classification of green hydrogen, the standardisation of safety requirements and the verification of cross-border trade. Sectors like aviation face particularly complex requirements, where certification processes can take years, further underscoring the need for regulatory clarity.

Many economies have established long-term hydrogen roadmaps and energy plans, but these often lack clear implementation pathways. Although enabling legislation and the recognition of hydrogen as a strategic priority represents positive progress, policy ambition must be translated into practical and coordinated action to achieve meaningful progress.

Finally, participants have also framed hydrogen governance within broader narratives of energy security, export strategy and gradual transition, underscoring the need for economies to navigate the shift carefully to avoid fiscal disruption or public resistance.

Table 15: Governance, Standards and Strategic Policy Direction for Green Hydrogen

Sub-Theme	Summary Description	Interviewees
Policy Fragmentation	Overlapping mandates and unclear leadership slow decision-making.	P5
Regulatory Readiness Gap	Missing standards, certification pathways and safety protocols.	P2, P4, P5
Roadmaps & Regulations	Ambitious strategies exist but need detailed, coordinated implementation.	P1, P3, P4
Subsidy & Transition Strategy	Subsidy systems shape competitiveness; transition must be phased.	P1, P4, P5
Hydrogen for Energy Security & Export	Hydrogen positioned as strategic asset for export and resilience.	P1, P2, P3

1. Policy Fragmentation Reduces Effectiveness and Slows Progress

Multiple agencies share hydrogen-related responsibilities, leading to duplication and unclear leadership.

Verbatims:

- “Streamline, lot of agencies will involve because we have a lot, from KeTTHA, MOSTI, then who are involved in an industry, MITI.” — **P5**

2. Regulatory Readiness Gaps in Standards, Safety and Certification

Key sectors face uncertainty due to underdeveloped regulatory, safety and certification frameworks.

Verbatims:

- “Safety is issue but always the solution, you do the safety requirement and that's resulted into big problem, is the regulation. so you need to convince the regulator.” — **P2**
- “We actually in the midst of developing the hydrogen regulation.” — **P4**
- “Safety standard. Are we, our economy ready or not?” — **P5**

3. Hydrogen Roadmaps and Regulations Provide Direction but Need Execution

Domestic strategies and laws signal long-term ambition, though execution mechanisms remain uneven.

Verbatims:

- “We are still in fast phase one roadmap. Based on our road map, we are supposed to be able to produce or we target about 1.5 megaton per annum of hydrogen because our target is source to three economies, Japan; Republic of Korea; and Singapore.” — **P1**
- “Law number 31992 declaring green hydrogen a domestic interest and mandating the Ministry of Energy and Mines to lead policy development,

financial incentives, infrastructure planning and the creation of a regulatory and certification framework." — **P3**
- "To implement the action plan, but it's still in the early phase. We have 3 phases, from 2020 to 2030, 2031 to 2040 and 2041 to 2050." — **P4**

4. Subsidy and Policy Interactions Shape Realistic Transitions

Transition speed must reflect economic, social and fiscal constraints.

Verbatims:

- "Because they see fossil fuel, gas, coal, still cheap.. You can incentivise, take away a bit from the fuel subsidy." — **P1**
- "Because early days we have abundant of fossil fuel to become energy resource, but maybe energy become depletion. We need to outsource another new technology." — **P5**
- "We actually in the midst of developing the hydrogen regulation. Future policies could boost hydrogen demand, for example a strong carbon tax." — **P4**

5. Hydrogen as a Tool for Energy Security and Export Strategy

Green hydrogen is framed not only as an energy transition tool but as a strategic asset.

Verbatims:

- "The second decade 2030 to 2040, that's when we go in a large scale to supply green hydrogen, blue hydrogen to consumer economies." — **P1**
- "The idea of export green hydrogen or green ammonia in the future is very real, it's very feasible." — **P3**
- "Green hydrogen is the goal and we are now trying to produce green hydrogen using electrolyser and use it as you know as liquefied hydrogen or liquid hydrogen to increase the energy density." — **P2**

5.7 Ecosystem Capacity & Capability Building

Human capital and institutional capability are central to green hydrogen deployment. While technological readiness and policy ambition are important, participants stressed that hydrogen cannot scale without a workforce equipped to design, operate, integrate and maintain the green hydrogen systems across different sectors. The interviews revealed an urgent need for skilled technologists, cross-disciplinary engineers and hands-on specialists in safety, diagnostics and hydrogen system operations.

Workforce readiness cannot rely solely on traditional engineering degrees. These experts highlighted that hydrogen-related competencies need to be integrated into existing engineering, chemistry and technical programmes, supported by practical training through demonstration facilities and applied laboratories where both industry professionals and students can gain hands-on experience. Reskilling via micro-credentials and short courses also emerges as a critical pathway for upskilling the existing workforce.

Finally, capacity building must extend beyond the individual level to encompass institutional collaboration across industry, academia and government. These partnerships facilitate knowledge transfer, minimise duplication and accelerate the development of the workforce required for hydrogen adoption.

Table 16: Ecosystem Capacity and Capability Building for Green Hydrogen

Sub-Theme	Summary Description	Interviewees
Need for Hydrogen-Skilled Workforce	Demand for technologists, operators and cross-disciplinary specialists.	P1, P2, P5
Curriculum Integration	Embed hydrogen into existing programmes to scale knowledge quickly.	P1, P2, P3, P5
Skills Development	Hands-on learning via demonstration facilities and micro-credentials was seen as key to rapidly developing a hydrogen-ready workforce.	P1, P2, P3
Cross-Sector Collaboration	Industry–academia partnerships accelerate capability building.	P2, P3, P5

1. Need for Hydrogen-Skilled Workforce

The deployment of hydrogen technologies requires specialised skills that remain limited across the existing workforce.

Verbatims:

- “We need to graduate technologist. They are not technician; they are not professional engineers. And that's what the industry need in five years from now, including hydrogen.” — **P2**
- “How this industry can be supported or the capability or the manpower or the talent to handle the technology is actually one of another aspect that we need to address.” — **P5**
- “How do we get on to the hydrogen bandwagon which is recognised – micro credential, short courses just to connect to our existing knowledge.” — **P1**

2. Curriculum Integration Rather Than New Degrees

Embedding hydrogen-related competencies within existing academic programmes, rather than developing separate degree pathways.

Verbatims:

- “You don't need to create an undergrad degree, you just need to insert that agenda into your elective, your final year project.” — **P1**
- “Are we ready with the knowledge? Because it's not under the undergraduate syllabus.” — **P5**

- “Using our PEM electrolyser to produce a green hydrogen, especially for academic research, to build capabilities in our students and to the green hydrogen economy.” — **P3**
- “Developed one course called renewable energy for aviation industry and too many chapters of them about hydrogen.” — **P2**

3. Practice-Oriented Skills Development through Demonstration Facilities and Flexible Training Pathways

Applied learning was viewed as essential for building hydrogen workforce readiness, combining hands-on training at demonstration plants with micro-credentials and short courses for students, technicians and professionals.

Verbatims:

- “In my university, for example, the vision or the most important goal to build the green hydrogen plant, it was exactly develop skills in our students and Peruvian engineers.” — **P3**
- “We need to educate our technician and that's basically our role as aviation student because we are not only higher education, we are TAFE.” — **P2**
- “How do we get on to the hydrogen bandwagon which is recognised – micro credential, short courses just to connect to our existing knowledge” — **P1**

4. Collaboration Across Industry, Academia and Agencies Strengthens Capability

Capacity building requires multi-stakeholder participation, not isolated efforts.

Verbatims:

- “Cooperate, collaborate. communicate. Three Cs. We need to communicate. We need to collaborate and cooperate together and support each other” — **P2**
- “We have many players here in Peru which are from different sectors, from the government, the academy, from the private sector, many companies are involved with and the international partnerships are very important.” — **P3**
- “I'm involving on the very specific project from industry for improvement of HER (hydrogen emission reaction).” — **P5**

5.8 Public Acceptance, Safety Narratives and Social Licence

A shared perspective among experts is that public perception and social acceptance play a significant role in shaping green hydrogen adoption. Although there is no strong societal resistance, hydrogen is often perceived as dangerous, explosive, or experimental, largely due to limited public exposure and persistent misconceptions. These perceptions often obscure an understanding of hydrogen’s actual safety characteristics, highlighting the need for structured communication and increased real-world visibility.

A comparative safety framing explaining hydrogen’s behaviour relative to conventional fuels such as petrol or LPG emerges as an effective approach to addressing misconceptions. Given that hydrogen disperses rapidly and rises rather than pooling, risk communication should be grounded in clear scientific comparisons rather than general reassurance.

Demonstration projects also play a critical role in building social confidence. Visible and tangible applications such as hydrogen-powered food trucks, drones, university-based hydrogen plants and rural electrification pilots, help normalise hydrogen and build trust. These projects create familiarity, reduce fear and demonstrate that hydrogen can be managed safely across different contexts.

Finally, government-led communication is critical to building public trust. Safety messaging and information delivered by credible public institutions are more likely to gain acceptance than those communicated solely by industry or academic actors. Clear and consistent government narratives therefore support public understanding and facilitate early market development.

Table 17: Public Acceptance, Safety Narratives and Social License for Green Hydrogen

Sub-Theme	Summary Description	Interviewees
Hydrogen Fear Narrative	Public associates hydrogen with explosions as unfamiliarity increases perceived risk.	P1, P2, P4, P5
Comparative Safety Framing	Scientific comparisons (hydrogen vs petrol/LPG) help debunk misconceptions.	P1, P2, P5
Demonstration Projects	Visible real-world use builds trust and normalises hydrogen.	P1, P2, P4, P5
Low but Positive Awareness	Public has limited knowledge but is receptive when informed.	P1, P3, P4
Government-Led Communication	Official agencies must lead safety messaging to gain social licence.	P1, P2

1. Hydrogen Fear Narrative

Hydrogen is frequently associated with risk, largely as a result of limited public exposure.

Verbatims:

- “In a grand scheme of things, the ‘pop’ sound can be boom, massive explosion.” — **P1**
- “Hydrogen is dangerous, definitely, because of it is a flammable gas” — **P5**
- “First public will concern about- they will say that, so it will blow up.” — **P4**
- “We commission bus using compressed natural gas and everyone's scared to jump into the bus because, how I'm going to sit there and there's bottle of gas, if this gas going to explode. So same way exactly for the hydrogen.” — **P2**

2. Comparative Safety Framing Helps Counter Misconceptions

The distinct physical behaviour of hydrogen compared with petrol or methane was emphasised, highlighting the need for communication grounded in scientific comparison.

Verbatims:

- “When we do the, what they call, awareness with them, we make comparison. This is actually the safety of hydrogen and this is the safety of fuel.” — **P5**
- “Hydrogen atomic number is 1. Lightest known material. The moment it's leak, it goes straight up to the atmosphere. There's no chance for it to accumulate it down as opposed to natural gas.” — **P1**
- “we commission bus using compressed natural gas from airport to city and everyone's scared to jump into the bus because how I'm going to sit there and there's bottle of gas, if this gas going to explode. So same way exactly for the hydrogen. Now people, they sit in the car, they don't know what's the fuel of the car. Compressed natural gas become very normal in knowledge.” — **P2**

3. Demonstration Projects as Social Proof and Confidence Builders

Public-facing demonstrations reduce perceived risk and provide assurance of hydrogen’s safe handling.

Verbatims:

- “we can deploy at night markets, places of common interest, food truck area, cause that would definitely have a great optics because then you will translate into that awareness.” — **P1**
- “They took our drone and they go to school and they do a lot of presentation.” — **P2**
- “Do demonstration, open for them to visit. Maybe allow them to have a site visit.” — **P5**
- “Let people see the pilots project. Let people see the demonstration here. the propaganda is to what benefits public other than industries.” — **P4**

4. Public Awareness is Low but Generally Positive When Informed

Public awareness of hydrogen remains limited, however, receptiveness is generally high when the technology is clearly explained.

Verbatims:

- “People who attends to green hydrogen events are lower than people attending to another energy events related. The main source of green hydrogen knowledge is media coverage at the moment, particularly news reports.” — **P3**
- “The best way is deploying a community level, CSR hydrogen projects. Validation leads to awareness and the awareness will attract both investors, off takers and even the public.” — **P1**

- “Actually people are not against hydrogen, they are unsure, so they want plain answer on safety, who pays and who benefits” — **P4**

5. Government-Led Communication is Essential for Social Licence

Public trust depends on advocacy that is authoritative and consistent.

Verbatims:

- “How to raise awareness, you started with the government.” — **P2**
- “He's powering the food truck... interesting, no sound, clean, sustainable. I think and that needs to be initiated through government initiative.” — **P1**

5.9 Sectoral Priorities and Market Application

Green hydrogen deployment will not distribute uniformly across all sectors. Instead, the adoption will be shaped by sectoral characteristics, demand profiles, existing infrastructure and decarbonisation pressures. The nearest-term role of hydrogen is most relevant in hard-to-abate sectors, export-oriented value chains and niche applications where electrification is not technically or economically feasible.

A recurring insight is that hydrogen’s contribution is frequently overstated in public discourse, particularly in relation to passenger mobility. Experts highlighted that while hydrogen cars create visibility, their contribution to emissions reduction is relatively minor compared to industrial and heavy-transport applications. Consequently, greater emphasis is placed on prioritising sectors where hydrogen can deliver substantive decarbonisation outcomes, rather than focusing on symbolic or high-visibility uses.

Additionally, export-oriented pathways have emerged as a key focus, particularly through hydrogen-derived fuels such as ammonia, attracting strong interest from mining companies, petrochemical industries and aviation fuel producers. At the same time, green hydrogen shows promise in rural and off-grid contexts, where small-scale production can replace diesel generation and enhance energy security, demonstrating that hydrogen’s value extends beyond large-scale infrastructure to community-level energy solutions. According to the experts, these strategies are integral to domestic hydrogen plans and support the development of hydrogen valleys centred on industrial applications.

Table 18: Sectoral Priorities and Market Applications for Green Hydrogen

Sub-Theme	Summary Description	Interviewees
Hard-to-Abate Sectors	Priority applications in aviation, mining, steel, chemicals.	P1, P2, P3, P4
Rural & Off-Grid Hydrogen	Small-scale production for remote communities and energy access.	P1
Mobility Optics and Impact	Passenger vehicles are symbolic but low-impact; industry matters more.	P1
Export Pathways	Ammonia and hydrogen exports drive investment strategies.	P1, P3, P4

1. Hard-to-Abate Sectors as Priority Markets

Hydrogen demand is strongest where electrification is infeasible.

Verbatims:

- “for long run I think we will have no option, …will be able to see something tangible when it comes to hydrogen.” — **P2**
- “In my economy, mining industry is very important, …had published some papers or studies regarding how the green hydrogen will be used to decarbonise some operation.” — **P3**
- “Green hydrogen in those sectors will eventually become mainstay because … the real winner is volume - electronics, fertiliser, food, steel.” — **P1**
- “I think first is on the carbonising hard-to-abate sectors is a top priority.” — **P4**

2. Hydrogen for Rural and Off-Grid Applications

Small-scale hydrogen production can enable energy access and replace diesel systems.

Verbatims:

- “We have deployed our solid-state hydrogen reactor there to power their communal building” — **P1**

3. Mobility Optics against Real Decarbonisation Impact

Hydrogen cars get attention but do not represent meaningful emissions reductions.

Verbatims:

- “The impact of hydrogen economy to the society economy from mobility is actually very small” — **P1**

4. Export-Oriented Hydrogen and Ammonia Pathways

Export markets drive investment, especially where domestic demand is limited.

Verbatims:

- “Peru is currently in its nascent stage but shows potential with a vision seeing green hydrogen as part to decarbonise the Peruvian economy and export to international markets.” — **P3**
- “… for us to coordinate, facilitate the initial target of exporting either green or blue hydrogen to Japan; Republic of Korea; and SIngapore.” — **P1**
- “regional export demand is the driver, Malaysia Road map envision selling hydrogen and derivative to Japan; Republic of Korea; and SIngapore.” — **P4**

5.10 Cross-Theme Integration and Interconnections

The seven themes illustrate that hydrogen readiness across APEC is not determined by a single factor but by a network of interdependent conditions. The insights show that technology, infrastructure, governance, economic structures, skills, public acceptance and sectoral demand must evolve together for hydrogen to scale meaningfully. The key interconnections across themes:

1. Technology depends on ecosystem readiness

Even with progress in AEM, PEM and SOEC technologies (Theme 1), deployment is limited by:

- high electricity costs
- storage and transport challenges
- dependency on imported equipment
- renewable intermittency (Theme 2)

Without resolving these ecosystem constraints, technological advances cannot reduce hydrogen’s cost enough to be competitive.

2. Structural economic conditions shape feasibility

Themes 2 and 3 reinforce each other:

- Fossil-fuel reliance slows transition momentum.
- Subsidies distort market prices, making hydrogen appear costlier.
- Industry willingness to pay remains low until prices fall significantly.

These structural realities limit investor confidence and set the boundaries of what hydrogen can achieve in the short term.

3. Governance influences all dimensions

Regulatory clarity and institutional coordination (Theme 4) directly affect:

- ecosystem development (Theme 2)

- cost competitiveness (Theme 3)
- public trust (Theme 6)
- sectoral deployment pathways (Theme 7)

Policy fragmentation emerged as a cross-cutting barrier that slows hydrogen investments and project approvals across sectors.

4. Skills and capabilities are foundational

A capable workforce (Theme 5) is essential for:

- operating new hydrogen technologies
- implementing safety standards
- running hydrogen plants, labs and training centres
- enabling industrial and aviation integration (Theme 7)

Capability gaps weaken the impact of governance, technology and infrastructure improvements.

5. Public acceptance influences social licence and safety confidence

Public awareness and perception (Theme 6) intersect with:

- governance (safety standards, communication campaigns)
- sectoral pilots (especially those visible to communities)
- technology integration in aviation and industrial sites (Theme 7)

Without strong communication and safe demonstrations, scaling hydrogen becomes politically difficult.

6. Sectoral demand anchors domestic hydrogen strategies

Hydrogen is most viable in sectors where alternatives are limited (Theme 7):

- aviation
- mining
- steel and industrial heat
- ammonia export
- off-grid systems

These sectors shape the technical requirements, policy needs, training pipelines and investment priorities across themes 1-6. Together, these interconnections show that hydrogen ecosystem development is systemic rather than linear. Scaling hydrogen in APEC requires synchronised progress across technology, governance, infrastructure, economics, workforce development and public acceptance. No single theme can drive the transition alone as readiness depends on alignment across all seven themes, supported by the broader contextual pressures of climate urgency and economic modernisation.

5.11 Summary of Findings

The findings reveal that hydrogen development in APEC economies is shaped by a combination of technological advancements, ecosystem gaps, structural constraints, governance readiness, human capital, public acceptance and sectoral priorities. Key insights include:

1. Technology Drivers
   - Climate urgency and decarbonisation goals motivate hydrogen exploration.
   - Modernisation agendas position hydrogen as an economic opportunity beyond fossil fuels.
2. Technology is progressing, but materials and integration challenges remain
   - PEM and alkaline technologies are mature, but cost breakthroughs depend on materials innovation.
   - Diagnostics and durability remain weak points.
3. Ecosystem readiness is the main bottleneck
   - High electricity prices dominate hydrogen cost.
   - Storage and transport challenges restrict scalability.
   - Domestic manufacturing capacity is limited.
4. Structural economic conditions shape feasibility
   - Subsidy lock-in and fossil reliance distort competitiveness.
   - Market willingness to pay remains below current production costs.
5. Governance alignment is essential
   - Policy fragmentation and regulatory gaps limit investment.
   - Certification, safety standards and definitions require harmonisation.
6. Workforce and institutional capability must expand
   - Skills gaps exist in hydrogen operations, diagnostics, safety and integration.
   - Micro-credentials, hands-on training and cross-sector collaboration are critical.
7. Public acceptance needs strengthening
   - Misconceptions about safety persist.
   - Demonstration projects and government communication improve trust.
8. Hydrogen's value lies in priority sectors
   - Aviation, mining, heavy industry, off-grid systems and ammonia export represent viable markets.
   - Passenger mobility is low-impact and low priority.

In summary, hydrogen readiness across APEC hinges on coordinated progress across multiple dimensions. While technology is improving, ecosystem limitations, economic structures, governance fragmentation, capability gaps and social acceptance issues collectively shape the trajectory of hydrogen development.

6.0 SEMINAR: KEY INSIGHTS AND HIGHLIGHTS

6.1 About the Seminar

On 15 and 16 October 2025, a two-day seminar under APEC initiative PPSTI_101_2024 on Advancing Energy Transition and Circular Economy in Building Up Capabilities to Net Zero/Carbon Neutrality: Advocacy and Stakeholder Management in Accelerating Green Hydrogen was organised at Concorde Hotel, Kuala Lumpur, Malaysia. The project, overseen by Prof Ts Dr Shahrina Md Nordin, Director of the Institute of Sustainable and Smart Living (ISSL), Universiti Teknologi PETRONAS (UTP), was proposed by Malaysia and co-sponsored by Chile; People's Republic of China; Republic of Korea; Chinese Taipei; and Thailand with alignment to APEC's Putrajaya Vision 2040, Aotearoa Plan of Action, APEC Priorities 2024, PPSTI 2016-2025 Strategic Plan, Peru 2024 APEC Priorities and PV 2040. The seminar was held under the Policy Partnership on Science Technology and Innovation (PPSTI) and includes cross-fora collaboration with Energy Working Group (EWG) and Human Resources Development Working Group (HRDWG) to enhance human resource development through economic and technical cooperation.

The seminar gathered participants and experts from ministries, agencies, industries, scholars and representative of APEC economies for capacity building and advocacy in clean energy transition. The project acknowledges the need for greater efforts to accelerate clean, sustainable, affordable and inclusive energy transitions across economies. It also emphasises strengthening human resource development and enhancing economic and technical cooperation to equip stakeholders with the necessary skills and knowledge for future energy advancements.

The seminar serves as a collaborative platform to strengthen the collective capabilities of APEC economies in green hydrogen by sharing the latest advancements in high-efficiency and low-cost production technologies, while strengthening understanding of the ecosystem, which includes storage, market assessments, energy applications and the establishment of safety protocols for transportation. In addition, the initiative seeks the assess the economic viability of related production costs in setting up clean energy economy. Furthermore, the seminar promotes the enhancement of green hydrogen network by fostering collaboration among industry players, academia, policymakers and stakeholders across APEC economies. Overall, the seminar serves as a platform to foster collaboration, knowledge exchange and strategic action towards accelerating the adoption of green hydrogen across APEC economies.

6.2 Tentative of the Seminar

The seminar on Advancing Energy Transition and Circular Economy in Building Up Capabilities to Net Zero/Carbon Neutrality: Advocacy and Stakeholder Management in Accelerating Green Hydrogen, held on 15–16 October 2025, followed a comprehensive two-day programme featuring distinguished speakers, expert panels and interactive discussions.

The morning of day 1 commenced with welcoming remarks delivered by Mr Imran Abdul Kadir, Vice President of Strategy, Sustainability and Transformation at Universiti Teknologi PETRONAS (UTP). This was succeeded by the opening and officiating speech by YBhg. Datuk Seri Hj. Hasnol Zam Zam Hj. Ahmad, Secretary-General of the Ministry of Science, Technology and Innovation (MOSTI), Malaysia. The seminar's foundation was further set through a context setting session presented by Prof Ts Dr Shahrina Md Nordin, Project Overseer for the APEC Project PPSTI_101_2024 and Director of ISSL, UTP. The morning session continued with an in-depth presentation on the part 1 of APEC Energy Perspective 2025: Green Hydrogen Outlook by Assoc Prof Ir Dr Suriati Sufian and Dr Syaza Izyanni Ahmad, researchers from ISSL.

The technical sessions resumed after the morning break with Mr Peter Godfrey, Managing Director for Asia Pacific at the Energy Institute, Singapore, who delivered the first keynote topic, Green Hydrogen: A Catalyst for Circular Growth across the APEC Region. This was followed by the second keynote topic, Synergizing Circular Economy & Green Hydrogen: Pathways for Supply, Demand and Policy, presented by Dr Umi Karomah Yaumidin, Head of the Research Center for Behavioral & Circular Economics at the National Research and Innovation Agency (BRIN), Indonesia. Shortly thereafter, Green Hydrogen Production & Utilisation in Japan: Economy-wide & Locally was presented as the third keynote topic by Prof Junji Inukai from the Hydrogen & Fuel Cell Nanomaterials Center, University of Yamanashi, Japan. After the lunch break, the session transitioned into Forum 1, titled Advancements in High-Efficiency, Low-Cost Green Hydrogen Production Technologies, moderated by Ir Dr Mubarak Wahab, Head of the Centre of Urban Resources Sustainability at UTP. The forum featured three speakers: Mr Fernando Maceda, Executive Director of H2 Peru (The Peruvian Hydrogen Association), Peru; Mr Danial Khairi Ahmad, Global Head Projects of Hydrogen at Gentari Sdn Bhd, Malaysia; and Dr Umi Karomah Yaumidin of BRIN. The afternoon included a short break before the final session of the day, Topic 4: Green Hydrogen Development: Challenge & Path, delivered by Prof Emeritus Dato' Ir Dr Wan Ramli Wan Daud, Fellow of the Academy of Sciences Malaysia and President of the Malaysian Association of Hydrogen Energy.

Day 2 commenced with a renewed perspective on the green hydrogen landscape through a presentation on the APEC Energy Perspective 2025: Green Hydrogen Outlook, this time delivered by Assoc Prof Dr Amjad Shamim from ISSL, UTP. This was followed by Topic 5: The Peruvian Experience: Developing a Renewable & Low-Carbon Hydrogen Ecosystem, presented by Mr Fernando Maceda, highlighting Peru's domestic strategies and industry progress. After a morning break, the seminar proceeded with Forum 2, themed Future Green Jobs: The Case of Green Hydrogen, moderated by Ir Tengku Kahar Muzaffar, Vice President of Strategy at NanoMalaysia Berhad, Malaysia. Forum speakers included Prof Peta Ashworth, Director of the Curtin Institute for Energy Transition, Curtin University, Australia; Ir Noraziah Muda @ Omar, Head of Renewable Energy & Green Technology at TNB Research, Malaysia; and Mr Goh Chiat Wooi, Project Manager at Plug Power, Malaysia. The programme continued with Topic 6: Solid State Hydrogen Ecosystem, presented by Dr Rezal Khairi Ahmad, Chief Executive Officer of NanoMalaysia Berhad. Following lunch, the seminar transitioned to the Interactive Session, where participants engaged in break-out Focus Group Discussions (FGDs) aimed at policy and strategies recommendations, facilitated by Ir Dr M. Mubarak A. Wahab as Lead Facilitator and Assoc Prof Ts Dr Fawnizu Azmadi as Co-lead Facilitator, both from UTP. After an afternoon tea break, the seminar concluded formally with closing remarks by Prof Dato' Ir Ts Dr Mohamed Ibrahim Abdul Mutalib, Provost and Chief Academic Officer of UTP, before officially adjourning the event.

6.3 Summary of Speakers and Sessions

The seminar brought together a diverse group of experts from academia, industry, research institutions and international organisations to share insights on green hydrogen development across the APEC region. Across the two-day programme, speakers delivered specialised presentations covering technological advancements, circular economy linkages, case studies and future workforce needs. In addition, two expert forums and an interactive focus group discussion provided a platform for in-depth dialogue and multi-stakeholder engagement. The speakers and their respective sessions are summarised as follows.

Keynote Speakers

- Topic 1: **Mr Peter Godfrey** – Green Hydrogen: A Catalyst for Circular Growth across the APEC Region
- Topic 2: **Dr Umi Karomah Yaumidin** – Synergising Circular Economy & Green Hydrogen: Pathways for Supply, Demand and Policy
- Topic 3: **Prof Junji Inukai** – Green Hydrogen Production & Utilisation in Japan: Economy-wide & Locally
- Topic 4: **Prof Emeritus Dato' Ir Dr Wan Ramli Wan Daud** – Green Hydrogen Development: Challenge & Path
- Topic 5: **Mr Fernando Maceda** – The Peruvian Experience: Developing a Renewable & Low-Carbon Hydrogen Ecosystem
- Topic 6: **Dr Rezal Khairi Ahmad** – Solid State Hydrogen Ecosystem

Green Hydrogen Forums

1. Forum 1 – Advancements in High-Efficiency, Low-Cost Green Hydrogen Technologies

Moderator: Ir Dr Mubarak Wahab
Speakers:

- Mr Fernando Maceda
- Mr Danial Khairi Ahmad
- Dr Umi Karomah Yaumidin

2. Forum 2 – Future Green Jobs: The Case of Green Hydrogen

Moderator: Ir Tengku Kahar Muzaffar
Speakers:

- Prof Peta Ashworth
- Ir Noraziah Muda @ Omar
- Mr Goh Chiat Wooi

6.3.1 Topic 1: Green Hydrogen: A Catalyst for Circular Growth Across the APEC Region

Keynote Address by Mr Peter Godfrey

Managing Director, APAC, Energy Institute, Singapore

Mr Peter Godfrey delivered a comprehensive keynote addressing on global energy transition and challenges, highlighting the rapid expansion of global energy capacity comparable to the combined generation capacities of China; the European Union; and Japan. He emphasised that solar photovoltaic (PV) systems are leading this transformation, contributing approximately 80% of new global capacity, followed by wind, hydro, bio-energy and geothermal sources. Despite this progress, he noted several challenges, including strained supply chains, grid bottlenecks, financial constraints and shifting energy policies, particularly in China and the United States (US). While US policy changes are unlikely to cause long-term disruption, China's continued leadership in clean technology is expected to sustain global decarbonisation momentum. Mr Godfrey underscored that the success of the energy transition depends on the resilience of supply chains, the expansion of grids and storage capacity and the ability to translate clean energy growth into enduring prosperity and stability.

He further discussed on shifting energy paradigms, emphasising how growing energy security concerns are driving economies, especially import-dependent economies to diversify into non-fossil fuel sources. He projected a significant rise in electricity demand due to digitalisation and artificial intelligence, which could consume up to 12% of global power within the next 10 to 15 years. Emerging markets such as electric vehicles and digital technologies are becoming key forces in driving energy transition, even as hard-to-abate sectors like heavy industry, shipping and aviation remain dependent on hydrocarbons. The APEC region, accounting for about 56% of global energy demand, will play a major role in shaping global energy trends. With APEC economies on track to meet their goals of reducing energy intensity by 45% (from 2005 levels) and doubling modern renewable use by 2030, Mr Godfrey stressed the importance of reimagining the entire energy system rather than focusing on individual technologies or fuel substitutions.

Mr Godfrey noted that the focus of sustainability efforts is shifting toward building resilience. The shift towards building resilience includes:

1. Planetary Boundaries
   - Operate within ecological limits (climate, biodiversity, water, soils, oceans).
   - Ensure human activity no longer overshoots Earth's regenerative capacity.
2. Intergenerational Equity
   - Safeguard the ability of future generations to thrive.
   - Design systems that are future-proofed, not short-term.
3. Just and Inclusive Transition
   - Balance environmental goals with social justice.
   - Guarantee fair access to energy, food, education and livelihoods.
4. Resilient, Regenerative Systems
   - Shift from "less harm" to net-positive impact.
   - Restore ecosystems and empower communities.
5. Integrated Metrics of Value
   - Redefine progress beyond conventional economic return to include well-being and natural/social capital.

He emphasised the need to move beyond the extractive logic of past energy systems and adopt distributed, value-driven and adaptive models, supported by meaningful metrics to measure progress. Green hydrogen is widely recognised as a potential bridge to a cleaner and more resilient energy future, ideally integrated into a broader energy, food and water nexus. Its adoption is most effective when market-driven rather than producer-driven and it is economically viable primarily in regions where renewable energy is abundant and inexpensive. However, several challenges must be addressed:

1. High production costs and infrastructure gaps: Limited offtake agreements, permitting processes and logistics constrain growth.
2. Risk of fossil fuel dependency: Overreliance on blue or grey hydrogen could lock economies into fossil fuels and divert investment from renewable energy.
3. Localised applicability: Green hydrogen is particularly suitable for hard-to-decarbonise industries but is not a universal grid solution.

To overcome these challenges, strategies for APEC economies include:

1. Promoting regional cooperation and site-specific approaches to maximise efficiency.
2. Developing integrated ecosystem thinking to connect production, infrastructure and market demand.
3. Establishing collaborative and scalable value chains and industrial hubs to support long-term adoption.

In his closing remarks on roles and collaboration to advance green hydrogen development across the APEC region, it is important to foster regional collaboration on projects, with a focus on scalable and ecosystem-based approaches. Frameworks should be developed to connect financing, infrastructure and market demand for green hydrogen, while policy alignment and supply chain integration must be promoted to avoid fossil fuel lock-in and support a circular economy. Academic and research institutions should be actively engaged in project development and capacity building and governments along with multilateral organisations are encouraged to incentivise and enable new business models for low-carbon industries.

6.3.2 Topic 2: Synergising Circular Economy & Green Hydrogen: Pathways for Supply, Demand, & Policy

Keynote Address by Dr Umi Karomah Yaumidin

Head of Research Center for Behavioral & Circular Economics, National Research & Innovation Agency (BRIN), Indonesia

Dr Umi Karomah Yaumidin emphasised the critical link between circular economy principles and green hydrogen development to support sustainable supply, demand and policy strategies. She highlighted Indonesia's commitment to achieving net-zero emissions and carbon neutrality by integrating circular economy concepts into the domestic energy transition framework. Dr Umi discussed the dynamics of hydrogen supply and demand, the economy's hydrogen roadmap and the policy directions aligning energy transition efforts with circular economy objectives. Figure 4 illustrates the green hydrogen projects in Indonesia.

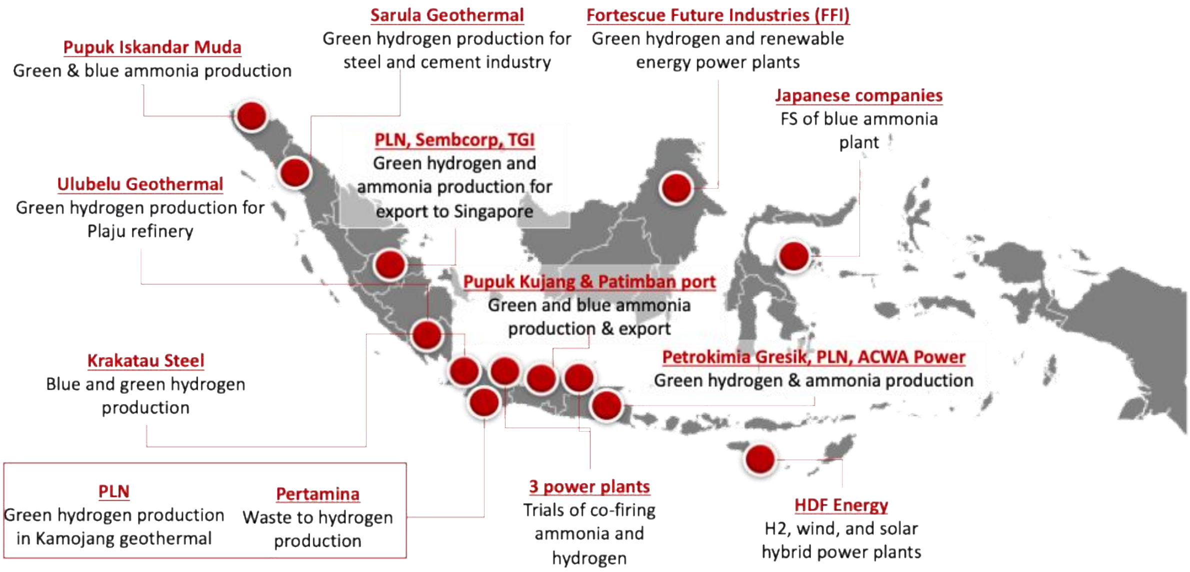


Figure 4: Green hydrogen projects in Indonesia

In her presentation, Dr Umi underscored the role of green hydrogen as a key solution to the intermittency challenges of renewable energy sources such as solar, wind and hydro. She explained that a circular economy approach is essential to secure and recycle critical raw materials, such as platinum group metals, iridium and lithium, thereby reducing import dependency and strengthening international trade. While much of Indonesia's circular economy research has traditionally focused on battery technologies, she noted that hydrogen policies are still in early stages of development. Indonesia's efforts include implementing eco-design standards, recycling targets and extended producer responsibility programs that align with international regulations.

Dr Umi also elaborated on Indonesia's domestic hydrogen roadmap, which envisions hydrogen as a cross-sectoral energy carrier and export commodity by 2060 with an aspiring production of 17 million tonnes per annum (Mtpa) as shown in Figure 5. The roadmap targets, which are summarised in Table 19, include increasing electrolyser capacity, biogas reforming, establishing early infrastructure and introducing hydrogen blending into the gas grid network. She shared that hydrogen demand in Indonesia is expected to grow significantly across industries, where industrial and electricity sectors to drive the demand such as ammonia and methanol production, steel and cement manufacturing and fuel for transportation. Hydrogen is also being explored as a potential replacement for traditional fuels like coke, natural gas and coal in industrial processes.

Table 19: Summary of the green hydrogen roadmap in Indonesia

Initiation Phase (2025–2034)	Development & Integration Phase (2035–2044)	Acceleration & Sustainability Phase (2045–2060)
a. Development of strategic plans and implementation roadmap b. Feasibility studies for production, storage, transportation, and utilization c. Launch of pilot projects d. Formulation of regulations, standards, and certification frameworks e. Design of incentive schemes and carbon trading mechanisms f. Establishment of financing models g. Initiation of research and development for supply chain infrastructure h. International partnerships and collaboration i. Capacity building and personnel competency development	a. Infrastructure integration enhancement studies b. Increased investment in hydrogen-related infrastructure c. Policy formulation to accelerate implementation d. Expansion of incentive schemes and carbon trading mechanisms e. Scaling up hydrogen use across industry, power generation, gas networks, and transportation f. Mainstreaming technological innovation in supply chain infrastructure g. Positioning Indonesia as the ASEAN hub h. Continued capacity building and personnel competency development	a. Increased investment in supply chain infrastructure b. Strengthening international partnerships and collaboration c. Establishing Indonesia as a key player in the global market

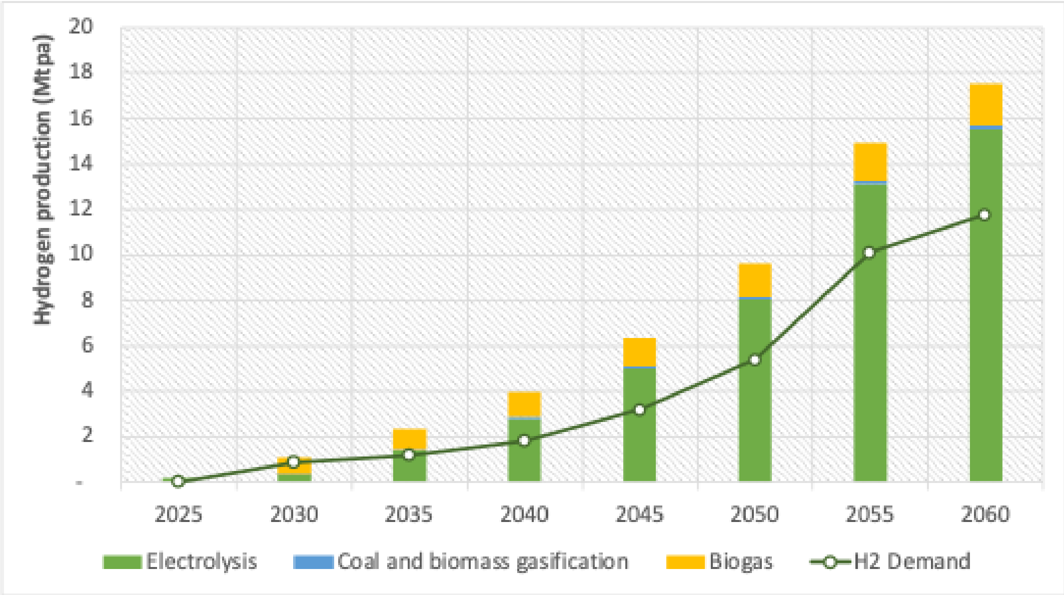


Figure 5: Indonesia's Hydrogen and Ammonia Roadmap target for hydrogen production by 2060

Addressing cost and policy challenges, Dr Umi highlighted that the Levelised Cost of Hydrogen (LCOH) remains capital-intensive, with major costs stemming from electricity costs. The government has introduced various incentives, including tax holidays and tax allowance, such as accelerated depreciation schemes, to encourage investment. Optimisation models are also being developed to reduce production and delivery costs by leveraging surplus electricity during low-load hours. She added that subsidies on domestic gas and the increasing reliance on imported liquefied natural gas (LNG) may narrow the cost gap between green, blue and grey hydrogen in the future.

Dr Umi further emphasised the importance of integration between ministries overseeing green hydrogen and circular economy initiatives to maximise cross-sectoral synergies. Coordination is particularly crucial in overlapping sectors such as construction, plastics, textiles and electronics through joint monitoring, setting target for sustainable development and alignment with international standards. She highlighted BRINs active role in research, innovation and human capital development through laboratory establishment, capacity-building programs and international collaborations with partners from Australia; Japan; Republic of Korea; and United States.

6.3.3 Topic 3: Green Hydrogen Production & Utilisation in Japan: Economy-wide & Locally

Keynote Address by Prof Junji Inukai

Clean Energy Research Centre, Hydrogen & Fuel Cell Nanomaterials Center, University of Yamanashi, Japan

Prof Junji Inukai from the University of Yamanashi delivered a keynote address highlighting Japan's progress and ongoing efforts in advancing clean energy and hydrogen technologies. He introduced the University of Yamanashi as a small but domestically distinguished institution with approximately 4,000 students and a strong legacy of excellence in hydrogen and fuel cell research. Established in 1795, the university is home to the Clean Energy Research Center and the Hydrogen and Fuel Cell Nanomaterials Center. Since 1978, the university has spearheaded Japan's fuel cell research, holding the highest number of publications and patents in the field within Japan.

Prof Inukai elaborated on Japan's hydrogen strategy from both economy-wide and local perspectives, describing hydrogen as a crucial secondary energy source, alongside heat and electricity, due to its potential for long-term storage and export. Japan's hydrogen development journey initially began with grey hydrogen derived from fossil fuels and has since transitioned toward blue and green hydrogen, driven by renewable energy sources and carbon capture technologies. The shift gained momentum after the 2011 earthquake, which reduced Japan's reliance on nuclear energy and imported fossil fuels, while accelerating the diversification of energy resources. He emphasised that Japan's adoption of hydrogen was initially driven more by economic sustainability concerns than by climate change mitigation, adopting a slow and phased approach that started with residential fuel cells before expanding into the transportation and industrial sectors.

Figure 6: Step by step approach for hydrogen illustrated by New Energy and Industrial Technology Development Organization (NEDO) Japan

At the domestic and international levels, Prof Inukai discussed Japan's evolving hydrogen policy and collaboration landscape. Initially, hydrogen imports came from Australia (Figure 7) through lignite-based processes, though these projects have since ended as Australia transitions toward green hydrogen. Japan now continues partnerships with Brunei shown in Figure 7, which uses grey hydrogen with toluene as a carrier and is exploring emerging collaborations with Malaysia displayed in Figure 8, which is developing both green and blue hydrogen for export. Japan's overall strategy remains pragmatic, utilising grey, blue and green hydrogen according to availability, while maintaining a long-term goal of achieving net-zero greenhouse gas emissions by 2050. The government incentives continue to support hydrogen infrastructure and mobility, though hydrogen remains costlier than petroleum at present.

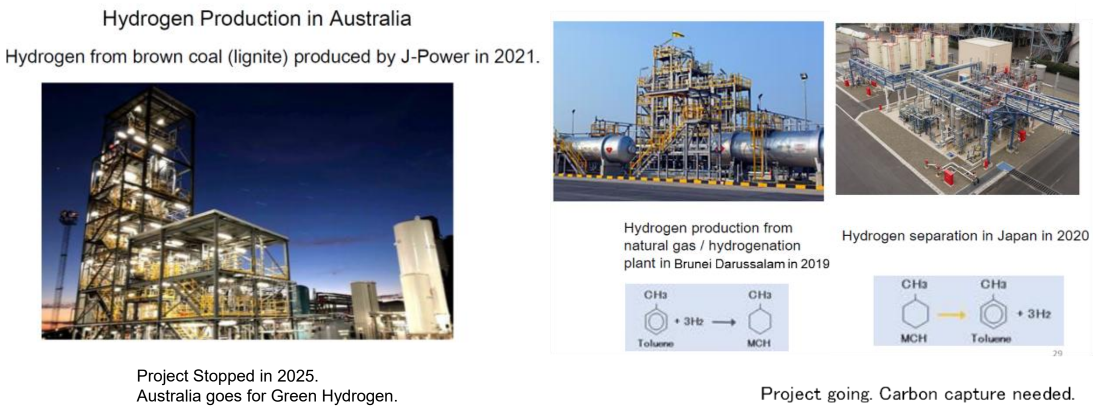


Figure 7: Japan's hydrogen partnerships with Australia and Brunei Darussalam

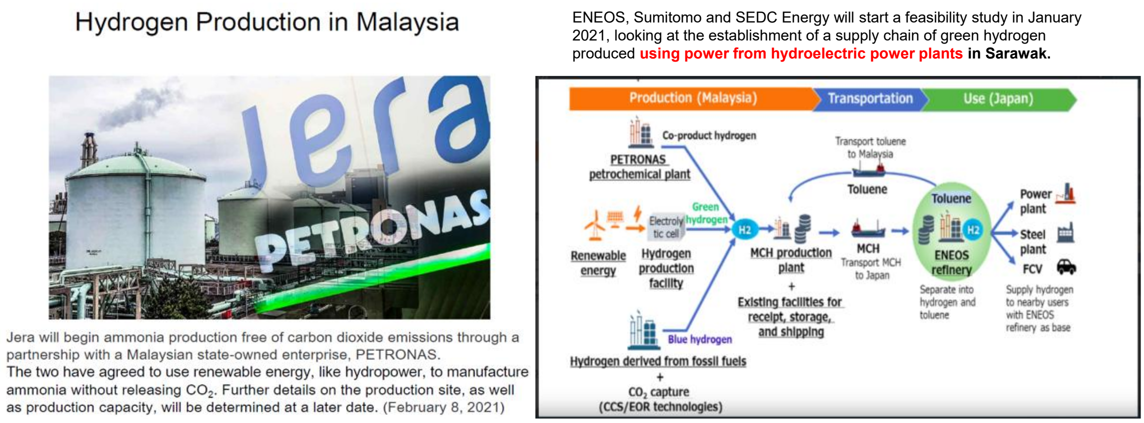


Figure 8: Japan's hydrogen collaboration with Malaysia

In describing regional initiatives, Prof Inukai highlighted Yamanashi Prefecture's unique advantages for green hydrogen production are its abundant sunlight and clean water resources. The prefecture is home to the Yonekura-yama Solar Plant that was established in 2012 and is among world's largest hydrogen facilities integrating large-scale solar plant, with hydrogen production and storage as seen in Figure 9. The local government plays an active role in advancing the hydrogen economy by establishing a company to sell green hydrogen and supporting education and training programs for local industries. Major corporations such as Toyota, Mitsubishi and Suntory are engaged in these initiatives, alongside smaller local enterprises adopting hydrogen for commercial and consumer applications, such as hydrogen-roasted coffee depicted in Figure 10, which demonstrates innovative uses of hydrogen's precise temperature control.

Figure 9: Hydrogen production facility in Yamanashi Prefecture, Japan

UCC makes Hydrogen-Roasted Coffee

Figure 10: Hydrogen roasted Coffee in Japan

In conclusion, Prof Inukai recommended several key action items to strengthen Japan's green hydrogen transition. These include sustaining international collaboration for hydrogen imports and technology exchange, promoting local education and community-level adoption of green hydrogen and continuing to refine cost-reduction strategies for hydrogen mobility and residential applications. He also encouraged further exploration of innovative hydrogen uses in local industries to foster public engagement and acceptance. His presentation underscored Japan's steady and pragmatic approach toward establishing a sustainable and globally connected hydrogen economy.

6.3.4 Topic 4: Green Hydrogen Development: Challenge & Path

Keynote Address by Prof Emeritus Dato' Ir Dr Wan Ramli Wan Daud

Fellow, Academy of Sciences Malaysia; President, Malaysian Association of Hydrogen Energy, Malaysia

Prof Emeritus Dato' Ir Dr Wan Ramli Wan Daud delivered an insightful keynote address on the drivers of energy transition and the critical role of hydrogen in advancing decarbonisation and circular economy efforts. His presentation covered a wide range of topics, including hydrogen's colour classification, projections for the global and APEC hydrogen economy by 2050, pathways for green hydrogen adoption in selected APEC economies and the major challenges and technological opportunities shaping the future of hydrogen development.

In his discussion on hydrogen's role in decarbonisation and circular economies as illustrated in Figure 11, Prof Dato' Wan Ramli explained that green hydrogen can be produced from water splitting or biomass and subsequently compressed, liquefied, transported and used as a clean fuel or industrial feedstock. He clarified common misconceptions about excess water generation from hydrogen processes, emphasising that the natural water cycle maintains equilibrium. Hydrogen is a crucial enabler of decarbonisation as it allows carbon dioxide to be converted into useful products and supports low-emission power generation through advanced technologies such as chemical looping and membrane-based methods. He highlighted that the integration of hydrogen and decarbonisation cycles creates both environmental and economic value, aligning with circular economy principles that promote resource efficiency and sustainability.

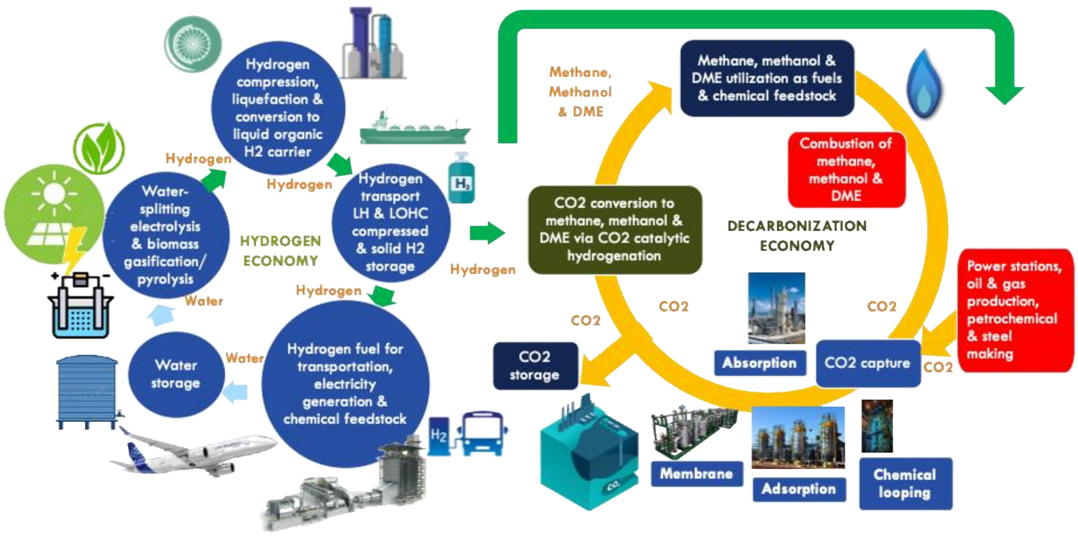


Figure 11: Hydrogen and decarbonisation economies

Prof Dato' Wan Ramli elaborated on the various hydrogen colour codes as summarised in Figure 12 that distinguish production pathways: grey and black hydrogen from fossil fuels with high emissions; blue hydrogen incorporating carbon capture, utilisation and storage (CCUS); pink hydrogen generated from nuclear energy; and green hydrogen derived from renewable sources or biomass. He also highlighted safety as a key aspect of hydrogen deployment, demonstrating through comparative evidence that hydrogen vehicles, when equipped with proper safety systems, can perform more safely than petrol vehicles in controlled fire and leakage tests.

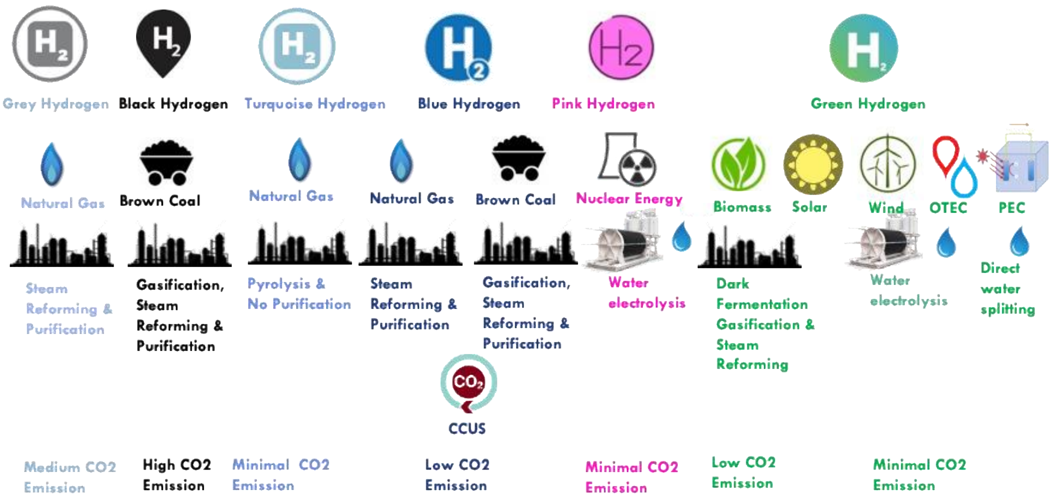


Figure 12: Hydrogen colour code

Figure 13: Controlled fire simulation from leakage tests of hydrogen fuelled vehicle and gasoline fuelled vehicle

Highlighting global and regional projections, in which all economies commit to achieve net-zero by 2050 through ambitious policies, the green hydrogen demand trajectory shows dramatic increase, with the fall of grey hydrogen demand by 2050 as shown in Figure 14. Prof Wan Ramli also noted that the hydrogen economy is projected to reach a market value of USD 2.5 trillion by 2050, creating approximately 30 million jobs and reducing up to 6 gigatonnes of carbon emissions. Hydrogen is expected to meet around 18% of global final energy demand by 2050 as summarised in Figure 15.

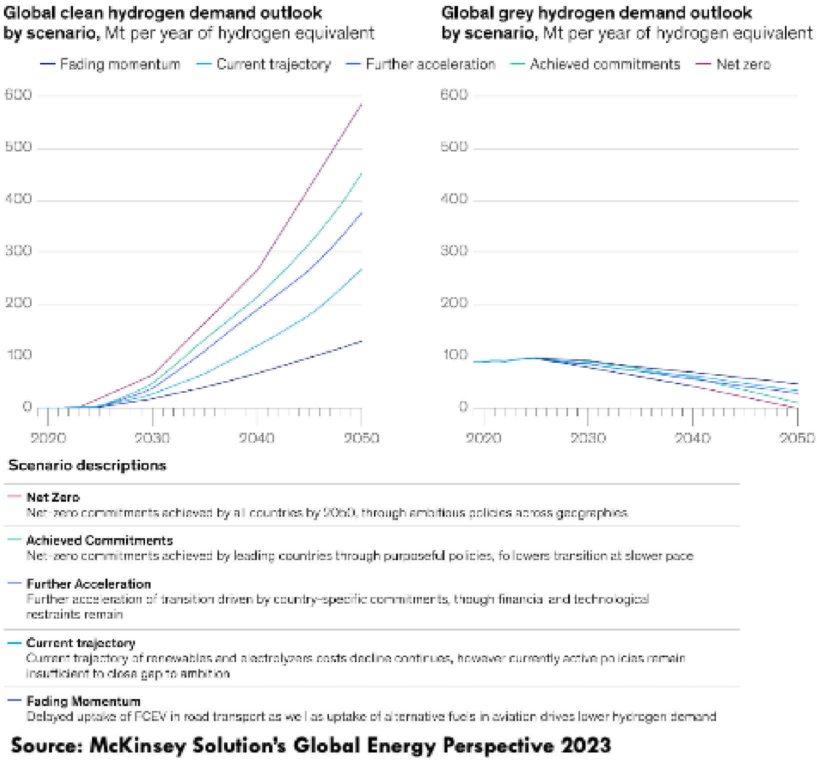


Figure 14: Global clean and grey hydrogen demand outlook by scenario

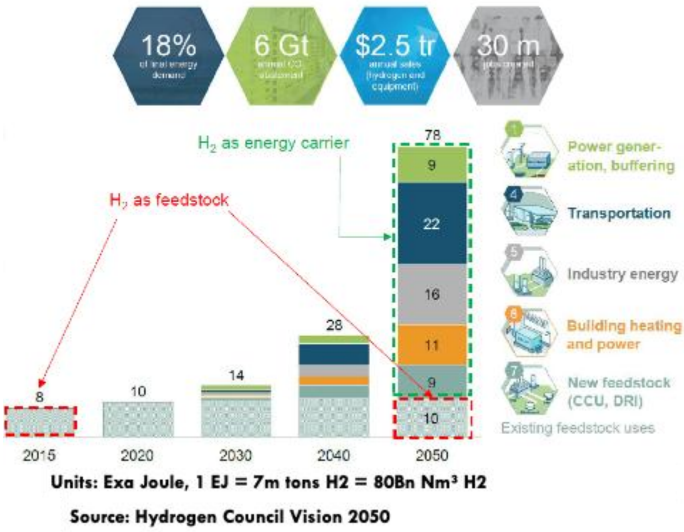


Figure 15: Hydrogen economy by 2050

Within the APEC economies in 2024, hydrogen's contribution to the global market is estimated at 47.22%, driven by strong green hydrogen initiatives powered by renewable sources such as wind energy at over 47.68%. The PEM electrolyser generate the highest revenue share of over 26.38%, even though the technology is more expensive than alkaline electrolyser. Major end users currently include the oil refining industry. He identified Australia; Indonesia; and Malaysia as key exporters in the region, while People's Republic of China and Japan are emerging as major importers, each with comprehensive hydrogen roadmaps envisioning balanced domestic consumption and trade by mid-century as detailed in Figure 16. Australia; Indonesia; and Malaysia project steady growth in green hydrogen production capacity aligned with their respective domestic roadmaps and net-zero timelines, with Malaysia increasing from 2 Mtpa in 2030 to 16 Mtpa by 2050, Indonesia from 2.4 Mtpa to 17.5 Mtpa by 2060 and Australia from 1 Mtpa to 15 Mtpa by 2050. These economies rely increasingly on renewable energy sources such as hydro, solar and wind to support hydrogen for power, industry, transport and export markets. In contrast, China and Japan, as major hydrogen-importing economies, anticipate rapid expansion in hydrogen consumption by 2050, with Japan's demand rising from 3 Mtpa in 2030 to 20 Mtpa and China's from 34 Mtpa to 110 Mtpa. Both economies plan to scale their reliance on green hydrogen, particularly from solar and wind, primarily for industrial applications.

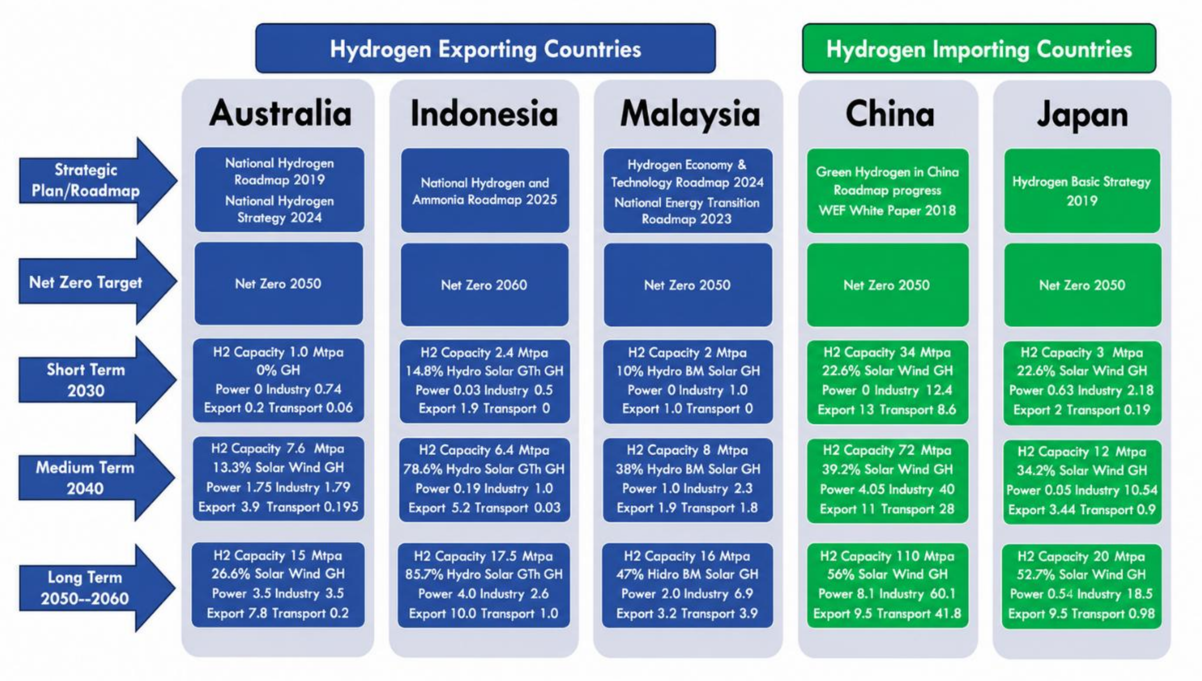


Figure 16: Green hydrogen pathway in some APEC economies
(Hydro – hydropower; BM – biomass; GH – green hydrogen; GTh – geothermal)

Prof Dato' Wan Ramli also provided an in-depth overview of the key challenges impeding green hydrogen development. These include economic and financial, infrastructure and logistical, policy and regulatory, technical and resource and market and demand. The details on the major challenges to green hydrogen development in APEC economies as follows.

1. Economic and financial

- High production costs: Green hydrogen remains expensive due to high electrolyser and renewable electricity costs.
- Cost competitiveness: Electrolysis efficiency (60–70%) limits cost competitiveness, requiring costs to fall to around USD 2/kg to compete.

- Investment uncertainty: High investment risks and long payback periods create uncertainty for investors.
- Financing complexity: Capital-intensive projects require risk-sharing mechanisms such as public-private partnerships, government-backed loans and R&D subsidies.

2. Infrastructure and logistical

- Lack of established infrastructure: Lacks established pipelines, storage terminals and refuelling networks, requiring major upfront investment.
- Difficult transportation and storage: Transport and storage are costly due to low energy density and energy-intensive processes (compression, liquefaction, carriers).
- Fragmented supply chains: Supply chains face bottlenecks, including limited electrolyser manufacturing and reliance on critical minerals (Platinum (Pt), Iridium (Ir)).

3. Policy and regulatory

- Lack of harmonised standards: No harmonised standards for certification (e.g., guarantees of origin or carbon intensity), hindering cross-border trade and market confusion.
- Policy fragmentation: Many economies have roadmaps but lack binding targets or strong incentives, creating inconsistent regional policy support and adds to investors uncertainty.
- Permitting delays: Overlapping jurisdictional responsibilities, slow and complex permitting processes delay project development.

4. Technical and resource

- Electrolyser efficiency: Limitation on scalability and efficiency of PEM and AEM electrolysers, while alkaline types struggle with variable renewable power.
- Water scarcity: Electrolysis requires substantial water, raising concerns in water-scarce regions.
- Competition for renewables: Large renewable energy expansion for hydrogen competes with the need to decarbonise electricity grids directly.

5. Market and demand

- Uncertain demand: Future demand remains uncertain, particularly in transport, complicating investment decisions.
- Limited end-use applications: Many end-use technologies are still emerging and adoption in key sectors remains limited.

Discussing cost and technology pathways as illustrated in Figure 17, he highlighted that current green hydrogen production costs can reach up to USD 8 per kilogram, primarily due to high capital expenditure and electricity prices. While increase in the efficiency of electrolysers and improvement in plant operations with heat and mass integration can help to lower the LCOH, the most significant reductions depend on cheaper renewable electricity and the development of alternative and low-cost catalysts (such as nickel and copper). As highlighted in Figure 18, advancements such as the use of non-PGM electrodes, increases in current density and reductions in balance-of-plant components contribute only marginally to lowering the LCOH. A significant reduction in LCOH is observed only when the electricity tariff decreases. Transporting hydrogen in the form of ammonia or MCH is currently more practical and cost-effective than liquid hydrogen, though each method presents efficiency trade-offs and energy losses.

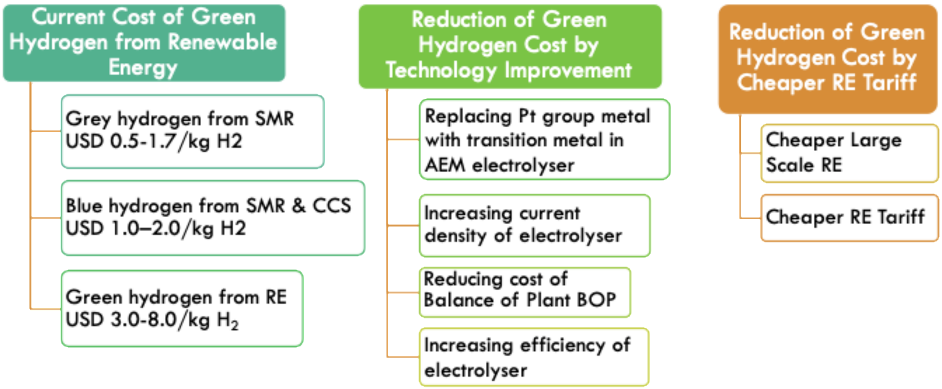


Figure 17: Cost of green hydrogen by 2050

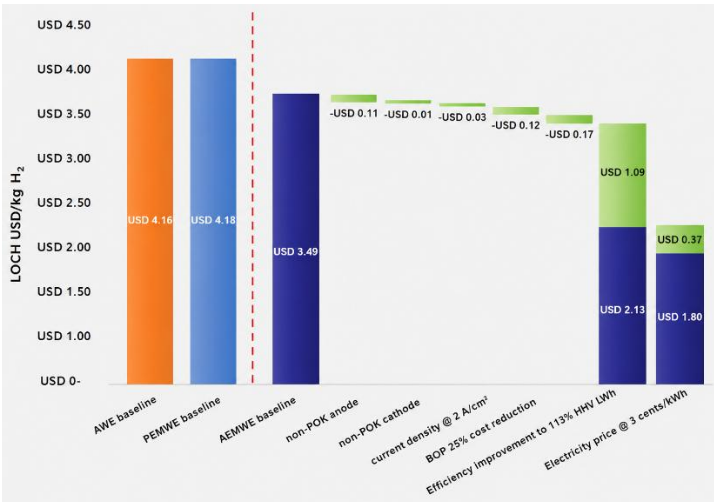


Figure 18: Levelised cost of hydrogen (LCOH) by technology improvement

In his final remarks on exploring research and next-generation technology opportunities for hydrogen, there are several key frontiers as displayed in Figure 19, including the development of more efficient, lower-emission and cost-effective electrolysers such as PEM, AEM and high-temperature solid oxide systems, alongside emerging biotechnologies like microbial electrolysis, fermentation and enhanced biomass conversion. Advancements in fuel cell technologies (PEM, solid oxide, direct methanol and microbial fuel cells) as well as innovations in hydrogen storage such as unitized regenerative fuel cells were highlighted as critical areas for future progress. He also underscored the importance of strengthening carbon capture and conversion technologies and expanding socioeconomic research to better understand the impacts of hydrogen adoption. These efforts will require strong interdisciplinary and international collaboration as hydrogen deployment accelerates across industrial and transport sectors.

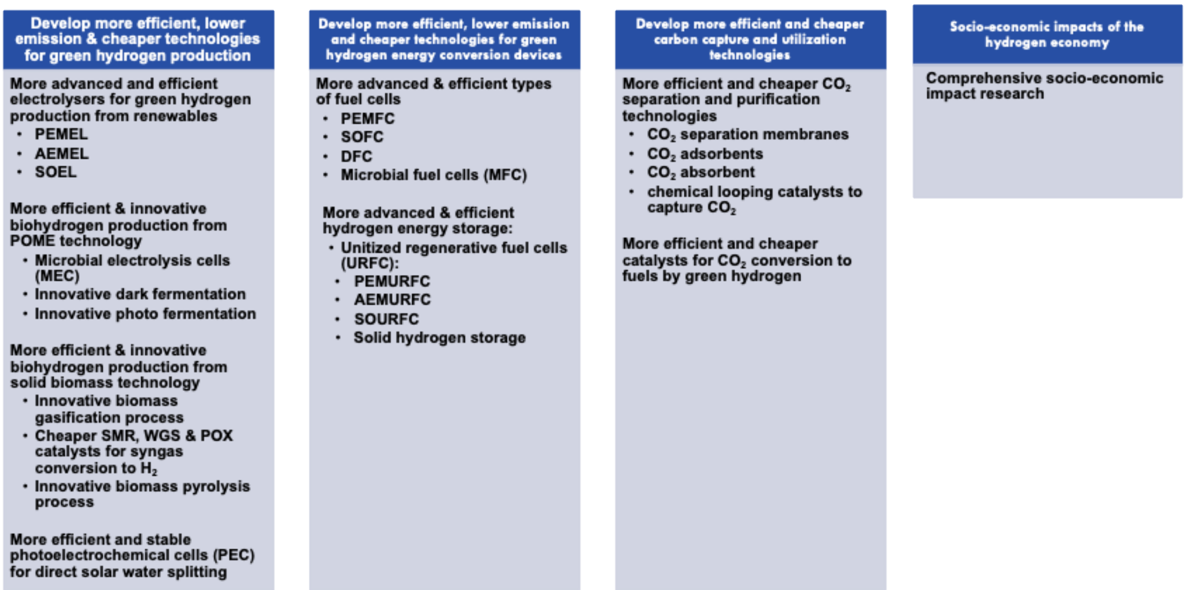


Figure 19: Research and development challenges for green hydrogen

6.3.5 Topic 5: The Peruvian Experience: Developing A Renewable & Low-Carbon Hydrogen Ecosystem

Keynote Address by Mr Fernando Maceda

Executive Director of H_2 Peru, The Peruvian Hydrogen Association, Peru

Mr Fernando Maceda shared insights into Peru's domestic direction for hydrogen development and its role in the global energy transition. He introduced H2 Peru as a nonprofit association established in December 2020, dedicated to promotes the decarbonisation of the economy through the use of renewable and low-emission hydrogen as a cornerstone of Peru's sustainable growth. The association's mission is to position Peru as a leader in the production and export of hydrogen and its derivative, driving economic growth while protecting the environment. H2 Peru currently involves over 70 corporate and strategic partners across key sectors representing the full hydrogen value chain, from production to application. The association also collaborates with international partners, including the International Energy Agency (IEA) and the World

Bank, to promote investment, technology transfer and capacity building in the hydrogen sector.

Mr Fernando elaborated on regional and local investment trends, as stated in Figure 20, the Americas invested approximately USD 450 billion in the energy transition in 2024, accounting for 22% of global investment despite political and policy uncertainties. The United States leads regional investment at USD 338 billion, followed by Brazil (USD 3.4 billion) and Canada (CAD 1.5 billion). He highlighted strong growth across key sectors as shown in Figure 21, where renewable energy expanded by 2.2%, grid investments increased by 10%, energy storage surged by 49% and electrified transport rose by 16% driven by tax incentive, power demand and electric vehicle adoption. Though carbon capture and storage (CCS), hydrogen and clean energy sector shows a declined due to the Inflation Reduction Act (IRA).

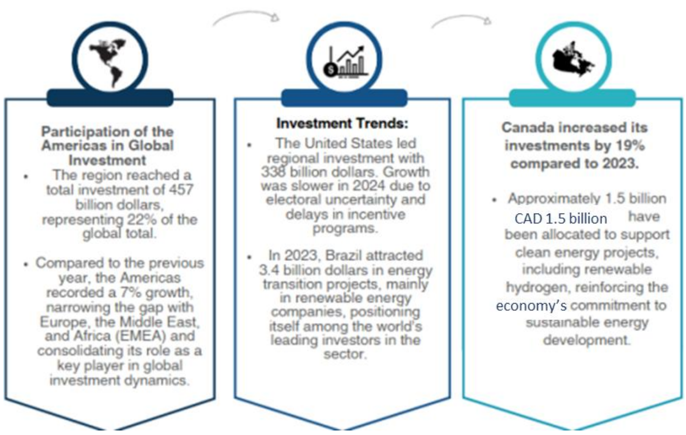


Figure 20: Americas energy transition investment

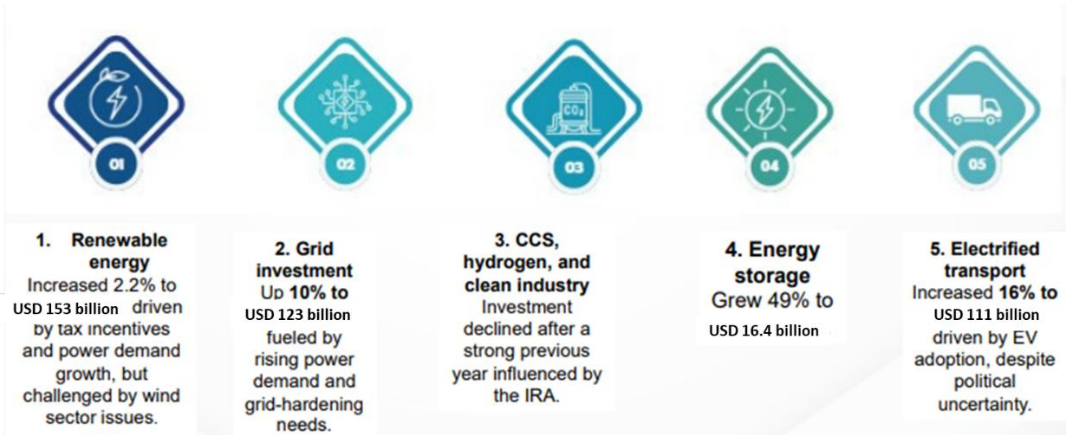


Figure 21: Investment performance based on sector in Americas

In current position, Peru's climate targets for 2030 are insufficient to align with 1.5°C pathway. Though, Peru has implemented policies targeting a net-zero emissions by 2050 according to the National Climate Change Strategy (ENCC). In Peru, emissions stem largely from land use, land-use change and forestry (LULUCF) at 43% and the energy sector (30%). The share of renewable energy in Peru has continued to increase (8–10% by 2024). Another key milestone in advancing Peru's climate agenda, on 8 April 2025, the Official Gazette El Peruano published the draft of Supreme Decree that approves the list of adaptation and mitigation measures that make up Peru's Nationally Determined Contribution (NDC).

In discussing Peru's Energy Transition and Clean Industry Initiatives, Peru is taking steps to improve system efficiency, expand renewable integration and reduce dependence on traditional fuel gas. The Camisea project, for example, has increased access to cleaner fuels, while liquefied petroleum gas (LPG) has replaced kerosene for domestic use across the economy. He noted that transport accounts for 41% of energy consumption, followed by industry and mining at 30%, commercial and public sectors at 25%. Hydrogen, therefore, plays a critical role in decarbonising these high-emission sectors. As displayed in Figure 22, there are five ongoing intiatives in Peru to promote energy transition: Peru's NDC for 2030, Just Energy Transition Initiative (JETI), promotion or renewable and low-emission hydrogen production, renewable energy target for 2030 and legal reform proposals for renewable energy.

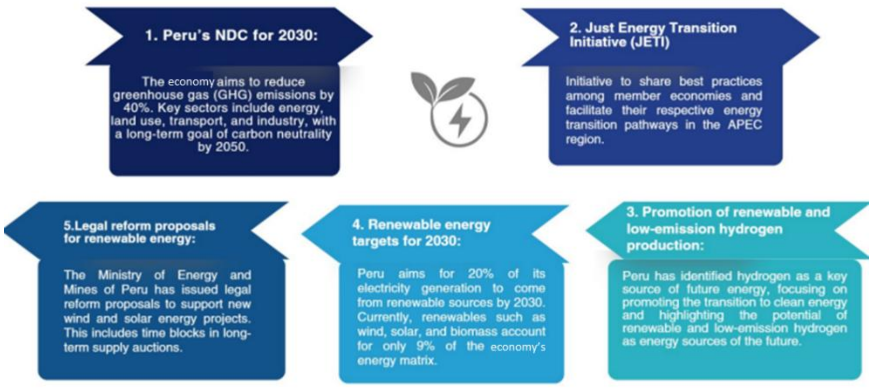


Figure 22: Ongoing initiatives to promote the energy transition in Peru

Peru's mining industry, a major energy consumer, stands to benefit significantly on critical mineral extraction from hydrogen usage in metallurgical processes, low-carbon explosives, drilling, heavy machinery and energy transition. Mineral transportation alone requires 5GW-7GW of new renewable capacity creating power synergy between mining and clean energy sectors and positioning Peru as a leader as next phase decarbonisation. He also highlighted that there is one of the world's oldest renewable hydrogen facilities in Cusco which is run by Industrias Cachimayo that currently produces certified green hydrogen for ammonia and mining applications in collaboration with Egie Energía Perú. Moreover, Peru's estimated renewable potential of hydro, wind and solar is 125.5 GW, which represents 9 times of the current installed capacity in the economy of 13.4 GW. This condition creates opportunity to produce low cost electricity, which translates into competitive hydrogen production costs as Peru's LCOH can fall to USD 1.6 – 2.6 /kg H_2 by 2050, depending on renewable mix and scale of deployment as shown in Figure 23.

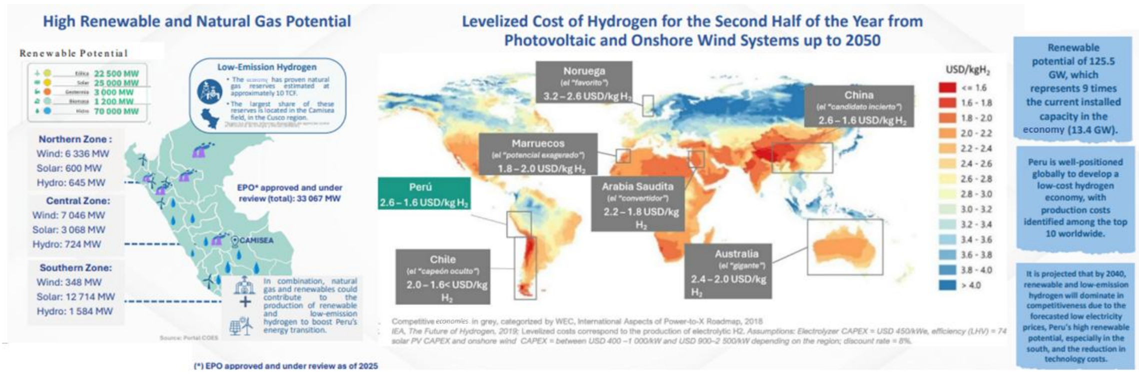


Figure 23: Renewable potential and hydrogen vision in Peru

Peru's momentum in hydrogen has gained international recognition, as Mr Fernando progresses his presentation. According to the 2025 H2LAC Index, Peru is classified among the "Fast Followers" in Latin America, advancing two positions compared to the 2023 edition. This progress reflects key milestone in Peru:

- Approval of the Law for Green Hydrogen Promotion;
- Active efforts by H2 Peru (in collaboration with the UK Embassy) to present a Proposed Regulation covering the full hydrogen value chain, including certification and export titles (12 regulatory chapters) ;
- Daniel Cámac (President of H2 Peru) won an H2LAC Industry Award in 2025 as "Hydrogen Energy Leader MVP" as recognition of leadership.

On governance, regulation and collaboration, Mr Fernando emphasised that Peru's hydrogen development is rooted in early with inclusive stakeholder engagement across government, industry and academia, which includes a proposal, framework and draft of Supreme Decree as presented in Figure 24. The development of hydrogen is possible with early involvement of stakeholders which enhances legitimacy and avoids conflicts, collaborative drafting that ensures technical soundness and social acceptance and transparency in the process which builds trust.

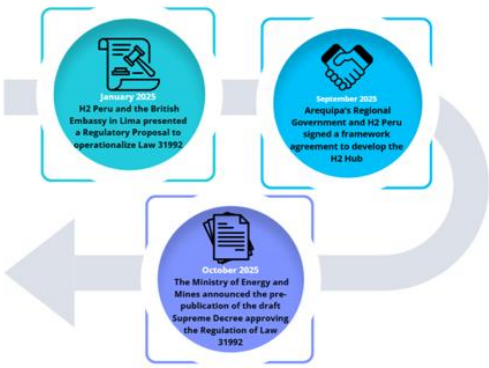


Figure 24: Stakeholder management to accelerate hydrogen deployment in Peru

Key milestones include the formation of a multi-sectoral hydrogen working group in April 2023, the enactment of the Green Hydrogen Promotion Law in March 2024, the creation of the Technical Standardisation Committee in September 2024 and the draft Supreme Decree in October 2025 as depicted in Figure 25. He also cited the Arequipa Hydrogen Hub as a model regional initiative that leverages Peru's abundant renewable resources, industrial demand and strategic port infrastructure to accelerate hydrogen deployment. International partnerships, including collaboration with the British Embassy, are instrumental in supporting Peru's regulatory frameworks, pilot projects and capacity-building programmes.

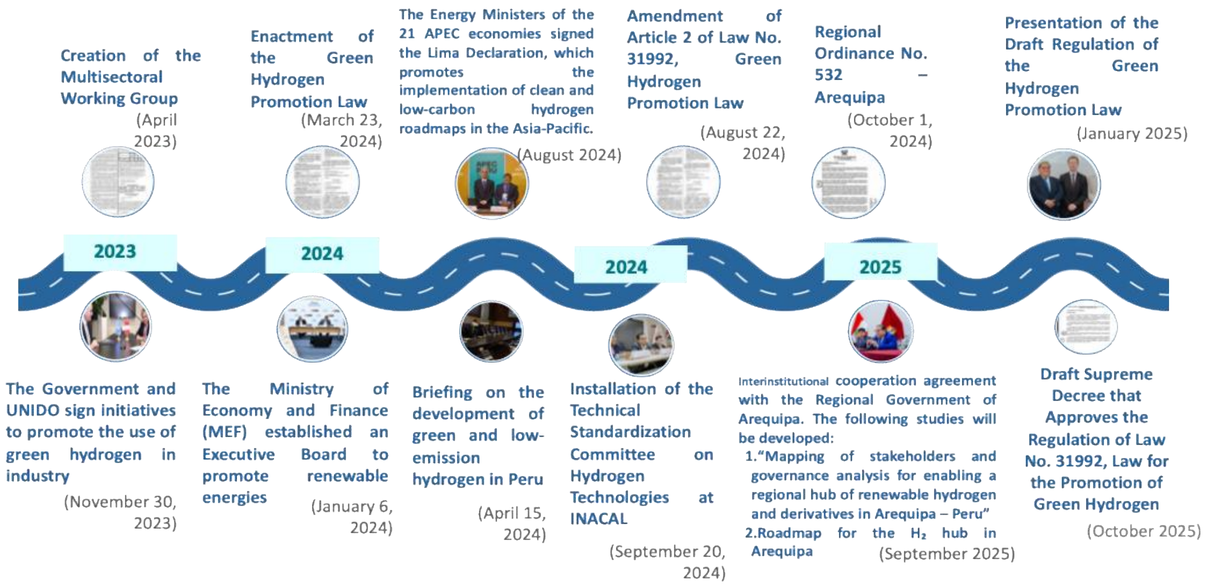


Figure 25: Peru's journey to hydrogen regulation

In closing, Mr Fernando underscored the importance of coordinated, transparent and collaborative governance to ensure that hydrogen development in Peru remains safe, inclusive and competitive. He reiterated that the hydrogen transition represents not only a technological shift but also an opportunity to foster sustainable economic growth, attract investments, industrial innovation and social inclusion across the Latin American region.

6.3.6 Topic 6: Solid State Hydrogen Ecosystem

Keynote Address by Dr Rezal Khairi Ahmad

Chief Executive Officer, NanoMalaysia Berhad, Malaysia

Dr Rezal Khairi Ahmad delivered an engaging keynote presentation introducing Malaysia's advancements in hydrogen technology and its journey towards a renewable energy future. He began by outlining NanoMalaysia Berhad (recently rebranded as NMB) as a key domestic agency driving the commercialisation of nanotechnology across various sectors, particularly energy and the environment. He shared that NMB's efforts are closely aligned with Malaysia's strategic local frameworks, including the National Graphene Action Plan and the Hydrogen Economy Technology Roadmap (HETR). One of the company's initiatives, the Hydrogen EcoNanoMY programme, focuses on designing, developing and deploying locally made hydrogen technologies. The Malaysia Hydrogen Industry Alliance (MHIA), a domestic platform for hydrogen was formed between government, innovators and industry players to facilitate Malaysia's commitment to achieve sustainable future and establishing itself as a leading regional player in the hydrogen economy through innovation, collaboration and technological self-reliance.

Malaysia has included renewable energy in their policies and plans since 2000 up until the most recent National Energy Transition Roadmap (NETR), launched in 2023 as shown in Figure 26. A few completed projects under NMB includes solid state hydrogen technology, AEM nanomembrane electrolyser and hydrogen generation through direct photochemistry. He further elaborated on the HETR, launched in 2023, which focuses specifically on developing Malaysia's hydrogen sector. The roadmap outlines the economy's strategic vision to build the necessary local infrastructure and strengthen domestic industry players. It also emphasises the importance of international collaboration to ensure Malaysia benefits from a sustainable and well-developed hydrogen ecosystem. The HETR targets on achieving cost competitive for hydrogen production, as low as USD 1/kg, whilst building hydrogen infrastructure, policies and incentives.

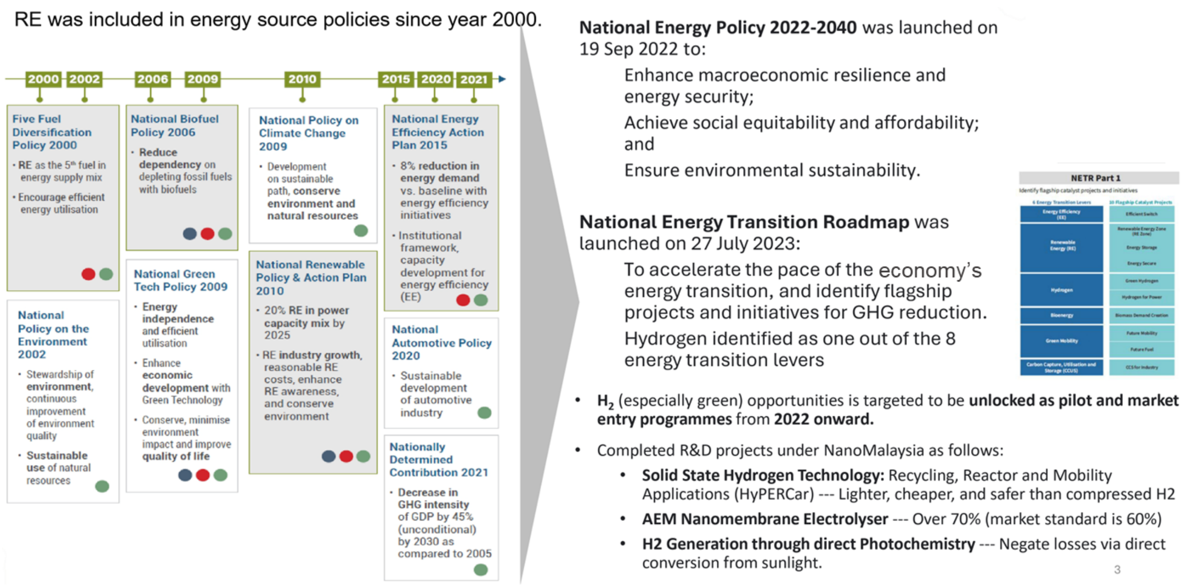


Figure 26: Malaysia's Energy Policies

The roadmap is structured into three implementation phases as shown in Figure 27, which are short-term (technology validation), mid-term and long-term as shown in Figure 27. It presents projections under two scenarios: the Business-as-Usual (BAU) scenario, which reflects outcomes in the absence of additional policy interventions and the Emission Division Scenario (EDS), which reflects the expected contributions from measures aimed at reducing carbon emissions. Dr Rezal highlighted that the roadmap's dual objectives encompass both economic growth and environmental sustainability, targeting up to MYR 500 billion in revenue by 2050 while substantially reducing carbon emissions.

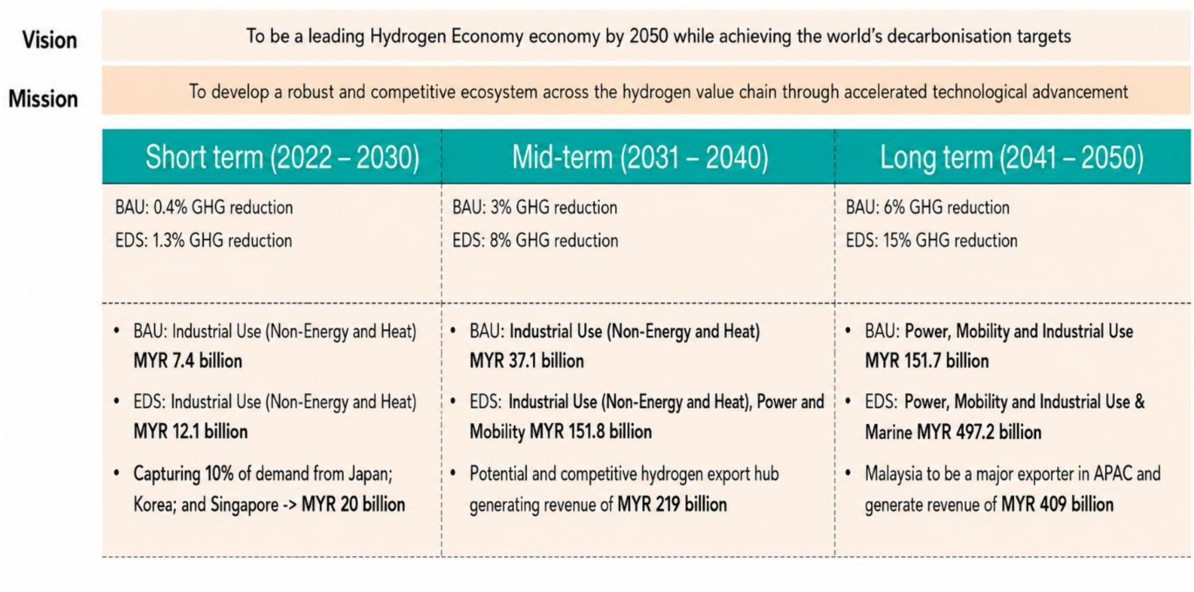


Figure 27: Malaysia's Hydrogen Economy Technology Roadmap (HETR) implementation phases

Measures should be taken to reduce dependency on imported materials, particularly from China, which currently dominates the global market. The key focus of Dr Rezal's address was solid-state hydrogen storage technology, a domain in which NMB has made significant progress. He compared different hydrogen storage methods, gaseous, liquid and solid-state as illustrated in Figure 28 and emphasised that solid-state hydrogen, particularly utilising sodium borohydride, offer major advantages in safety, efficiency and cost-effectiveness. Unlike high-pressure gaseous or cryogenic liquid storage, solid-state storage operates at safer conditions and more stable. NMB's HyPEReactor as demonstrated in Figure 29 employs sodium borohydride integrated with nanocatalysts and chemical stabiliser to produce in-situ and on-demand hydrogen through hydrolysis, supported by an innovative recycling process that enables a localised circular economy model. The system has achieved up to 3,000 recycling cycles, with industrial limit of 1,000 cycles, thus demonstrating its high durability and scalability potential. The recycling process collected sodium borate ($NaBO_2$) and convert it back to sodium borohydride ($NaBH_4$) with ball milling and rotary evaporation as illustrated in Figure 30.

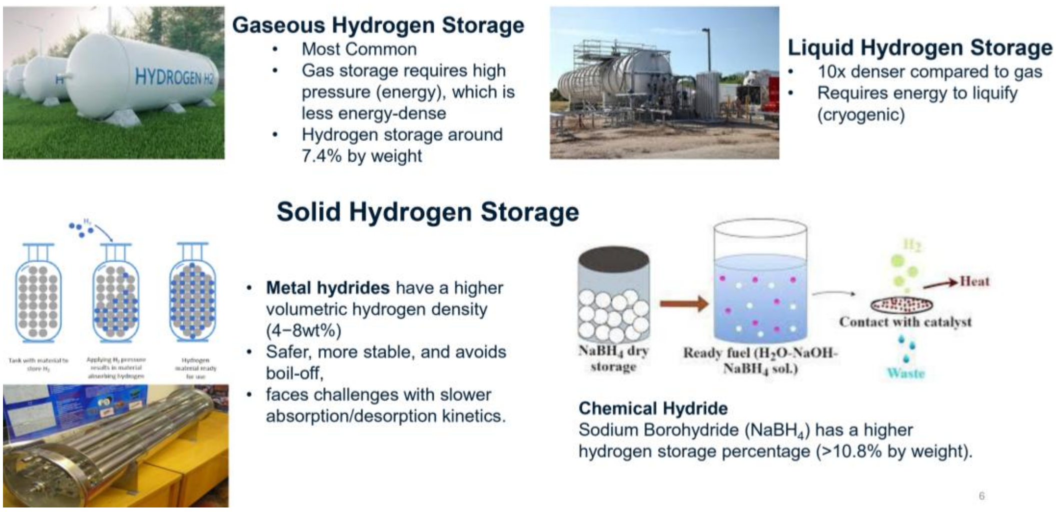


Figure 28: Hydrogen storage technology

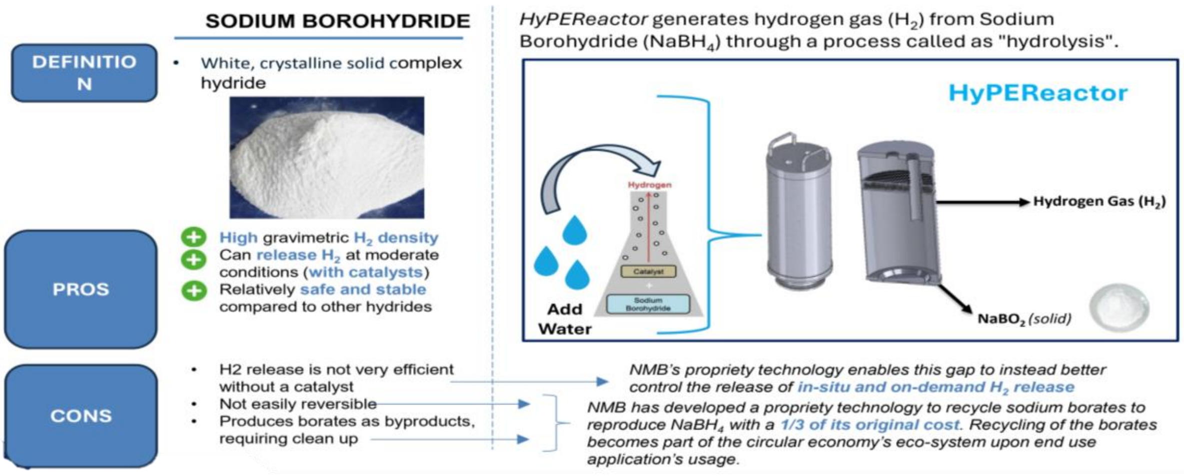


Figure 29: Solid state hydrogen – chemical hydrides using sodium borohydride

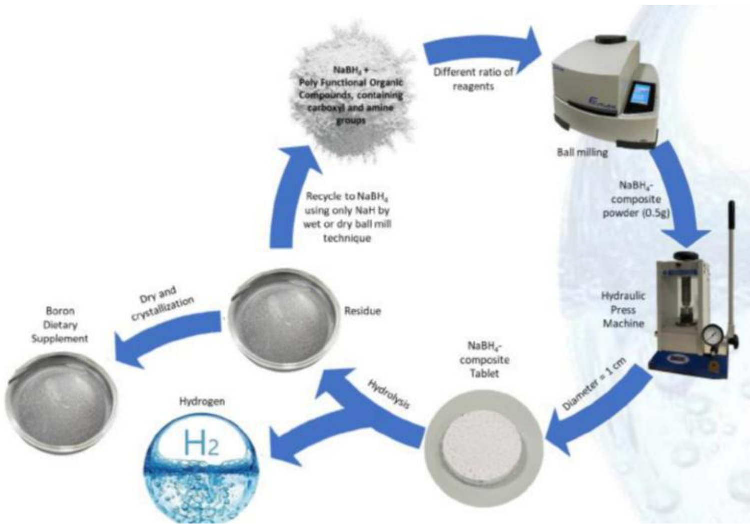


Figure 30: Recycle process of solid-state hydrogen

Dr Rezal further discussed pilot projects as demonstrated in Figure 31 where NMB's solid-state hydrogen systems have been deployed, including applications in mobility (such as hydrogen-powered buses, trucks, race cars and two-wheelers) and rural electrification projects for community hall in Pos Tibang, Perak and backup power generator in Kg Tekam, Johor. These initiatives not only support energy access and resilience but also replace diesel-based systems, contributing to emission reductions and local sustainability. Further research and development are being pursued for aerial applications such as small planes and drones.

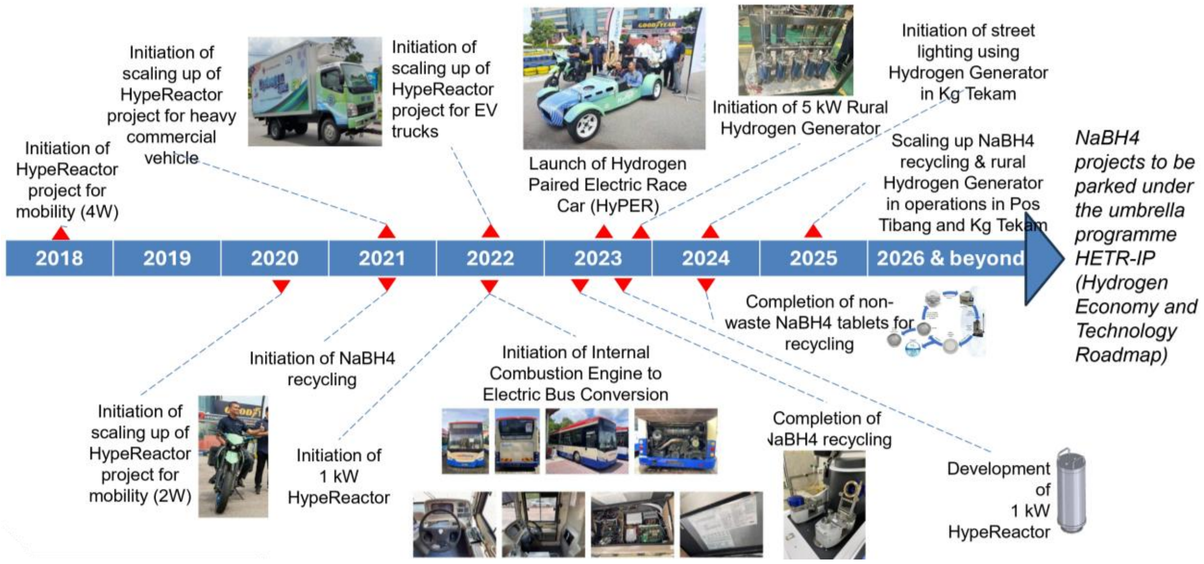


Figure 31: Existing and planned R&D projects by NMB

Looking ahead, Dr Rezal outlined future directions for NMB's hydrogen technology initiatives, which include scaling up recycling and compactification processes that is safe and stable for broader deployment across mobility and stationary energy systems. He noted that international collaboration remains vital, citing Turkey as a promising partner due to its extensive boron reserves, though China continues to be the dominant global supplier.

The techno-economic analysis for the solid-state hydrogen in Figure 32 showed higher initial values because the calculations were based on retail-scale prices. Details on the cost breakdown as follows:

- Recycled $NaBH_4$ can be produced at three times lower cost (USD 12.46/kg) than the current market price, reducing operating costs from USD 116.25/kg to USD 37.04/kg, though still above compressed hydrogen at USD 27.72/kg.
- Operating costs may be further reduced to USD 20.74 per kg of H_2 through lower raw material prices and industrial-scale production.
- At USD 20.74 per kg of $NaBH_4$, 1 kg of $NaBH_4$ produces 0.21 kg of H_2 and since 1 kg of H_2 delivers 33 kWh of energy, $NaBH_4$-based hydrogen systems can generate energy at USD 2.99/kWh.

However, costs decrease substantially when materials are purchased in bulk quantities, such as by the ton and can be further reduced through recycling processes. When adjusted to reflect large-scale procurement, the system becomes significantly cheaper than traditional energy options such as diesel generators or rooftop solar panels. Therefore, the system could achieve an electricity cost of MYR 0.17 per kWh, making it cost-competitive and more economical than conventional alternatives.

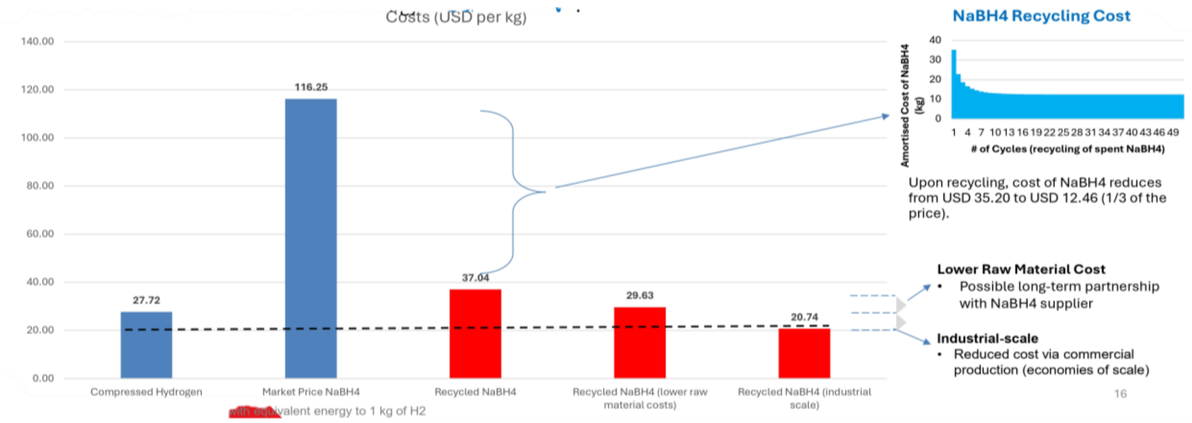


Figure 32: The projected cost of sodium borohydride with recycling and compression

In closing, Dr Rezal extended an invitation to both local and regional partners to explore collaboration opportunities in solid-state hydrogen technology development and deployment. He encouraged continued expansion of pilot projects to generate more operational and economic data, strengthening Malaysia's position as a technology developer rather than merely a consumer. He also stressed the importance of enhancing recycling capabilities for sodium borohydride to build a resilient local supply chain and reduce costs, alongside policy engagement to encourage government incentives for hydrogen commercialisation. Dr Rezal concluded by highlighting the value of public outreach and STEM engagement in building awareness and interest in hydrogen technologies, reinforcing Malaysia's vision to transition towards a sustainable, innovation-driven energy future.

6.3.7 Forum 1: Advancements in High-Efficiency, Low-Cost Green Hydrogen Production Technologies

The forum focused on exploring innovative pathways to accelerate the adoption of low-cost and high-efficiency hydrogen technologies. The session was moderated by Ir Dr Mubarak Wahab, Head of the Centre of Urban Resources Sustainability at Universiti Teknologi PETRONAS and featured three distinguished speakers: Mr Fernando Maceda, Executive Director of H2 Peru, Peru; Mr Danial Khairi Ahmad, Global Head of Hydrogen Projects at Gentari Sdn Bhd (also known as Gentari), Malaysia; and Dr Umi Karomah Yaumidin, Head of the Research Center for Behavioral and Circular Economics at BRIN, Indonesia. Each speaker brought valuable perspectives from their respective regions, highlighting current challenges, technological progress and collaborative opportunities in advancing hydrogen economies.

Technological Innovations Driving Efficiency and Cost Reduction

As Gentari advances on the development of water electrolysers and energy storage solutions to enhance the competitiveness of green hydrogen, the focus centred on identifying the most transformative technologies currently shaping the sector and understanding how these advancements are influencing production economics. The detailed responses from Mr Danial that followed outlined the key breakthroughs, their practical applications and their implications for the future scalability and affordability of green hydrogen.

Key points:

- Technological advances in electrolyser efficiency and manufacturability, such as high-temperature solid oxide systems and capillary-fed cells, are significantly improving hydrogen production efficiency up to 95%.
- Industrial symbiosis, particularly integrating hydrogen production with automation, utilisation of waste-heat, can reduce energy consumption and improve economics.
- Digitalisation, smarter control systems and preventive maintenance are crucial for operational reliability and lowering the levelised cost of hydrogen (LCOH).
- The need for quality control and due diligence to maintain uptime and achieve economic targets.

Drawing from the experience of H2 Peru, understanding the key factors that enables key industry players to innovate, in relation to efficiency and cost reduction. The points from Mr Fernando that follow summarise the key success factors, reflecting the approaches and priorities that support meaningful technological advancement in the sector.

Key points:

- Peru's experience emphasised adapting technologies to local conditions such as altitude and leveraging unique renewable resources, for instance the solar radiation and wind.
- Early-stage education, strong collaboration and public awareness are seen as critical for long-term adoption.
- Key success factors on the stable and predictable regulation, finance, human capital development and local and international collaboration.
- Knowledge sharing with industry and the public on the benefits, risks and key challenges of green hydrogen also helps align Peru's efforts in advancing its green hydrogen agenda.

Based on insights from ongoing research into Indonesia's green hydrogen landscape by Dr Umi, the focus was on the key barriers to reduce the production costs and technology innovation to achieve price parity with conventional hydrogen. The points that follow summarise the main issues shaping these cost dynamics in Indonesia context.

Key points:

- There is geographical challenge due to Indonesia's archipelagic geography with multi-level terrains limits wide adoption of green hydrogen, as it increases the production cost.
- There is consumer resistance to renewables and current landed costs are still higher than conventional alternatives.
- Green hydrogen production is currently limited to individual companies, supported by government incentives that allow them to purchase electricity directly from industry. Additional mechanisms, such as renewable energy certificates and carbon offset opportunities linked to clean energy, as well as tax holidays, further encourage investment and production.
- The carbon price remains too low, creating a bottleneck for progress and there is still no agreement among stakeholders on common standards and pricing measurement.

Scaling Up: Financing, Infrastructure and Regional Collaboration

H2 Peru is actively developing regional green hydrogen hubs, including its partnership with the Arequipa Regional Government, while promoting collaboration across various sectors strengthens the sustainable hydrogen value chain. The following points by Mr Fernando explored how multi-economy cooperation across APEC economies could enable a more integrated and connected hydrogen value chain, while also improving access to financing and support on the development of infrastructure.

Key points:

- Success in scaling up green hydrogen depends on structured collaboration and knowledge sharing between government, academia, industry and international partners, which lower risks for technology adoption.
- Shared infrastructure (e.g., ports, pipelines, storage), stakeholder mapping and governance and risk-sharing models attract investments.

BRIN engages government, industry and the public to address innovation, policy, economic and environmental challenges. Dr Umi highlighted emerging financial and partnership models across APEC member economies designed to mitigate investment risks.

Key points:

- Diverse experiences across APEC member economies indicate that innovative financial models and cross-border knowledge transfer can enable broader adoption and scale.
- Financial mechanisms such as contracts for difference, blended finance, public-private partnerships and involvement of multilaterals (e.g. World Bank) were discussed as ways to de-risk projects.
- Co-funding can reduce the risk in research and development with domestic development planning.
- Knowledge transfer and investment can occur with due diligence between two economies

Gentari is advancing green hydrogen through strategic partnerships, developing large-scale production hubs in India and Malaysia, exploring export opportunities and supplying industrial sectors. Key details shared by Mr Danial focused on strategies and financing mechanisms that support the transition of green hydrogen technologies from pilot projects to local and regional deployment.

Key points:

- Technology scale up depends on partnerships, finance and technology integration.
- Collaborative project structure, similar to business partnerships can distribute capabilities between supplier, technical knowledge and market access.
- Integrating multiple energy hubs can reduce costs per ton through shared infrastructure and resources.
- Innovative financing can leverage regional capital and corporations willing to assume hydrogen-related risks.
- Transparency, clear risk profiles, cost expectations, safety and clearly orchestrated partnerships are key to managing multi-party collaborations.

Policy Alignment, Human Capital and the Role of Behavioural Economics

Dr Umi outlined the policy frameworks, skills development programs and behavioural insights needed to support the hydrogen transition across APEC economies.

Key points:

- Gaps and variability in policy maturity and human capital readiness across APEC economies present opportunities for collaboration and capacity building.
- Develop skills through joint research, TVET programs and cross-sector collaboration.
- Social readiness can create new jobs and improve livelihoods, though inequalities remain across different communities.
- Coordinate policies at the leadership level across all economies.
- Data sharing, open dialogue and leveraging artificial intelligence (AI) for workforce and policy development were highlighted as tools for harmonising efforts across regions.

Mr Danial points out practical insights from the diverse APEC economies for regional collaboration, which can provide guidance on the collective approaches to hydrogen standards and workforce development.

Key points:

- Hydrogen economy across APEC economies are on different standards, definitions and skills. Diversity is good for learning network.
- Clean and harmonised definition are required for standardisation on carbon intensity and certification.
- Align policy with delivery reality streamlined across grid connectivity and land access.

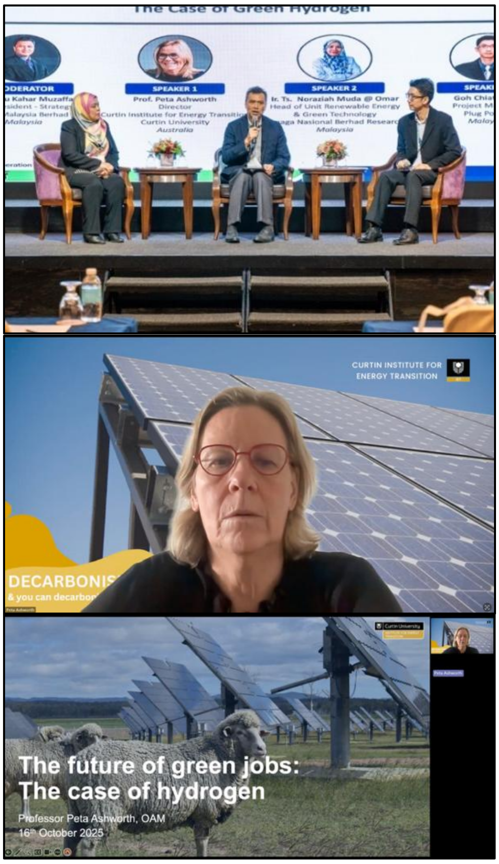
- Building integrated, cross disciplinary mindset and talent across technology, economics and project executions by collaborating with universities.

Ensuring inclusive and socially sustainable hydrogen strategies requires aligning education and industry training to develop the next generation of hydrogen professionals in APEC economies. The points highlighted on the approaches and best practices for achieving this alignment by Mr Fernando.

Key points:

- Hydrogen presents social opportunities when approached from a territorial perspective, with projects aligned to local development goals.
- Engage local suppliers, service providers and communities in logistics and other project activities.
- Provide communities with information and opportunities to participate through webinars and outreach programs.
- Education and training are essential to ensure a sustainable hydrogen economy and to nurture local talent.
- Hydrogen initiatives can contribute to emissions reduction, social inclusion, prosperity and equity for local communities.

6.3.8 Forum 2: Future Green Jobs: The Case of Green Hydrogen



The forum explored the evolving landscape of workforce development, social engagement and policy alignment needed to support Malaysia's transition toward a sustainable hydrogen economy. Moderated by Ir Tengku Kahar Muzaffar, Vice President of Strategy at NanoMalaysia Berhad, the session featured distinguished panelists: Professor Peta Ashworth, Director of the Curtin Institute for Energy Transition at Curtin University, Australia; Ir Noraziah Muda @ Omar, Head of Renewable Energy and Green Technology at TNB Research, Malaysia; and Mr Goh Chiat Wooi, Project Manager at Plug Power, Malaysia. Together, they discussed the multifaceted challenges and opportunities of building a future-ready green hydrogen workforce, establishing community trust and ensuring an inclusive and just transition.

Professor Peta Ashworth emphasised that securing a social licence to operate (SLO) is essential for public acceptance and long-term success of green hydrogen projects, as new infrastructure can affect local livelihoods and trigger community resistance if not managed well. Trust, transparency and early engagement are critical for project approval and preparing communities to participate in emerging hydrogen workforce opportunities. Governments and industry must work together to support rural and transitioning regions through clear communication, fair benefit-sharing and capacity-building.

Key points:

- SLO reflects ongoing acceptance from communities and stakeholders whose support directly affects project viability.
- New hydrogen and transmission infrastructure can disrupt livelihoods and trigger opposition if expectations and concerns are not addressed.
- Without SLO, projects face complaints, blockades and delays, as trust takes time to build and is easily lost.
- Acceptance is shaped by trust, procedural and distributional justice and local place attachment.
- Fair sharing of project benefits such as jobs, opportunities and social infrastructure helps strengthen community support.
- Provide clear, timely information without over-consultation to maintain trust and avoid fatigue.
- Early, place-based engagement is essential to understand local needs, build capacity and prepare communities for hydrogen-related jobs.
- Identify local leaders and ambassadors to support engagement and credibility.
- Maintain transparency throughout to manage expectations and reinforce trust.

Shifts in Talent Needs in Transition to a Hydrogen Economy

Ir Noraziah explained that Malaysia's transition toward a hydrogen economy is transforming the talent landscape. Tenaga Nasional Berhad (TNB) traditionally focused on thermal power, coal, gas and hydroelectric operations and their engineering capabilities have been heavily mechanical and electrical. As the company transitions from "electrons to molecules," new competencies are needed in hydrogen technologies, system integration, decarbonisation pathways and cross-disciplinary areas. TNB Research (TNBR) has been preparing for this shift since as early as 2015 through pioneering hydrogen utilisation projects involving hydrogen with CO_2 to produce e-fuels (methanol, methyl ethane), predating domestic roadmap, National Energy Transition Roadmap (NETR), announcements.

Key points:

- Green hydrogen viability depends heavily on low-cost, reliable renewable electricity, creating a new dimension of skill needs.
- Local workforce development is essential for large-scale projects such as the Tasik Kenyir dam hydro–hybrid floating solar plant with integrated hydrogen components.
- Creating demand for new job roles, deeper understanding of green electrons and workforce readiness for a more integrated hydrogen ecosystem.
- The hydrogen value chain requires multidisciplinary talent across engineering, economics, project execution and system integration.
- Research and development with reskilling and upskilling program to introduce engineers and manpower to new technology, understand the whole ecosystem of the hydrogen economy.

Mr Goh Chiat Wooi highlighted that Malaysia's growing green hydrogen industry requires a strong combination of conventional engineering competencies and cross-disciplinary soft skills. These skills support Plug Power's standardised yet customisable hydrogen products while ensuring structural integrity and operational safety.

Key points:

- Require technical skills similar to oil and gas industry: process, mechanical, electrical, instrumentation and control, civil/structural and piping.
- Ability to work with standardised solutions while customising according to client's requirements.
- Roles required: operations and maintenance (O&M), business development, project management, construction, commissioning/service teams.
- Soft skills: adaptability, communication, coordination, safety-consciousness.

Preparing Current and Future Workforces for Green Hydrogen Initiatives

TNBR is actively developing internal capacity through structured training, upskilling and strategic collaborations. This includes Hydrogen 101 courses across the organisation to build basic literacy in hydrogen technologies, from engineers to managers. Collaborations with Petronas, Japanese partners (e.g., IHI Corporation), local technology providers and international consultants help build technical and commercial understanding of global hydrogen markets and standards.

Key points:

- Training efforts include internal upskilling through TNB Integrated Learning Solution (ILSAS) and hydrogen literacy programs.
- Collaboration with universities and industries builds capability which covers the full hydrogen ecosystem, especially in areas such as hydrogen compression, piping, storage and lifecycle analysis.
- Engagement with international partners supports knowledge transfer.
- Mapping export requirements (Singapore, Europe) helps understand hydrogen standards, certification, emissions criteria and market expectations.
- Research and capacity development aim to ensure Malaysia understands both the technical and economic aspects of hydrogen deployment.

Mr Goh explained that Plug Power strengthens workforce readiness through a mix of theoretical learning, digital knowledge exchange and hands-on international training. While the core electrolyser engineering based in other countries support engineering functions.

Key points:

- Employees encouraged to take own initiative with online courses.
- Frequent virtual knowledge-sharing across the company's global team due to geographical dispersion.
- Hands-on training or practical exposure at their Viet Nam assembly facility (final assembly and factory acceptance testing).

- Exposure trips to the company's core technology centres to understand manufacturing process.
- Training for contractors and opportunities for site visits to enhance practical, safety-focused experience are highly encouraged.

Bridging Hydrogen Industry Demand in Attracting Talent to Green Hydrogen

Ir Noraziah highlighted the need for structured frameworks and partnerships to align talent supply with hydrogen sector requirements. Although Malaysia's hydrogen standards and training frameworks are still developing, coordinated action is underway within government, industry and academia to support future workforce readiness.

Key points:

- Australia's TAFE model illustrates how unified vocational and higher-education pathways can produce job-ready hydrogen talent.
- Malaysia's HETR and NETR frameworks recognise hydrogen as a cross-sector ecosystem involving energy, IT and industrial integration.
- Academic collaborations and state-level coordination help create local job opportunities and supply chains.
- Ensuring students and young engineers are future-ready is a priority as hydrogen becomes part of Malaysia's long-term energy strategy.

According to Mr Goh Chiat Wooi, the biggest barrier to attracting talent into Malaysia's hydrogen sector is project uncertainty with many hydrogen projects are still in the feasibility and financing stages. However, he emphasised that the sector offers rare and exciting opportunities, particularly as companies participate in "first-of-its-kind" initiatives such as delivering initial electrolyser systems for international markets.

Key points:

- Main challenge: project uncertainty (feasibility, CAPEX/OPEX modelling, financing issues).
- Malaysia's hydrogen initiatives largely export-oriented, limiting domestic readiness.
- Project delays or cancellations can demotivate teams and deter new talent.
- Opportunities include first-time project experiences and exposure to advanced renewable technologies, international standards and safety codes.
- Strong potential to attract oil and gas (O&G), manufacturing and IT talent due to transferable engineering skills.
- Ability to tap into growing sustainability motivations among younger and mid-career professionals.

7.0 IMPLEMENTATION PLAN

7.1 Interactive Session: Break-Out Focus Group Discussion For Policies & Strategies Recommendations

The Interactive Session: Break-out Focus Group Discussion (FGD) for Policies & Strategies Recommendations, led by Ir Dr M. Mubarak A. Wahab and co-led by AP Ts Dr Fawnizu Azmadi Hussin of Universiti Teknologi PETRONAS (UTP), served as a collaborative platform to identify key challenges, gaps and strategic interventions to accelerate green hydrogen development across APEC economies. Participants were divided into four thematic groups; Production Technologies, Ecosystem, Economic Viability and Network Building, where each facilitated by UTP experts and comprising multidisciplinary representatives from academia, industry, government agencies and research institutions.

Table 20: Participant break out for focus group discussion

Group 1 GH Production Technologies	Group 2 GH Ecosystem	Group 3 GH Economic Viability	Group 4 GH Network Building
Facilitator: AP Ir Dr Suriati Sufian **Assistant Facilitator:** Dr Husna Takaijudin **Rapporteur:** Yon Norasyikin Samsudin	**Facilitator:** Dr Hayyiratul Fatimah M Zaid **Assistant Facilitator:** Prof Dr Shameem Rafik-Galea **Rapporteur:** Farah Amelia Shahirah Roslan	**Facilitator:** Dr Nabila Farhana Jamaludin **Assistant Facilitator:** Dr Parvez Alam Khan **Rapporteur:** Dr Syaza Izyanni Ahmad	**Facilitator:** Dr Siti Nur Azella Zaine **Assistant Facilitator:** Dr Syed Emad Azhar Ali **Rapporteur:** Dr Raihan Mahirah Ramli
Participants			
1. AP Dr Mohd Shahbudin Bin Mastar @ Masdar 2. AP Dr Rozan Mohamad Yunus 3. Dr Chrisminder Dain 4. Dr Korakot Sombatmankhong 5. Dr Rezal Khairi Ahmad 6. Ir Ts Noraziah Muda @ Omar 7. Mr Naim Husni Latif 8. Mr Zainul Sham	1. AP Dr Wai Yin Wong 2. Dr Indra Al Irsyad 3. Dr Taib Iskandar Mohamad 4. Ir Tengku Kahar Muzaffar Tengku Mohd Yusof Anuar 5. Ir Ts Mohammad Za'im Azyze Mustapha Azyze 6. Mr Amirullah Bin Abdul Hadi 7. Mr King Anthony Ting	1. Mr Amir Othman 2. Dr Ali Samer Muhsan 3. Dr Azuraien Jaafar 4. Dr Umi Karomah Yaumidin 5. Dr Visarn Lilavivat 6. Mr Elijah Tamugo 7. Mr Goh Chiat Wooi 8. Ir Dr Nur Hidayati Othman 9. Mr Kong Eng Choo	1. Mr Benson Maul 2. Mr Danial Khairi Ahmad 3. Dr Hoang Anh Viet 4. Dr Lily Eurwilaichitr 5. Dr Luqman Yunos 6. Dr Nurul Asyikin Kamaruzaman 7. Mr Dwi Aji Darmawan 8. Mr Fernando Maceda

9. Mr Alpres Russel S. Bustillo 10. Mrs Yok Pee Tey 11. Prof Dato’ Ts Dr Kamaruzzaman Sopian 12. Ts Dr Mohd Nur Ikhmal Bin Salehmin 13. Ts Dr Nik Abdul Hadi Sapiaa @ Md Nordin 14. Mr Gao Haoyu 15. Prof Emeritus Dato’ Ir Dr Wan Ramli Wan Daud	8. Mr Surendran Kandasamy 9. Mrs Ana Georgina Terrazos Aguilar 10. Ms Nur Ruzanna Alias 11. Mr Peter Godfrey 12. Prof Dr Edy Herianto 13. Prof Junji Inukai 14. Mr Jack Zhang 15. Dr Ali Samer	10. Mr Vu Kim Hung 11. Mrs Paula Alexia Gonzalez Caceres 12. Mr Muhammad Izham Mohd Mokhtar 13. Ts Mohd Zubir Abdullah 14. Mr Vimal Rao Veerasamy 15. Mr Updeshraj Singh Bulvant Singh	9. Mr Ashley F. Rivera 10. Mr Fazary Azad Bin Abd. Latif 11. Ms Corinne Bonner Ribbons 12. Ms Ch’ng Phui Khan 13. Ts Dr Mohd Muzzammil Ismail 14. Mr Louis Loo

Overall, the FGD identified major barriers including renewable energy intermittency, high electrolyser costs, fragmented standards, policy misalignment, weak market demand and low public awareness. Participants proposed targeted incentives across the hydrogen value chain, phased transitions from blue to green hydrogen, talent development and stronger governance frameworks. Emphasis was placed on harmonising regional policies, enhancing R&D collaboration and establishing an APEC data hub to support coordinated implementation. Priority actions for the next five years include scaling emerging electrolyser technologies, developing domestic hydrogen master plans, strengthening academia–industry partnerships and forming specialised regional networks to accelerate technology transfer. These recommendations should be applied with due regard to the differing circumstances across APEC economies, as their relevance and sequencing will depend on each economy’s energy mix, industrial base, infrastructure readiness, policy maturity and cost structure.

7.2 Group 1: Green Hydrogen Production Technologies

Table 21: Group 1 – Green Hydrogen Production Technologies

Group 1	Green Hydrogen Production Technologies
Gaps & Barriers	1. Renewable Energy - Energy source Intermittency of RE - Technology maturity - Insufficient of RE capacity 2. Electrolyser - 70% source of electricity (OPEX) high cost - 30% on the systems - Efficiency – 60 to 70% - Technology maturity - No standard & certification in some APEC economies
Policy & Strategy Recommendations	1. Targeted incentives –across cluster for the whole GH value chain 2. Good governance 3. Awareness by included in early school syllabus 4. Facilitating enabling environment & economic instrument 5. Accelerating R&D and Commercialisation & Innovation (C&I) 6. Talent capacity development 7. Localised the value chain
Priority Action (Next 5 years)	1. Scaling-up SOEC/AEM up to 1 GW 2. Long term partnership. e.g. between academia & industry 3. Developing a master plan for APEC economies – e.g. Australia; People's Republic of China; Japan; and The Russian Federation 4. Short term : Enhancement of SOEC & AEM efficiency 5. Have more specific platforms among APEC economics

- **Gaps and Barriers**

The discussion within Group 1 highlighted several critical technological and operational barriers that currently constrain the scalability of green hydrogen production across APEC economies. A key challenge identified was the intermittency and insufficient capacity of renewable energy (RE) sources, particularly solar and wind, which form the backbone of green hydrogen generation. Although RE technologies are widely recognised as mature, their deployment remains uneven and inadequate in many economies, leading to unstable power supply for continuous electrolyser operation. This intermittency directly affects hydrogen production reliability, increases operational risk and requires costly energy storage or grid-balancing systems to stabilise output. Participants also observed that while RE technologies are advancing rapidly, their maturity levels vary significantly across APEC economies, resulting in uneven adoption and limited integration into hydrogen production systems.

Electrolyser-related challenges formed the second major cluster of barriers. Stakeholders noted that approximately 70% of the total operational expenditure (OPEX) for green hydrogen production is attributed to electricity consumption alone, with the remaining 30% linked to system components such as compressors, cooling systems, power electronics and balance-of-plant equipment. This cost structure underscores the sensitivity of hydrogen production to electricity tariffs, which differ widely among APEC members and often remain prohibitively high, thereby impeding commercial viability. Electrolyser efficiency, currently around 60–70% for most commercially available systems, was also cited as a limiting factor, particularly for economies operating in high-cost power markets. Furthermore, while PEM and alkaline electrolysers are considered technologically mature, solid oxide (SOEC) and anion exchange membrane (AEM) technologies are still under development, restricting opportunities for cost reduction through next-generation systems. The group also emphasised the absence of standardised certification schemes for electrolysers and hydrogen production technologies in several APEC economies, creating uncertainty for investors and complicating cross-border technology exchange.

- **Policy and Strategy Recommendations**

To overcome these barriers, Group 1 proposed a comprehensive set of policy and strategic interventions designed to strengthen the hydrogen production ecosystem. Central to the recommendations was the need for targeted incentives across the entire green hydrogen value chain, including production, storage, transportation and end-use applications. Such incentives would help reduce the cost of entry, stimulate early market demand and encourage companies to invest in local manufacturing and system integration capabilities.

Participants stressed the importance of good governance frameworks, including the development of hydrogen-specific standards, permitting guidelines and cross-economy certification systems that can harmonise regulatory approaches across APEC. Additionally, the group highlighted the need to foster public literacy and early-stage awareness by integrating hydrogen education into school curricula, enabling long-term capacity building and reducing societal resistance to hydrogen technologies. The creation of an enabling environment supported by strong economic instruments such as special tariffs for renewable-powered electrolysis, feed-in mechanisms and grants for technology deployment, was also emphasised as essential to strengthening investor confidence.

To accelerate technology development, the group recommended prioritising R&D, commercialisation and innovation (C&I) initiatives, particularly those focused on next-generation electrolysers and system integration with intermittent renewable sources. The development of talent pipelines and technical competencies was considered equally critical, with participants proposing structured training programmes, hydrogen-focused academic pathways and professional certifications. Finally, Group 1 encouraged the localisation of hydrogen value chains, including the manufacturing of critical electrolyser components and balance-of-plant systems, to reduce import dependence and build regional resilience.

- **Priority Actions for the Next Five Years**

Group 1 outlined several high-impact priority actions to be implemented over the next five years to accelerate the growth of green hydrogen production technologies across APEC economies. Foremost among these was the recommendation to scale up emerging electrolyser technologies such as SOEC and AEM from laboratory-scale prototypes to utility-scale systems of up to 1 GW. Such scaling would enable economies of scale, drive down system costs and validate performance under real-world operating conditions. Participants also highlighted the importance of establishing long-term partnerships between academia and industry, enabling collaborative R&D, workforce development, technology transfer and the commercialisation of innovations.

A central priority identified was the development of comprehensive local hydrogen master plans, taking inspiration from early movers such as Australia; People's Republic of China; Japan; The Russian Federation. These master plans should outline strategic priorities, investment roadmaps, technology pathways, workforce requirements and regulatory frameworks. In the short term, participants emphasised the need to enhance the efficiency and performance of SOEC and AEM technologies, focusing on durability improvements, catalyst optimisation and integration with renewable energy systems.

Finally, Group 1 recommended the formation of dedicated, specialised platforms among APEC economies, enabling continuous dialogue, joint research and coordinated planning on hydrogen production technologies. These platforms would serve as strategic enablers for knowledge exchange, policy alignment and collective problem-solving, strengthening APEC's leadership in the global hydrogen sector.

7.3 Group 2: Green Hydrogen Ecosystem

Table 22: Group 2 – Green Hydrogen Ecosystem

Group 2	Green Hydrogen Ecosystem
Gaps & Barriers	1. Technology/Infrastructure - Storage - Human capital - High OPEX and CAPEX 2. Standards/Regulations - Standardise Partnership – Import/Export 3. Awareness - Social acceptance - Access of knowledge 4. Economy - Market demand - Cost
Policy & Strategy Recommendations	1. Intensify R&D - Economies incentives 2. Subsidies Hydrogen

	- Carbon tax 3. Market creation - Create hydrogen research hubs centres to exchange knowledge 4. Enhancing human capital
Priority Action (Next 5 years)	1. Alignment KPIs – Energy mix 2. Clear Relations/Policies – In terms of demand, tariffs 3. International standardise policies – import and export

- **Gaps and Barriers**

Group 2 identified a series of interconnected barriers within the broader hydrogen ecosystem, with technology and infrastructure emerging as the most pressing challenges. Participants highlighted that existing storage technologies, including compressed hydrogen, liquefied hydrogen and hydrogen carriers such as ammonia and methylcyclohexane (MCH), remain costly, energy-intensive and technologically complex. Many APEC economies lack the infrastructure required for large-scale storage, distribution and end-use applications, limiting the ability to develop fully integrated hydrogen supply chains. The ecosystem is further strained by a shortage of human capital, with limited numbers of engineers, technicians, safety specialists and policy experts equipped with hydrogen-specific technical competencies. High CAPEX and OPEX continue to impede deployment, particularly in economies with underdeveloped renewable energy sectors or high electricity tariffs.

The group also identified significant gaps in standards and regulations, particularly in harmonised policies governing hydrogen import and export. Currently, economies operate with divergent safety codes, certification schemes and emissions accounting methodologies, creating barriers to cross-border hydrogen trade and limiting prospects for regional hydrogen corridors or supply chains. In terms of awareness, participants noted that social acceptance of hydrogen remains low in many APEC economies due to concerns about safety, limited public knowledge and lack of exposure to hydrogen applications. Public misperceptions further impede the deployment of hydrogen mobility, residential applications and industrial substitution.

From an economic perspective, weak market demand and cost competitiveness were cited as critical barriers preventing the development of a robust hydrogen ecosystem. Many industries remain reluctant to switch from established fossil-based technologies to hydrogen alternatives due to high costs, uncertain returns on investment, limited offtake agreements and the absence of strong government incentives. Without clear demand signals, markets remain underdeveloped, creating a cycle wherein infrastructure delays further hinder adoption.

- **Policy and Strategy Recommendations**

To address these ecosystem-level gaps, Group 2 proposed an integrated policy and strategy framework aimed at strengthening technological readiness, stimulating market growth and enhancing regional cooperation. A central recommendation was the need to intensify research and development (R&D) efforts, especially in storage, infrastructure integration and system optimisation. Participants stressed that government-led economic incentives including grants, R&D tax credits and concessional financing, are essential to catalyse innovation and support early-stage commercial deployment.

The group also recommended exploring hydrogen subsidies, particularly linked to carbon pricing mechanisms such as carbon taxes or emissions trading systems. These instruments would accelerate hydrogen's cost competitiveness relative to fossil-based alternatives and create stronger economic drivers for industrial adoption. Additionally, participants emphasised the importance of market creation strategies, including the establishment of hydrogen research hubs and innovation centres across APEC economies. These hubs would serve as platforms for open knowledge exchange, technology incubation, pilot project testing and cross-economy collaboration.

Strengthening human capital development was highlighted as a core strategic priority. Participants recommended structured capacity-building programmes, technical training modules, academic curricula enhancements and professional certification pathways to expand the skilled workforce needed to support hydrogen ecosystem deployment. Collectively, these recommendations aim to build a resilient, technology-driven and market-ready green hydrogen ecosystem across APEC.

- **Priority Actions for the Next Five Years**

Group 2 outlined several priority actions to guide ecosystem development over the next five years. First, participants emphasised the need to establish aligned key performance indicators (KPIs) across APEC economies, with particular focus on the energy mix, renewable integration levels and hydrogen adoption targets. These KPIs would provide a clear benchmark for progress, support coordinated policymaking and ensure economies remain on track toward their respective net-zero commitments.

The group also called for clear and coherent policy frameworks, especially relating to hydrogen demand creation, electricity tariffs for electrolysis and pricing structures for hydrogen-based products. Transparent policies would reduce investor uncertainty, accelerate infrastructure planning and support industry adoption. Finally, participants stressed the importance of developing internationally standardised policies for hydrogen import and export, enabling APEC economies to participate effectively in global hydrogen markets. Such harmonisation would facilitate cross-border trade, strengthen supply chain resilience and position the Asia-Pacific region as a coordinated hydrogen powerhouse.

7.4 Group 3: Green Hydrogen Economic Viability

Table 23: Group 3 – Green Hydrogen Economic Viability

Group 3	Green Hydrogen Economic Viability
Gaps & Barriers	1. Electricity Tariff - Producer of the green hydrogen will need to pay more depend on the tariff 2. Electrolyser Cost - Electrolyser needed to produce green hydrogen
Policy & Strategy Recommendations	1. Strengthen the ecosystem of green hydrogen implementation - Add more incentives in using green hydrogen - Special tariff for local use - Stakeholder: Ministry of Energy for APEC Economies, ASEAN Centre for Energy (ACE) 2. Start with blue hydrogen to unlock the demand and, increase economies of scale - To balance on the supply & demand. Once the demand is there, supply can be more - Stakeholders: Ministry, industrial players 3. Tax exemption for procurement of critical equipment Stakeholders: Import Export related Ministries (MIDA & MITI) for Malaysia
Priority Action (Next 5 years)	1. Make sure the demand is there 2. Start with blue hydrogen to unlock the demand and, increase economies of scale 3. Establish standards specific to hydrogen

- **Gaps and Barriers**

Group 3 identified several economic barriers that significantly constrain the commercial viability of green hydrogen across APEC economies. One of the most critical challenges is the high electricity tariff, which directly affects the cost of producing green hydrogen via electrolysis. Since electricity represents the largest operational expenditure in hydrogen production, producers in economies with high power tariffs face disproportionately elevated production costs. This makes green hydrogen uncompetitive relative to fossil-derived alternatives such as grey or blue hydrogen. Participants noted that tariff structures vary widely across APEC economies and in many cases, hydrogen producers are required to pay commercial or industrial rates without any preferential mechanisms. This results in green hydrogen production costs that are too high to attract early adopters or support industrial substitution.

The second major barrier relates to the high cost of electrolysers, which remain the most capital-intensive component of green hydrogen facilities. Whether PEM, alkaline, SOEC, or AEM, electrolysers require significant upfront investment and ongoing maintenance, making them cost-prohibitive for many emerging markets. The reliance on imported components, limited manufacturing capacity within the region and global supply chain constraints further drive-up costs. As a result, many industries hesitate to commit to hydrogen adoption due to uncertain returns on investment and the lack of established demand-side markets.

- **Policy and Strategy Recommendations**

To strengthen the economic viability of green hydrogen, Group 3 recommended a set of targeted policies designed to reduce production costs, stimulate market demand and stabilise the investment landscape. A primary recommendation was to strengthen the overall green hydrogen ecosystem by expanding incentive mechanisms and introducing special electricity tariffs for local hydrogen use. Such tariffs would lower production costs and encourage industries to adopt hydrogen-based solutions. Participants emphasised that ministries of energy within APEC economies, alongside organisations such as the ASEAN Centre for Energy (ACE), should play a coordinating role in developing regional incentive frameworks and aligning tariff structures.

A significant strategic recommendation was the adoption of a phased transition model, beginning with blue hydrogen deployment to unlock early market demand and achieve economies of scale. Participants stressed that without sufficient demand, the green hydrogen market cannot grow, regardless of technology readiness or policy ambition. By starting with blue hydrogen, industries can transition gradually, infrastructure can be optimised and supply-and-demand dynamics can stabilise before economies move toward fully renewable hydrogen. This approach requires close collaboration between government ministries and industrial stakeholders, particularly in sectors such as steel, ammonia, petrochemicals and transportation.

Group 3 also recommended implementing tax exemptions for the procurement of critical hydrogen-related equipment, such as electrolysers, compressors, storage tanks, power electronics and safety systems. These exemptions would significantly reduce capital expenditure and encourage faster deployment of production facilities. For Malaysia, relevant agencies such as MIDA and MITI were identified as key stakeholders, while equivalent import–export ministries across other APEC economies would be crucial in implementing similar incentive structures.

- **Priority Actions for the Next Five Years**

To ensure the long-term economic viability of hydrogen markets, Group 3 identified several priority actions that should be pursued over the next five years. The most urgent priority is to ensure that market demand for hydrogen is established and sustained, as demand is the foundation for scaling up production, reducing costs and justifying infrastructure investments. Without clear demand signals, whether driven by industry commitments, government procurement, or market regulations, hydrogen adoption will remain limited.

Participants reiterated the importance of beginning with blue hydrogen as a transitional pathway, enabling economies to unlock immediate demand, expand hydrogen infrastructure and cultivate industrial readiness while green hydrogen technologies continue to mature and decrease in cost. This phased approach would also enable economies to achieve early emissions reductions in hard-to-abate sectors while building momentum toward fully renewable hydrogen pathways.

Finally, Group 3 underscored the need to establish clear standards and regulations specific to hydrogen, including safety protocols, quality specifications, emissions accounting and certification frameworks. Harmonised standards across APEC economies would enhance investor confidence, facilitate cross-border trade and strengthen the region's position in the global hydrogen economy. These standards are essential to ensuring that hydrogen produced and traded within APEC is reliable, safe and aligned with international best practices.

7.5 Group 4: Green Hydrogen Network Building

Table 24: Group 4 – Green Hydrogen Network Building

Group 4	Green Hydrogen Network Building
Gaps & Barriers	1. Fragmented practices: • Noncentralised i.e. no standard definition/common language of hydrogen colours • Policies, data, structure, knowledge structure, funding availability 2. Low public acceptance and unsupportive government policy
Policy & Strategy Recommendations	1. Centralised digital hub for all related to H_2 2. Advertise benefits of adapting H_2 – public awareness program, fiscal incentive 3. Regulatory framework for networking 4. Strengthen governance at regional level 5. Promoting APEC members /economies involvement in global governance system (ISO, IPHE)
Priority Action (Next 5 years)	1. APEC to lead the effort via co-funded project between the economies, covering on R&D on technology development, public awareness program, policies development 2. Regulate international supply chain database 3. Success - Network secretariat development by APEC to promote inspired projects by sharing success stories & challenges

- **Gaps and Barriers**

Group 4 highlighted that one of the most significant challenges in advancing green hydrogen deployment across APEC economies is the fragmented nature of existing practices, governance structures and knowledge systems. Participants noted that there is currently no centralised platform that consolidates information, standards, or resources related to hydrogen, resulting in inconsistent definitions particularly regarding the hydrogen colour classification system and a lack of common technical language. This fragmentation extends to policies, data frameworks, institutional structures and funding mechanisms, where each economy operates largely in isolation, limiting opportunities for coordinated progress or shared learning. Without standardisation, economies face difficulties in aligning hydrogen strategies, benchmarking performance and establishing cross-border partnerships.

Another major barrier identified was low public acceptance, driven by limited exposure to hydrogen technologies and persistent concerns about safety, affordability and relevance. In many APEC economies, the general public has minimal understanding of hydrogen's role in energy transition, which slows adoption in sectors such as transportation, residential supply and commercial applications. Furthermore, in several economies, government policies remain unsupportive or insufficiently developed, leading to gaps in regulatory direction, funding prioritisation and cross-ministerial coordination. This policy uncertainty creates hesitation among investors and industries, hindering broader ecosystem development and regional cooperation.

- **Policy and Strategy Recommendations**

To overcome these barriers, Group 4 proposed a suite of region-wide policy and networking strategies aimed at fostering coherence, collaboration and shared momentum across APEC economies. A central recommendation was the establishment of a centralised digital hub that houses all hydrogen-related data, technical resources, standards, certification information and policy updates. This APEC-wide platform would create a unified knowledge architecture, enabling economies to access up-to-date information, share best practices and align their domestic strategies with regional priorities. The hub would also facilitate technology transfer, regulatory harmonisation and transparent monitoring of hydrogen development.

Public awareness emerged as another key priority area. Participants recommended that economies implement coordinated public education and outreach programmes to highlight the benefits, safety and economic value of hydrogen adoption. These campaigns could be supported by fiscal incentives, such as rebates or grants, to encourage early adoption by industries and consumers. The group further emphasised the need to develop a robust regulatory framework for hydrogen networking, ensuring that cross-border cooperation, data sharing and governance processes follow common rules and are supported by legally recognised structures.

Strengthening governance at the regional level was also highlighted as essential. Participants recommended that APEC play a more proactive role in convening economies, establishing joint task forces and ensuring sustained multilateral cooperation. In addition, APEC economies were encouraged to increase their participation and influence in global hydrogen governance bodies such as the International Organization for Standardization (ISO) and the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). This would ensure that APEC perspectives and requirements are reflected in the evolving global standards landscape.

- **Priority Actions for the Next Five Years**

Group 4 identified several strategic, high-impact actions to be pursued over the next five years to strengthen network building and regional integration. Foremost, participants recommended that APEC lead large-scale, co-funded initiatives involving multiple economies, focusing on hydrogen R&D, public awareness outreach, technological innovation and policy development. These projects would not only accelerate capacity building but also foster collective ownership and shared progress across the region.

The group also proposed the creation of a regulated international supply chain database to track hydrogen production, transport pathways, market flows, costs and technology availability. Such a database would enhance transparency, reduce duplication and provide critical intelligence for planning cross-border hydrogen trade and investments. It would also support supply chain resilience by identifying bottlenecks and opportunities for regional coordination.

Finally, Group 4 envisioned the establishment of an APEC Network Secretariat dedicated to promoting collaboration, sharing success stories and documenting the challenges encountered by member economies. This secretariat would serve as the central point of coordination for hydrogen-related initiatives, facilitating matchmaking among economies, supporting project replication and ensuring continuity of knowledge across leadership cycles. By institutionalising these collaborative mechanisms, APEC would play a transformative role in strengthening hydrogen governance architecture and elevating regional leadership in the global hydrogen ecosystem.

Conclusion

In summary, the Interactive Focus Group Discussion provided a structured mechanism to translate seminar insights into concrete, implementation-oriented strategies for advancing green hydrogen in APEC economies. Across the four thematic groups, namely Production Technologies, Ecosystem, Economic Viability and Network Building, participants converged on the need to address technological and infrastructure gaps, reduce production costs through targeted incentives and tariff reforms, strengthen regulatory and governance frameworks and build public trust and human capital. The outcomes underscore that green hydrogen deployment cannot be treated as a purely technological agenda; it must be supported by coherent policies, robust markets, regional cooperation and sustained multistakeholder engagement.

The collective recommendations from the FGD form a practical roadmap for the next five years, highlighting priority actions such as scaling up emerging electrolyser technologies, developing local hydrogen master plans, aligning standards and certification systems and establishing digital and institutional platforms for APEC-wide collaboration. These findings directly inform the policy directions and strategic recommendations presented in the subsequent section of this report and position APEC economies to play a leading role in shaping a sustainable, resilient and inclusive green hydrogen future.

8.0 POST-EVALUATION FINDINGS

A post-event evaluation survey was administered to assess the relevance, effectiveness and overall quality of the APEC PPSTI_101_2024 Seminar on Green Hydrogen. The feedback reflects strong satisfaction with seminar content, technical depth and alignment with APEC capacity-building objectives. Quantitative and qualitative findings are presented below.

8.1 Quantitative Results

Eight indicators were assessed using a five-point Likert scale. Numerical values were assigned from 1 (Strongly Disagree) to 5 (Strongly Agree). All indicators scored above 4.20.

Table 25: Summary of Participant Ratings

Evaluation Item	Mean Score	Interpretation
The objectives of the training were clearly defined	4.55	Very High
The project achieved its intended objectives	4.48	Very High
The agenda items and topics covered were relevant	4.58	Very High
The content was well organised and easy to follow	4.42	High
Gender issues were sufficiently addressed	4.21	High
Trainers and facilitators were well prepared and knowledgeable	4.67	Very High
The materials distributed were useful	4.52	Very High
The time allotted for the training was sufficient	4.36	High

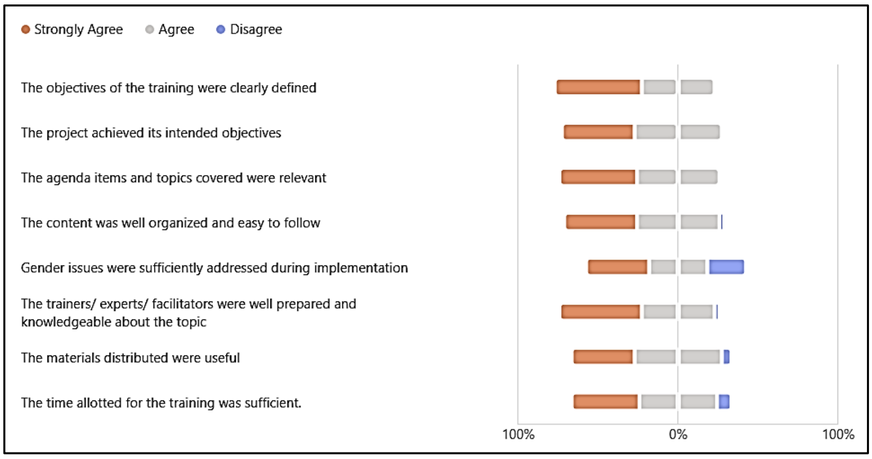


Figure 33: Consolidated distribution of participant responses across all eight post-evaluation indicators

8.2 Qualitative Feedback

Six themes emerged from thematic analysis of open-ended responses in the feedback form.

- **Theme 1: High Relevance to Economies and Job Functions**

Participants consistently stated that the seminar was directly applicable to their domestic priorities and professional roles.

Representative statements:

1. "Most of the discussion is very relevant to us."
2. "Green hydrogen plays a crucial role in decarbonisation and achieving net-zero targets."
3. "Very important for my work on hydrogen strategy development."
4. "Useful for understanding what other economies are doing in this space."

- **Theme 2: Significant Knowledge and Skills Gained**

Respondents highlighted the substantial knowledge gained from technology sessions, policy sharing and ecosystem presentations.

Representative statements:

1. "The seminar strengthened my knowledge and skills."
2. "Helpful to understand hydrogen within the circular economy context."
3. "I learned a lot, especially from the business model and policy parts."
4. "This gives me a better foundation to talk to agencies and industry players."

- **Theme 3: Policy and Strategic Insights**

Participants emphasised the value of insights for shaping local hydrogen roadmaps, regulatory enhancements and institutional alignment.

Representative statements:

1. "This will influence the development of domestic strategies."
2. "Useful for policy initiatives and workplans in my agency."
3. "I can use this to refine our local hydrogen policy discussions."
4. "Very relevant for institutional planning and long-term energy transition."

- **Theme 4: Collaboration and Regional Knowledge Exchange**

The programme was praised for enabling cross-border learning, networking and coordination among APEC economies.

Representative statements:

1. “Continue networking, especially with other economies.”
2. “Strengthens collaboration and knowledge exchange.”
3. “Good to hear from various APEC members on their hydrogen efforts.”
4. “Important platform for sharing and cooperation.”

- **Theme 5: Growing Interest in Technology and Technical Depth**

Participants expressed strong interest in hydrogen production technologies, cost structures and techno-economic methods.

Representative statements:

1. “My main interest is technology and research.”
2. “Would like more techno-economic focus.”
3. “Interested in technology cost breakdowns.”
4. “More detailed technical sessions would be helpful.”

- **Theme 6: Suggestions for Improvement**

While feedback was highly positive, several constructive suggestions were offered.

Key suggestions:

- Provide deeper techno-economic and cost-modelling content
- Expand participation from more APEC economies
- Provide additional pre-reading materials for technical preparation
- Invite more industry practitioners and technical experts

Representative statements:

1. “More techno-economic focus would improve the programme.”
2. “Include more participants from developed economies.”
3. “Invite more scientists and practitioners.”
4. “More detailed technical case studies would be useful.”

8.3 Overall Assessment

The evaluation results confirm that the seminar met or exceeded its objectives. Participants appreciated the relevance of topics, high-quality speakers and opportunities for cross-economy exchange. Knowledge gains were evident across technology, policy and ecosystem dimensions. Suggestions for enhancement will inform the design of future capacity-building programmes under PPSTI.

8.4 Implications for Future APEC Programmes

The findings indicate opportunities for strengthening future programmes:

1. Introduce advanced techno-economic modules.
2. Facilitate deeper discussions on regulatory harmonisation.
3. Expand participation across additional economies.
4. Provide structured pre-reading resources.
5. Continue integrating gender and inclusion aspects.

These insights support continuous improvement and align with APEC's long-term sustainability and innovation objectives.

9.0 SUMMARY AND RECOMMENDATIONS

To accelerate a low-carbon transition across APEC economies through the energy transition and circular economy pathways of green hydrogen, a coordinated set of strategic actions is essential. These recommendations reflect insights from keynote sessions, forums, expert interviews and the Focus Group Discussion (FGD), which collectively outlined the key areas for technology advancement, regulatory harmonisation, market readiness, capacity-building and regional collaboration.

Together, they form practical recommendations for scaling green hydrogen deployment, ensuring economic competitiveness and building an inclusive, skilled and future-ready workforce that supports a resilient and sustainable hydrogen ecosystem across the APEC region. These recommendations should be adapted to the varying circumstances of APEC economies, taking into account differences in domestic conditions, sectoral priorities, levels of readiness and broader transition pathways.

1. Accelerate Technology Innovation and Cost Reduction

    - Prioritise high-impact electrolyser innovations such as capillary-fed cells, high-temperature solid oxide systems and improved manufacturability to enhance efficiency and lower the levelised cost of hydrogen (LCOH).

    - Promote industrial symbiosis, integrating hydrogen production with automation, waste-heat recovery and digital monitoring systems to reduce energy demand and improve operational reliability.

    - Support adaptive technology deployment by recognising diverse local conditions. For examples, altitude, solar/wind and other renewable energy resources, or dispersed geographies including archipelagos.

2. Strengthen Policy Alignment, Standards and Regulatory Clarity

    - Develop harmonised definitions, standards and certification systems, especially for carbon intensity, emissions accounting and hydrogen purity across APEC economies.

    - Ensure predictable and stable regulatory frameworks to attract investment, support R&D and enable long-term industry planning.

    - Improve market mechanisms such as carbon pricing, contracts for difference, renewable energy certificates to support a viable green hydrogen market.

3. Expand Financing Pathways and De-Risk Investments

    - Leverage innovative financial models including blended finance, public–private partnerships and international development financing to reduce project and technology risks.

    - Promote co-funding mechanisms for R&D, linking domestic development planning with private-sector innovation.

- Enable cross-border investment and knowledge transfer through structured bilateral and regional partnerships.

4. Build a Competent, Multidisciplinary Hydrogen Workforce

- Develop technical competencies in process, mechanical, electrical, instrumentation and control and civil/structural engineering, drawing from transferable skills in O&G, manufacturing and power sectors.

- Strengthen multidisciplinary skills in systems integration, project execution, digital systems, economics, safety management and regulatory literacy.

- Create structured pathways through vocational schools, universities and industry to produce job-ready hydrogen talent through academic curriculum, research agendas and TVET modules across APEC economies.

- Increase exposure to global hydrogen standards, export requirements and certification to prepare workers for international market demands.

- Offer upskilling opportunities for all levels of career professionals, leveraging transferable engineering skills and sustainability motivations.

5. Foster Regional Collaboration, Knowledge Sharing and Joint Innovation

- Create knowledge networks for data sharing, technology standards, workforce mapping and policy benchmarking.

- Utilise AI-enabled analytics to identify skills gaps, model workforce needs and design harmonised policy solutions.

- Encourage structured collaboration between government, industry, academia and multilaterals to accelerate innovation and demonstrate scalable pilot projects.

- Support the development of regional hydrogen hubs to connect supply chains, reduce costs and attract investment.

6. Prioritise Social Licence to Operate (SLO) and Community Inclusion

- Engage communities early with place-based strategies that account for local development goals, livelihoods and context-specific concerns.

- Promote procedural and distributional justice, ensuring fair sharing of project benefits such as jobs, training and local economic participation across broader community context.

- Maintain transparent, consistent communication, ensuring communities receive accurate information without being overwhelmed.

- Identify and empower local leaders and ambassadors to build trust, credibility and long-term acceptance.

- Design hydrogen initiatives as social opportunity pathways, contributing to equity, inclusion, prosperity and social infrastructure in rural or transitioning regions.

7. Strengthen Technology Deployment and Scale-Up

- Prioritise commercial-scale pilots for next-generation electrolysers (e.g., capillary-fed, high-temperature solid oxide) to validate performance across diverse APEC environments.

- Integrate hydrogen production with existing industrial ecosystems using waste-heat recovery, digital monitoring and co-location strategies to lower operational costs.

- Establish hydrogen technology testbeds and demonstration zones to enable faster adoption, especially in economies at early readiness stages.

- Expand cross-economy R&D collaboration between industry, universities and research institutes to accelerate innovation and co-develop intellectual property.

8. Develop a Robust Hydrogen Ecosystem and Governance Framework

- Develop or update domestic hydrogen master plans outlining long-term needs for infrastructure, storage, logistics and safety frameworks.

- Harmonise safety standards, permitting requirements and certification systems across APEC to improve interoperability and reduce regulatory fragmentation.

- Strengthen governance structures with integrated permitting, environmental safeguards and hydrogen-ready infrastructure planning.

- Enhance public awareness, community engagement and social licence by providing clear, accessible and transparent information on hydrogen safety and benefits.

9. Enhance Economic Viability and Market Confidence

- Introduce targeted fiscal incentives, including tariff reforms, competitive grants and investment guarantees, to drive down hydrogen production and delivery costs.

- Implement demand-creation mechanisms such as offtake agreements, procurement programmes and industrial decarbonisation incentives.

- Develop regional cost-transparency and performance platforms to compare production economics, logistics pathways and technology trends across economies.

- Promote blended-finance models and public–private partnerships to de-risk early-stage investments and encourage market uptake.

10. Strengthen Regional Collaboration, Data Integration and Institutional Capacity

- Establish an APEC Hydrogen Data Hub to consolidate information on production, infrastructure, standards, certification and market flows.
- Develop a regulated APEC-wide hydrogen supply-chain database to map bottlenecks, track trade pathways and enhance supply-chain resilience.
- Create an APEC Hydrogen Network Secretariat to coordinate partnerships, matchmake projects, share best practices and ensure continuity across leadership cycles.
- Promote joint pilot projects, harmonisation of standards and multi-economy capacity-building programmes including training exchanges, technical missions and knowledge-sharing workshops.

Collectively, these recommendations provide a comprehensive and actionable framework for strengthening the green hydrogen ecosystem across APEC economies. By aligning technology development, policy coherence, financing mechanisms, human capital growth, regional collaboration and community engagement, member economies can accelerate the shift toward a low-carbon, inclusive and competitive energy future. Advancing green hydrogen through coordinated regional action will not only support emissions reductions and industrial transformation, but also create high-quality jobs, enhance energy security and unlock new economic opportunities that benefit communities across the APEC region.

10.0 CONCLUSION

The project "Advancing Energy Transition and Circular Economy in Building Up Capabilities to Net Zero/Carbon Neutrality: Advocacy and Stakeholder Management in Accelerating Green Hydrogen (PPSTI_101_2024)" was undertaken to strengthen the capacity of APEC economies in advancing green hydrogen technologies, value-chain development and strategic policy implementation. As the region progresses toward sustainable, low-carbon energy systems, green hydrogen presents a critical pathway to enhance energy security, diversify energy sources and support green-industrial growth. However, significant barriers, such as high production costs and storage limitations to fragmented safety frameworks, regulatory uncertainty, public awareness gaps and workforce shortages continue to hinder large-scale deployment. These challenges, intensified by varying levels of readiness across APEC economies, underscore the need for coordinated capacity building, shared knowledge platforms and harmonised efforts to accelerate progress.

Through a combination of desktop research, cross-economy surveys, expert interviews and a two-day seminar held in October 2025, the project consolidated key findings on technological trends, policy gaps, economic viability and ecosystem needs within the green hydrogen landscape. The seminar's keynote sessions and focus-group discussions generated valuable insights on production technologies, storage and transportation systems, market potential, safety protocols, skills shortages and transition pathways across the region. These inputs informed a set of high-level recommendations focused on accelerating innovation, aligning policy standards, expanding financing pathways, strengthening workforce competencies, fostering regional collaboration and embedding community engagement as a core component of hydrogen deployment.

The findings presented aim to guide policymakers, industry leaders, researchers and other stakeholders in designing effective strategies, investment mechanisms and cooperation models to advance the green hydrogen economy within APEC. By addressing capability gaps, promoting best practices and enabling evidence-based decision-making, the report supports the broader capacity-building agenda and enhances understanding of emerging trends, technologies and policy needs. The expected outcomes include strengthened regional knowledge, improved coordination among stakeholders and greater readiness for economies to scale up hydrogen production and integrate circular economy principles in the transition toward net-zero carbon neutrality.

Recognising the diversity across APEC economies is critical to ensuring effective and inclusive energy transition strategies. Variations in resource availability, infrastructure readiness, technological maturity and economic priorities mean that no single decarbonisation pathway can be universally applied. While green hydrogen presents strong potential, particularly in hard-to-abate sectors, its deployment must be considered alongside other low-carbon solutions such as electrification, energy efficiency and carbon capture technologies. Moving forward, APEC economies should adopt flexible, context-specific approaches that balance cost competitiveness, system integration and long-term sustainability to achieve net-zero ambitions.

Ultimately, the successful implementation of the project's recommended strategies, ranging from technological advancement and human-capital development to policy harmonisation and regional collaboration, this will position APEC economies as leaders in the green hydrogen sector. This contributes not only to advancing inclusive and sustainable growth but also to addressing climate change and supporting the global shift toward a net-zero emissions future.

REFERENCES

Albarrak, A. A., Sowilam, G. M., & Kawady, T. A. (2025). Hybrid renewable energy systems in Saudi Arabia: exploring solar-wind integration with fuel cell hydrogen storage. *Journal of Umm Al-Qura University for Engineering and Architecture*, *16*(2), 482-500.

Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance and initiatives. *Journal of urban technology*, *22*(1), 3-21.

Atilhan, S., Park, S., El-Halwagi, M. M., Atilhan, M., Moore, M., & Nielsen, R. B. (2021). Green hydrogen as an alternative fuel for the shipping industry. *Current Opinion in Chemical Engineering, 31*, 100668.

Australian Renewable Energy Agency (ARENA). (2022, March 1). *Building the next generation hydrogen service station in Geelong*. (Accessed 13 August 2025).

Australian Renewable Energy Agency. (n.d.). ARENA: Australian Renewable Energy Agency. Retrieved August 12, 2025, from https://arena.gov.au/

Barendregt, L., Bendor, R., & van Eekelen, B. F. (2024). Public participation in futuring: A systematic literature review. *Futures*, *158*, 103346.

Ben-Gal, I., Weinstock, S., Singer, G., & Bambos, N. (2019). Clustering users by their mobility behavioral patterns. *ACM Transactions on Knowledge Discovery from Data (TKDD)*, *13*(4), 1-28.

BloombergNEF. (2022, August 24). Hydrogen costs to fall as scale-up speeds up. https://about.bnef.com/blog/hydrogen-costs-to-fall-as-scale-up-speeds-up/

Borup, R., Krause, T., & Brouwer, J. (2021). Hydrogen is essential for industry and transportation decarbonization. *The Electrochemical Society Interface, 30*(4), 79–84.

California Air Resources Board (CARB). (n.d.). *LCTI: Zero-Emission Hydrogen Ferry Demonstration Project (Sea Change)*. (Accessed 13 August 2025). https://ww2.arb.ca.gov/zero-emission-hydrogen-ferry-demonstration-project

Cardullo, P., & Kitchin, R. (2019). Being a 'citizen'in the smart city: Up and down the scaffold of smart citizen participation in Dublin, Ireland. *GeoJournal*, *84*(1), 1-13.

Clean Energy Finance Corporation. (n.d.). Clean Energy Finance Corporation. Retrieved August 12, 2025, from https://www.cefc.com.au/

Council of Australian Governments Energy Council. (2019). *Australia's national hydrogen strategy*. Australian Government Department of Industry, Science, Energy and Resources. https://www.industry.gov.au/publications/australias-national-hydrogen-strategy

CSIRO. (2021). *National hydrogen research, development and demonstration roadmap*. https://www.csiro.au/en/research/technology-space/hydrogen/hydrogen-research-development-roadmap

DNV. (2023). Energy Transition Outlook 2023. DNV. https://www.dnv.com/news/2023/energy-transition-outlook-renewables-still-not-replacing-fossil-fuels-in-the-global-energy-mix-247880/

DNV. (2023). *Hydrogen forecast to 2050*. https://www.dnv.com/hydrogen-forecast-to-2050/

Fabled Sky Research. (2020, June 12). *Smart cities*. https://fabledsky.com/knowledge-base/smart-cities/

Ferro-Escobar, R., Vacca-González, H., & Gómez-Castillo, H. (2022). Smart and sustainable cities in collaboration with IoT: the Singapore success case. In *Machine learning for smart environments/cities: An IoT approach* (pp. 213-243). Cham: Springer International Publishing.

Fontes, T., Arantes, M., Figueiredo, P. V., & Novais, P. (2022). A cluster-based approach using smartphone data for bike-sharing docking stations identification: Lisbon case study. *Smart Cities*, *5*(1), 251-275.

Glenk, G., & Reichelstein, S. (2019). Economics of converting renewable power to hydrogen. *Nature Energy, 4*(3), 216–222. https://doi.org/10.1038/s41560-019-0326-1

Gracias, J. S., Parnell, G. S., Specking, E., Pohl, E. A., & Buchanan, R. (2023). Smart cities—a structured literature review. *Smart Cities*, *6*(4), 1719-1743.

Hydrogen Council & McKinsey & Company. (2023, December). *Hydrogen Insights: 2023 December Update*. (Accessed 13 August 2025).

Hydrogen Council. (2021). *Hydrogen Decarbonization Pathways: A Life-Cycle Assessment*. (Accessed 13 August 2025).

Hydrogen Council. (2023, December). *Hydrogen insights: 2023 update*. https://hydrogencouncil.com/wp-content/uploads/2023/12/Hydrogen-Insights-Dec-2023-Update.pdf

International Energy Agency (IEA). (2023). *Global Hydrogen Review 2023*. (Accessed 13 August 2025).

International Energy Agency. (2019). *The future of hydrogen: Seizing today's opportunities*. https://www.iea.org/reports/the-future-of-hydrogen

International Energy Agency. (2022). *Global hydrogen review 2022*. https://www.iea.org/reports/global-hydrogen-review-2022

International Energy Agency. (2023). *Global hydrogen review 2023*. https://iea.blob.core.windows.net/assets/618a0a87-0f8f-4fd1-b606-398696f71a23/GlobalHydrogenReview2023.pdf

International Energy Agency. (2023). *Towards hydrogen definitions based on their emissions intensity*. IEA. https://www.iea.org/reports/towards-hydrogen-definitions-based-on-their-emissions-intensity/executive-summary

International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). (2023). *Methodology for determining the greenhouse gas emissions associated with the production of hydrogen* (Working Paper, Ver. 3). https://www.iphe.net/iphe-wp-methodology-doc-jul-2023

International Renewable Energy Agency (IRENA). (2023). *Creating a Global Hydrogen Market: Certification to Enable Trade*. namgha.org

International Renewable Energy Agency. (2020). *Green hydrogen: A guide to policy making*. https://www.irena.org/publications/2020/Nov/Green-hydrogen

International Renewable Energy Agency. (2023, July). *Global hydrogen regulatory review 2023*. https://www.irena.org/Publications/2023/Jul/Global-hydrogen-regulatory-review

Japan Hydrogen Association. (2021). Hydrogen and fuel cell strategy roadmap in Japan. Japan Hydrogen Association (JH2A).

Marchesani, F. (2023). *The Global Smart City: Challenges and Opportunities in the Digital Age*. Emerald Publishing.

McKinsey & Company, & Hydrogen Council. (2021). *Hydrogen decarbonization pathways*. McKinsey & Company. https://www.mckinsey.com/capabilities/sustainability/our-insights/hydrogen-insights

Ministry of Economy, Trade and Industry. (2017, December 26). Basic hydrogen strategy. https://www.meti.go.jp/english/press/2017/1226_003.html

Moreno, R. (2023, March 30). Smart and sustainable cities: What does it mean? *bee smart city GmbH*. https://www.beesmart.city/en/smart-city-blog/smart-and-sustainable-cities-what-does-it-mean

Nam, T., & Pardo, T. A. (2011, June). Conceptualizing smart city with dimensions of technology, people and institutions. In *Proceedings of the 12th annual international digital government research conference: digital government innovation in challenging times* (pp. 282-291).

Norled. (2023). *MF "Hydra" — the world's first (liquid-hydrogen ferry)*. (Accessed 13 August 2025).

Oyadeyi, O. A., & Oyadeyi, O. O. (2025). Towards inclusive and sustainable strategies in smart cities: A comparative analysis of Zurich, Oslo and Copenhagen. *Research in Globalization*, *10*, 100271.

Przybyłowski, A., Kaszuba, A., & Suchanek, M. (2024). Smart and sustainable urban mobility-public and shared transport users' behavior in Gdynia city: a case study. *Transport Problems*, *19*(2).

Shahat Osman, A. M., & Elragal, A. (2021). Smart cities and big data analytics: A data-driven decision-making use case. *Smart Cities, 4*(1), 286–313. MDPI

Shan, Z., Zhang, Y., Zhang, Y., Tang, S., & Wang, W. (2021). A review of recent progress and developments in China smart cities. *IET Smart Cities*, *3*(4), 189-200.

Son, T. H., Weedon, Z., Yigitcanlar, T., Sanchez, T., Corchado, J. M., & Mehmood, R. (2023). Algorithmic urban planning for smart and sustainable development: Systematic review of the literature. *Sustainable Cities and Society*, *94*, 104562.

Tahar, L., & Nawel, A. (2023). Implementació de la plataforma Sentilo a municipis catalans: anàlisi i proposta per a Gavà.

Woods, O., Lim, A., & Kong, L. (2025). Sedimented surveillance in Southeast Asia's 'smart'city-state: the case of Singapore. In *Handbook on Cities and Crime* (pp. 468-482). Edward Elgar Publishing.

World Bank. (2022). *Enabling policies for green hydrogen in developing countries*. World Bank Group. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099730410312238297/p17794901462120570a6b023b3ff6c21a6b

APPENDICES

A. Speaker Biography

- **Peter Godfrey**

Peter is the Chief Representative for the Asia-Pacific region of the UK-headquartered Energy Institute (EI), based in Singapore. The EI represents a growing and diverse global community of energy professionals, working to accelerate the sector's transition towards a more sustainable future. Its mission is to:

1. Attract, develop and equip the future energy workforce;

2. Inform decision-making through expert convening and evidence-based insight;

3. Enable industry and consumers to make energy lower carbon, safer and more efficient.

Peter has a distinguished track record in the energy sector, having held senior positions in both upstream and downstream operations as well as strategy and energy finance with BP and Standard Chartered Bank. He is a committed advocate for cleaner, more resilient energy systems and the integration of sustainability into core industry practices.

In recent years, his focus has been on advancing the development of biofuels and engineered carbon sequestration. He served as the regional representative for UK-based CCUS and hydrogen developer Storegga before founding CarbonSync Technologies in late 2024, a Singapore-based company dedicated to the formation and consortium management of low-carbon industrial hub development projects across Southeast Asia and beyond.

- **Dr Umi Karomah Yaumidin**

Umi Karomah Yaumidin Ph.D is the Head of the Research Center for Behavioral and Circular Economics at Indonesia's National Research and Innovation Agency (BRIN). With over two decades of professional experience, she has led numerous local and international research projects on sustainable development, the circular economy and inclusive finance. Her current academic interest is directed toward exploring the application of carbon capture technologies to produce green hydrogen, which remains at an early stage of study. Dr Yaumidin has published extensively in peer-reviewed journals and policy reports and actively engages in global dialogues on sustainability and economic transformation. She is also a member of Indonesia's Committee for the

ISO 59000 series on circular economy. In addition, she actively participates in multidisciplinary research initiatives involving cross-ministerial collaboration, highlighting her role in advancing integrated approaches to energy transition, low-carbon innovation and the circular bioeconomy in Indonesia and beyond.

- **Prof Junji Inukai**

Professor Junji Inukai earned his BSc in 1987, MSc in 1989 and PhD in 1992 in Chemistry from the University of Tokyo, Japan. After working at Keio University and Tohoku University, he became a Full Professor at Clean Energy Research Center and Hydrogen and Fuel Cell Nanomaterials Center, University of Yamanashi in 2008.

His research interest covers clean energy, fuel cell and electrolyser materials, system analyses and instrument development. In 2021, he received Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Japan.

- **Prof Emeritus Dato' Ir Dr Wan Ramli**

Prof Dato' Ir Dr Wan Ramli Wan Daud is Emeritus Professor (2024-) at Department of Chemical & Process Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia. Career: Principal Research Fellow, University of Malaya (2022-2024), UKM-Petronas Professor of Sustainable Hydrogen Energy at Universiti Kebangsaan Malaysia (2019- 2021), Founding Director of the Fuel Cell Institute, Universiti Kebangsaan Malaysia (2007-2014), Professor of Chemical Engineering at Department of Chemical & Process Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia (1996-2021) and Principal Research Fellow at the Fuel Cell Institute, Universiti Kebangsaan Malaysia (2007-2021). Education: BEng degree (First Class Hon.) in chemical engineering from University of Monash, Victoria, Australia (1978) and PhD degree in chemical engineering from University of Cambridge, United Kingdom (1984). Professional Affiliations: Fellow of the Academy of Sciences Malaysia (2012-), Fellow of The World Academy of Sciences (2022-), Fellow of The Institution of Chemical Engineers (2007-), Founding President of the Malaysian Association of Hydrogen Energy (MAHE) (2018-2024), Professional Engineer with Practicing Certificate (PEPC) (1997-) and Chartered Chemical Engineer (CEng) (2007-). Strong advocate of hydrogen economy and led development of Roadmap of Hydrogen Energy and Fuel Cells Malaysia 2006 and Malaysia's Hydrogen Economy and Technology Roadmap HETR 2023. Awards: Won prestigious Merdeka Award 2016, the top Malaysia's science award. International Awards: World's Most Influential Scientific Minds. World's, top 1% scientists and Highly Cited Researcher 2015-2021 and World's top 2% Scientist 2019-2025. Won Award for Excellence in Research in Drying of Agricultural Products and the Outstanding Contribution to the Development of Drying Technology 2011, Outstanding Contribution to the Drying Community Award 2009, IChemE Highly Commended Shell Energy Award 2008 and ASEAN Energy Award 2007. Main Research Areas: green hydrogen energy from water splitting in photoelectrochemical cell (PEC), proton exchange membrane water electrolysis (PEMWE) and microbial electrolysis cell (MEC); proton exchange membrane fuel cells (PEMFC), solid oxide fuel cells (SOFC), microbial fuel cells (MFC) and direct methanol fuel cells (DMFC); solar, spray, drum, steam, microwave and fluidised bed drying; and history and philosophy of Malay & Islamic technology. Intellectual Property: Granted 30 patents and 1 Trademark. Publications: Published 432 articles in international journals, 402 articles in proceedings of international conferences and 235 articles in proceedings of local conferences. Up to 7 October 2025, he is cited in WOS 17,098 times with H-index 66; SCOPUS 19,628 times with H-index 72 and Google Scholar 26,332 times with H-index 81. International Keynotes: Invited to present 62 international plenary keynote and 10 invited papers on hydrogen energy, fuel cells and drying technology in People's Republic of China; Iceland; India; Indonesia; Iran; Japan; Malaysia; Netherlands; the Philippines; The Russian Federation; Singapore; Chinese Taipei; and Thailand. Local Keynotes: Invited to present 30 domestic plenary keynote papers.

- **Fernando Maceda**

Fernando Maceda is the Executive Director of H2 Perú, the Peruvian Hydrogen Association. He has a strong background in sustainability and energy transition, specialising in the design of strategies and management of projects focused on climate change mitigation and adaptation. His expertise also includes building multi-sector partnerships and engaging with key stakeholders to advance sustainable initiatives. Previously, he served as Sustainability Manager at Nestlé for Peru and Bolivia, where he led programs on environmental performance and corporate responsibility. He also held the position of Executive Director at AQUAFONDO, the Water Fund for Lima and Callao, promoting water security and nature-based solutions. Fernando is an environmental engineer with specialised studies in sustainability and is currently pursuing postgraduate studies in hydrogen technologies at the Pontifical Catholic University of Chile.

- **Prof Peta Ashworth**

Professor Peta Ashworth OAM is the Director of Curtin University's Institute for Energy Transition. She is a renowned expert in energy, communication, stakeholder engagement and technology assessment. Professor Ashworth has researched public attitudes towards climate and energy technologies, including wind, carbon capture and storage (CCS), solar photovoltaic, storage, geothermal and hydrogen, for almost two decades. An accomplished speaker and educator, she actively promotes energy literacy globally and contributes to policy briefings and educational events. Prior to joining Curtin University, Professor Ashworth was the Director of the Andrew N. Liveris Academy for Innovation and Leadership and Chair in Sustainable Energy Futures at The University of Queensland (UQ). She was also Chair of the Queensland Hydrogen Taskforce and is a member of CSIRO Hydrogen Mission Advisory Board. Professor Ashworth brings over thirty years' experience working in a range of senior management, consulting and research roles.

- **Danial Khairi Ahmad**

Danial Khairi Ahmad is a seasoned project delivery leader with over 28 years of experience across the energy value chain, spanning conventional oil & gas, deepwater FPSOs (Floating, Production, Storage and Offloading vessels) and large-scale new energy infrastructure including hydrogen, ammonia and carbon abatement technologies.

He currently serves as the Global Head of Projects for Hydrogen at Gentari, where he oversees multi-billion-dollar capital projects across Asia and North America. His portfolio includes full accountability for project execution, engineering, technology, procurement and HSE functions – supporting Gentari's mission to scale up green hydrogen as a cornerstone of the global energy transition.

Prior to joining Gentari in 2023, Danial was Head of Project Delivery and Engineering at Wood Group PLC (Malaysia), where he led project governance, technical assurance and execution for the regional E&C business.

From 2015 to 2023, Danial held various leadership roles at MISC Berhad, culminating as General Manager, Head of Topsides (Major Projects) within the Offshore Business Unit. He was a key figure in the company's successful bid and execution of the Mero 3 FPSO – MISC's first deepwater Gen-3 FPSO – and also pioneered marinisation of onshore technologies for offshore application, including gas-to-liquid and green ammonia processes.

Earlier in his career, Danial served as Head of Front-End / Field Development at Petrofac Malaysia, where he led the West Desaru Oil Field from concept through execution, commissioning and operational handover. His formative years included engineering roles at ExxonMobil, Technip, Aker and MMC Oil & Gas.

Danial is recognised for his ability to bridge deep technical expertise with strategic delivery leadership – enabling project outcomes that are not only on time and on budget, but also future-proofed and commercially resilient.

- **Dr Rezal Khairi Ahmad**

Dr Rezal Khairi Ahmad is the Chief Executive Officer of NanoMalaysia Bhd since June 2013. He possesses a PhD. in Nanotechnology, Electronic/Electrical Engineering from London Centre for Nanotechnology, University College London and Master's degree in Electrical Engineering from Tenaga Nasional University. He is an Adjunct Professor of Universiti Teknologi Malaysia. Recently, Dr Rezal has been designated as the President of Asia Nano Forum for the term 2024-2026. Under his tenure, Dr Rezal has successfully crafted the company structure and developed the business model and corporate positioning strategy relative to similar-minded government agencies and relevant industries. His current endeavours include Energy Storage, Renewables, Electric Vehicles, Hydrogen Economy and Biomass innovation. With his vast knowledge on technology and business and experience in hydrogen economy from involvement in projects, Rezal Khairi plays an important role by becoming the lead author as well as the Chief Consultant together with a group of authors on the H.E.T.R. (Hydrogen Economy Technology Roadmap) to the Malaysian government. He plays a leadership role in the "Build Some' part of the 'Build Some Buy Some' principle of H.E.T.R. covering electrolyser, solid state hydrogen storage and catalysts.

- **Ir Tengku Kahar Muzaffar**

Ir Tengku Kahar was appointed as Vice President, Strategy in January 2024. He is an active member involved in leading various consortium and associations that NMB was involved in such as the Swappable Battery System Consortium, ASEAN Battery Network, Malaysia Nanotechnology Industrial Group (MNIG) and Malaysia Hydrogen Industry Alliance (MHIA). He also initiated new battery development training programmes for the Hydrogen – EV - Battery Centre (HEBATT) to fulfil its role as a Centre of Excellence. Prior, he held the position of Vice President of Special Projects Office. Under his care, a number of major R&D project works were completed involving hydrogen technologies and EV's especially related to energy storage. He led the development of a white paper to convert ICE to EV that was approved by the Government in 2023 for JPJ and MOT to adopt. Prior to joining NMB, he was with the Ministry of Transport in the Strategic Planning and International Division, transferred after the dissolution of the Land Public Transport Commission (SPAD) in 2018.

- **Ir Noraziah Muda @ Omar**

Ir Noraziah Muda is the Head of Decarbonisation and Renewable Energy Centre, TNB Research, the research subsidiary of Tenaga Nasional Berhad, TNB. Her responsibilities include leading and driving the overall strategy for R&D and services in the field of renewable and green technologies which provide overall decarbonisation solutions from power generation up to interconnection to TNB Network.

Her expertise is on the green energy transition projects such as Carbon Capture and Utilisation (CCU), where she works on the potential of converting CO2 from power plants into useful commodities for other industries, in conformance to the Circular Economy framework. Her other area of expertise is green hydrogen production and use. She has also been highly involved in the research and development of renewable energy projects, such as grid-connected floating solar PV system design, PV system performance and reliability improvement, emerging solar PV technology, waste to energy and low-speed wind technology and others. Her works have been published in numerous technical publications.

She is the technical committee of many working committees under Jabatan Standard Malaysia, MOSTI, SwCorp and TNB. She is also the technical reviewer of local and international journals and currently serves as an external examiner for Higher Learning Institutes in Malaysia.

- **Goh Chiat Wooi**

Born in the small northern Malaysian town of Alor Setar, Mr Goh Chiat Wooi completed his Bachelor's degree in Electronics Engineering (majoring in Bio-Instrumentation) at MMU, Melaka Campus. In his free time, he enjoys jogging as a way to relieve stress.

He began his career in September 2008 as a commissioning engineer in natural gas power plants, which gave him the opportunity to travel the world, often blending into local cultures and living like a local. This continued until 2016, when he decided to settle down in Malaysia.

He had the valuable opportunity to gain exposure to the hydrogen industry back in 2022, which ultimately led him to his current role at Plug Power. Over the past three years, he has had the privilege of serving as a Project Manager, earning the trust to deliver our 1MW Electrolyser systems to clients across the APAC region — including projects in Australia; Republic of Korea; and New Zealand.

These experiences have shaped his passion for the Hydrogen industry, especially with Proton Exchange Membrane (PEM) technology and he is looking forward to contributing further to this field.

B. Event Flow Tentative

Day 1 — 15 Oct 2025 (Wednesday)		
Time	**Session / Topic**	**Speaker / Role**
8.00 am	Arrival & Registration	—
9:00 am	Welcoming Remarks	**Imran Abdul Kadir** Vice President, Strategy, Sustainability & Transformation Universiti Teknologi PETRONAS Malaysia
9:10 am	Opening & Officiating Remarks	**YBhg. Datuk Seri Hj. Hasnol Zam Zam Hj. Ahmad** Secretary-General Ministry of Science, Technology & Innovation (MOSTI) Malaysia
9:20 am	Context Setting	**Prof. Ts. Dr. Shahrina Md Nordin A.C.M., FASc, FEI** Project Overseer, APEC Project PPSTI_101_2024 Director, Institute of Smart & Sustainable Living (ISSL) Universiti Teknologi PETRONAS Malaysia
9:30 am	APEC Energy Perspective 2025: Green Hydrogen Outlook	**Assoc. Prof. Ir. Dr. Suriati Sufian & Dr. Syaza Izyanni Ahmad** Researchers Institute of Smart & Sustainable Living (ISSL) Universiti Teknologi PETRONAS Malaysia
10:00 am	Morning Tea Break	—
10:15 am	**Topic 1:** Green Hydrogen: A Catalyst for Circular Growth across the APEC Region	**Peter Godfrey** Managing Director APAC Energy Institute Singapore
11:15 am	**Topic 2:** Synergizing Circular Economy & GH: Pathways for Supply, Demand, & Policy	**Dr. Umi Karomah Yaumidin** Head of Research Center for Behavioral & Circular Economics National Research & Innovation Agency (BRIN) Indonesia

Day 1 — 15 Oct 2025 (Wednesday)		
Time	**Session / Topic**	**Speaker / Role**
12:15 pm	**Topic 3:** Green Hydrogen Production & Utilization in Japan: Nationally & Locally	**Prof. Junji Inukai** Clean Energy Research Centre Hydrogen & Fuel Cell Nanomaterials Center University of Yamanashi Japan
1:15 pm	Lunch	—
2:30 pm	**Forum 1:** Advancements in High-Efficiency, Low-Cost Green Hydrogen Production Technologies	**Moderator:** **Ir. Dr. Mubarak Wahab** Head Centre of Urban Resources Sustainability Universiti Teknologi PETRONAS Malaysia **Speaker 1:** **Fernando Maceda** Executive Director of H_2 Peru The Peruvian Hydrogen Association Peru **Speaker 2:** **Danial Khairi Ahmad** Global Head Projects of Hydrogen Gentari Sdn. Bhd. Malaysia **Speaker 3:** **Dr. Umi Karomah Yaumidin** Head of Research Center for Behavioral & Circular Economics (BRIN) Indonesia
4:00 pm	Afternoon Tea Break	Post-Seminar Evaluation Survey
4:15 pm	**Topic 4:** Green Hydrogen Development: Challenge & Path	**Prof. Emeritus Dato' Ir. Dr. Wan Ramli Wan Daud** Fellow, Academy of Sciences Malaysia President, Malaysian Association of Hydrogen Energy Malaysia
5:15 pm	Concluding Day 1	—

Day 2 — 16 Oct 2025 (Thursday)		
Time	**Session / Topic**	**Speaker / Role**
8.00 am	Arrival & Registration	—
9:00 am	APEC Energy Perspective 2025: Green Hydrogen Outlook	**Assoc. Prof. Dr. Amjad Shamim** Researcher Institute of Smart & Sustainable Living (ISSL) Universiti Teknologi PETRONAS Malaysia
9:15 am	**Topic 5:** The Peruvian Experience: Developing a Renewable & Low-Carbon Hydrogen Ecosystem	**Fernando Maceda** Executive Director of H_2 Peru The Peruvian Hydrogen Association Peru
10:15 am	Morning Tea Break	—
10:30 am	**Forum 2:** Future Green Jobs: The Case of Green Hydrogen	**Moderator:** **Ir. Tengku Kahar Muzaffar** Vice President - Strategy NanoMalaysia Berhad Malaysia **Speaker 1:** **Prof. Peta Ashworth** Director of Curtin Institute for Energy Transition Curtin University Australia **Speaker 2:** **Ir. Noraziah Muda @ Omar** Head Renewable Energy & Green Technology TNB Research Malaysia **Speaker 3:** **Goh Chiat Wooi** Project Manager Plug Power Malaysia
12:15 pm	**Topic 6:** Solid State Hydrogen Ecosystem	**Dr. Rezal Khairi Ahmad** Chief Executive Officer NanoMalaysia Berhad, Malaysia
1:15 pm	Lunch	—

Day 2 — 16 Oct 2025 (Thursday)		
Time	**Session / Topic**	**Speaker / Role**
2:30 pm	**Interactive Session:** Break-out FGD for Policies & Strategies Recommendations	**Lead Facilitator:** **Ir. Dr. M Mubarak A Wahab** Universiti Teknologi PETRONAS Malaysia **Co-lead Facilitator:** **Assoc. Prof. Ts. Dr. Fawnizu Azmadi** Universiti Teknologi PETRONAS Malaysia
4:30 pm	Afternoon Tea Break	Post-Seminar Evaluation Survey
4:40 pm	Closing Remark	**Prof. Dato' Ir. Ts. Dr. Mohamed Ibrahim Abdul Mutalib** Provost & Chief Academic Officer Universiti Teknologi PETRONAS Malaysia
5:00 pm	Adjourn & Concluding Day 2	—

D. Visual Highlights of the Seminar


Asia-Pacific Economic Cooperation
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ADVANCING ENERGY TRANSITION AND CIRCULAR
BUILDING UP CAPABILITIES TO NET ZERO/CARBON
ADVOCACY AND STAKEHOLDER
ACCELERATING GREEN
15-16 October 2025
Concorde Hotel, Kuala Lumpur, Malaysia
Prof. Dato'
CONCORDE HOTEL
KUALA LUMPUR


Evolution of Hydrogen & its Colour Codes


Steel Indust
95%
plants
CONCORDE HOTEL
KUALA LUMPUR
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Research Framework


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ZARA


PEAKERS


UNIVERSITI
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SPEAKERS


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Double A


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