Asia-Pacific Tech Monitor

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Green Hydrogen Technologies

Opportunities and Challenges for the Asia-Pacific Region

ESCAP
APCTT
Asian and Pacific Centre for Transfer of Technology

*The shaded areas of the map indicate ESCAP members and associate members.**

The Economic and Social Commission for Asia and the Pacific (ESCAP) is the most inclusive intergovernmental platform in the Asia-Pacific region. The Commission promotes cooperation among its 53 member States and 9 associate members in pursuit of solutions to sustainable development challenges. ESCAP is one of the five regional commissions of the United Nations.

The ESCAP secretariat supports inclusive, resilient and sustainable development in the region by generating action-oriented knowledge, and by providing technical assistance and capacity-building services in support of national development objectives, regional agreements and the implementation of the 2030 Agenda for Sustainable Development.

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Foreword

Green hydrogen has emerged as a promising opportunity for climate change mitigation and sustainable development, given its crucial role in reducing greenhouse gas emissions. Produced by splitting water into hydrogen and oxygen using renewable power, green hydrogen eliminates the use of fossil fuels. Successive Conference of Parties to the UN Framework Convention on Climate Change (UNFCCC) have highlighted the critical need to promote green hydrogen for decarbonisation by enhancing its supply, access and commercialisation. According to the Renewables 2023 report of the International Energy Agency, global renewable power capacity dedicated to hydrogen-based fuel production is forecast to grow by 45 GW between 2023 and 2028. The focus will increasingly shift to the Asia-Pacific region, which accounts for 50% of global industrial hydrogen demand, as revealed by the 2023 report 'Hydrogen in Decarbonization Strategies in Asia and the Pacific' of the Asian Development Bank Institute.

Green hydrogen strategies have been developed in a growing number of countries in the Asia-Pacific region with the aim of achieving a net-zero economy. For large-scale adoption of green hydrogen, countries will need to address various challenges, such as the high cost of production, storage and transportation, the unpredictability of demand, lack of standards and regulations, large infrastructure investment and inadequate skills and technical capacity. Countries will need to adopt appropriate policy instruments, such as feed-in tariffs, carbon pricing mechanisms, regulatory frameworks and incentives to promote green hydrogen. In addition, the production, application and value chain of green hydrogen will require technical support, cross-border cooperation, training and capacity building of stakeholders and institutions. Green hydrogen projects are often capital-intensive and require innovative financing approaches, such as public-private partnerships co-funding, government-backed loans, green bonds and R&D subsidies, among others. Pilot projects across different sectors and geography will provide valuable insights and learnings for large-scale deployment of green hydrogen.

The April-June 2024 special issue of Asia-Pacific Tech Monitor focuses on the theme 'Green Hydrogen Technologies: Opportunities and Challenges for the Asia-Pacific Region'. This edition features five articles presenting insightful analysis and discussions on the development and utilisation of green hydrogen technologies with examples from the region. One of the articles provides an overview of the challenges and opportunities of green hydrogen in the Asia-Pacific region, with a focus on technological advancements, national strategies and regional cooperation efforts. The other articles delve into country perspectives on green hydrogen with examples and case studies from India, Malaysia and the Russian Federation. These articles present valuable insights on green hydrogen initiatives, projects, technological solutions and their commercial viability in different situations.

We hope this edition of Tech Monitor will support its readers in making informed strategies and scaling up efforts towards the adoption of green hydrogen in the Asia-Pacific region.

Preeti Soni
Head, APCTT

Technology market scan

ASIA-PACIFIC

BANGLADESH

Draft AI policy published

On March 28, 2024, the Department of Information and Communication Technology (ICT Department) announced the publication of the National Artificial Intelligence Policy 2024. In particular, the draft policy lays down the objectives, artificial intelligence (AI) principles, AI policy implementation approaches, key sectors for AI development, challenges and mitigation approaches, and policy review.

The draft policy states that the following principles must guide the AI technologies:

- Social equity, equality, and fairness;
- Transparency and accountability;
- Safety, security, and robustness;
- Sustainability;
- Partnership and collaboration; and
- Human-centered AI.

The draft policy notes that the ICT Department in collaboration with relevant ministries, industry, academia, and civil society will take necessary steps to establish the institutional framework for AI policy implementation. An independent National Artificial Intelligence Centre of Excellence (NAICE) will incorporate its existing offices or agencies.

Notably, the draft policy states that the National Strategy for AI will be updated to include:

- A comprehensive framework outlining goals, policies, and initiatives for AI development, regularly updated to align with global innovations and advancements;
- AI ethics guidelines/principles;
- Data retention policies including the legal issues of data governance and ownership;
- Standardization and certification guidelines, focusing on interoperability and data exchange;
- A legal framework for ensuring data accessibility for researchers; and
- An intellectual property framework.

The draft policy also lays down the challenges and mitigation approach when using AI systems, and with regard to privacy it states that:

- Models must be trained with minimal use of potentially sensitive or personal data;
- Personal data usage will require valid consent, notice, and the option to revoke;
- Privacy measures like encryption, anonymization, and aggregation should be applied;
- Mechanisms should allow users to flag privacy and data protection issues during data collection and processing; and
- Dataset types and scopes must be assessed by domain experts.

https://www.dataguidance.com

CHINA

Patent applications for solar cells

China has filed 126,400 global patent applications for solar cells, ranking the first in the world, according to data released by the country's National Intellectual Property Administration recently. In recent years, the average annual growth rate of patent applications in the country's photovoltaic industry has reached 23.1 percent.

Chinese companies have set world records in solar cell photoelectric conversion efficiency 56 times, according to Wang Shijiang, secretary-general of the China Photovoltaic Industry Association. Among them, LONGi Green Energy Technology Co., Ltd., headquartered in Xi'an, northwest China's Shaanxi Province, set a new world record for the efficiency of crystalline silicon heterojunction back-contact (HBC) solar cells at 27.09 percent, certified by the Institute for Solar Energy Research Hamelin in Germany in December 2023.

Since 2012, China's photoelectric conversion efficiency for mass-produced solar cells has increased by more than 60 percent, while the costs have reduced by half. In many areas in China, it only costs 0.1 yuan ($0.014) to generate one kilowatt hour of electricity.

https://news.cgtn.com/

Action plan to improve technology standards

China has released a three-year action plan to strengthen standards in various cutting-edge technologies, such as artificial intelligence chips, generative AI, quantum information, and brain-computer interfaces, aiming to better drive technological and economic development and enhance international influence. The plan, issued by the Office of Central Cyberspace Affair Commission, the State Administration for Market Regulation, and the Ministry of Industry and Information Technology, was released to the public on Wednesday.

According to a news release from the office of the commission, the action plan has emphasized that standards for informatization — or the flow of information through a system — are an important part of the national standard system and serve as a crucial support for driving high-quality development.

By 2027, the plan expects the release of a batch of high-quality informatization standards and the cultivation of a "specialized, professional, and internationalized" team of talent in the field of standardization. Additionally, three years later, the role of standards in guiding technological innovation and driving economic and social development should be fully realized, leading to a significant increase in China's contribution and influence in international standards.

The action plan outlines major tasks in four areas, including innovating the work mechanism for informatization standardization and promoting the formulation of standards in eight key fields. For instance, in the field of critical information technology, it calls for focusing on key areas of integrated circuits, intensifying efforts to develop standards for advanced computing chips and new storage chips, and promoting the formulation of application standards for AI, automotive, and consumer electronic chips. Furthermore, a series of major cutting-edge technologies such as generative AI, blockchain, cloud computing, quantum information, brain-computer interfaces, next-generation internet, and metaverse are also prioritized for standardization efforts.

https://www.chinadaily.com.cn

Plan to establish AI and computing standards

China has launched an ambitious three-year plan to establish itself as a global leader in AI and computing standards. The initiative, "Action Plan for Information Standard Construction (2024-2027)," outlines a comprehensive strategy to strengthen China's position in the ongoing tech race with the US and other nations.

The plan, spearheaded by China's Central Cyberspace Affairs Commission, the Ministry of Industry and Information Technology, and the State Administration for Market Regulation, focuses on strengthening research and developing standards for advanced chips, computing power infrastructure, quantum technology applications, brain-computer interfaces, and AI, according to an official document published by Central Cyberspace Affairs Commission.

"The Action Plan emphasizes that information technology standards are an important part of the national standards system and an important support for high-quality development driven by information technology," the Commission said.

"By 2027, the information technology standard working mechanism will be more sound, the layout of the information technology standard system will be more complete, a batch of high-quality information technology standards will be released, the quality of standards will be significantly improved, the implementation effect will be significantly enhanced, the role of information technology standards in leading technological innovation and driving economic and social development will be fully played, and the contribution and influence of international standards will be significantly improved," the Commission added.

The plan places AI at the centre of this mission, recognizing its role as a game-changer. A key component of the plan is the development of "general, foundational, ethical, security and privacy standards" for large AI models and generative AI, the document added. It also aims to promote the construction of blockchain standards and the development of cross-chain interoperability and smart contract technology standards. Besides, advanced standards in important application and service fields such as cloud computing, cloud-native, distributed cloud, edge cloud, cloud-network integration, cloud applications, intelligent service, and other areas are also in focus.

The plan also intends to "promote the standardization of quantum computing, quantum communication, quantum measurement, and other key technologies, develop standards for brain-computer interfaces, enhance research on input-output, brain information decoding algorithms, brain information security, privacy protection, and related technologies and applications."

https://www.computerworld.com

INDIA

Growth of 24.6% in patents filing

Mirroring global trends, in FY2023, India witnessed 83,000 patents being filed, marking an annual growth rate of 24.6%, the highest in the last two decades, as per Patenting Trends report released by the National Association of Software and Service Companies (NASSCOM). The number of patents granted also witnessed significant growth rising over 2X between FY2019-FY2023. This trend was expected to increase significantly with over 100,000 patents granted between 15th March 2023 to 14th March 2024, it said.

The study also found that over the past decade, the proportion of patents filed by residents (primary filers based in India) has doubled, climbing from 33.6% of total filings in fiscal year 2019 to more than 50% in fiscal year 2023. "This significant increase reflects a growing focus and heightened awareness of intellectual property rights in the country. Educational Institutes have been a key driver to this growth," the report said. Artificial Intelligence, the Internet of Things and Neurotechnology are amongst the top technology patents filed by DeepTech Start-ups in India, reported NASSCOM.

Amongst the top application areas, Healthcare related patents, primarily around medical imaging, diagnosing, report generation, and testing saw the maximum applications, followed by Automation/Software Development and Retail/Ecommerce. Artificial Intelligence saw maximum patents filed in areas of image processing, Natural Language Processing, and Predictive modelling, while Gen AI, Medical Data Processing, and Cognitive computing are the key emerging areas.

https://www.thehindu.com

Over 100,000 patents granted in 2023

Indian patent office has granted over 100,000 patents in the past year on account of steps taken by the government to further strengthen the intellectual property rights ecosystem, an official statement said. It also said that there has been a notable surge in Geographical Indication (GI) registrations, demonstrating a threefold increase compared to the previous year. As on date, 573 GIs are registered in India. In 2023-24, 98 new GIs have been registered and another 62 will be registered by March 31 this year. Similarly, so far this fiscal, copyright and design registrations totalled 36,378 and 27,819 respectively.

"Every 6 minutes one technology is seeking IP protection in India. In 2023, an all-time high of 90,300 patent applications were received. The patent office granted over one lakh patents in the last one year (15-Mar-2023 to 14-Mar-2024). Every working day, 250 patents were granted," the commerce and industry ministry said. It added that the Patent Rules, 2024 have been notified and these rules introduced several provisions aimed at simplifying the process of obtaining and managing patents, thereby facilitating a conducive environment for inventors and creators.

In the revamped rules, a unique provision for a New 'Certificate of Inventorship' has been introduced to acknowledge the contribution of inventors in the patented invention.

Besides, the time limit to furnish foreign application filing details in a specified form has been changed from six months from the date of filing of an application to three months from the date of issuance of the first examination report. "Considering the fast pace of technology, the time limit for filing requests for examinations has been reduced from 48 months to 31 months from the date of priority of application or from the date of filing of application, whichever is earlier," it said. It added that the renewal fee has been reduced by 10 percent if paid in advance through electronic mode for at least 4 years.

https://www.business-standard.com

18 GW renewable energy capacity added in FY24

India has added a record renewable energy capacity of 18.48 GW in 2023-24, which is over 21 percent higher than 15.27 GW a year ago, according to the latest data of the Ministry of New & Renewable Energy. However, industry experts said there is a need to add at least 50 GW of renewable energy capacity annually for the next six years to meet the ambitious target of 500 GW of renewables by 2030.

According to the data, India's installed renewable energy capacity is 143.64 GW as of March 31, 2024, excluding 47 GW of large hydropower capacity (each plant is more than 25 GW or above). They pointed out that renewable energy capacity stood at around 190 GW, including large hydro projects, and therefore, India needs to add 310 GW in the next six years or at an average of 50 GW per annum.

The data showed that solar installations of 12.78GW led to the renewable energy capacity addition of 15.27 GW in 2023-24, followed by 2.27 GW of wind energy. Among the renewable energy capacity, the total solar installed capacity tops the chart at 81.81GW, followed by about 46 GW of wind energy, 9.43 GW of biomass cogeneration, and 5 GW of small hydro (up to 25 MW capacity each).

Among the states, Gujarat and Rajasthan have the largest renewable energy capacities of about 27GW each, followed by Tamil Nadu at about 22 GW, Karnataka at about 21 GW, and Maharashtra at about 17 GW. Himachal Pradesh and Andhra Pradesh have installed renewable energy capacity of about 11 GW each.

https://m.economictimes.com

INDONESIA

Storage of foreign CO2 allowed

Indonesia has issued new regulations on carbon capture and storage (CCS), under which CCS operators can earmark 30 percent of their total storage capacity for imported carbon dioxide that meets specific conditions. The presidential regulation allows oil & gas contractors to use depleted reservoirs or aquifers in their assets for CCS operations. The government will receive royalties on the storage fees charged.

Under the rules, which came into effect, companies with CCS operations can allocate up to 30 percent of their total storage capacity for storage of carbon originating from abroad, the regulation said. Storge is only currently allowed for emitters who have invested in Indonesia, or who are affiliated with companies that have done so. Indonesia also needs to have a bilateral agreement with the government of the country where the carbon emissions have originated from, the rules say.

https://etn.news

KAZAKHSTAN

New draft hydrogen strategy

Kazakhstan is targeting 10GW of electrolysis capacity by 2040, to be integrated with 10GW of new dedicated renewable energy capacity, according to the Central Asian nation's new draft hydrogen strategy. While the new draft notes the various pathways to hydrogen production, it explains that the oil & gas producing country plans to remain fully "technology-neutral" with regards to H_2 production, with no "discrimination" towards fossil fuels.

In total, the government in the capital of Nur-Sultan wants to see 5trn tenge ($11.2bn) in investment in the country's hydrogen sector by 2040 — which it also hopes will yield a pilot blue hydrogen project that will use some of the country's massive fossil gas reserves, with carbon capture and storage (CCS).

Although the strategy is in draft form, Kazakh Prime Minister Oljas Bektenov has recommended the document for approval. The strategy envisages Kazakhstan becoming an exporter of hydrogen, as well as stimulating demand in its own domestic markets for use in industry, heavy-duty transport (trucking and buses), and rail. It also seeks to prioritise the development of hydrogen blending projects, utilising its existing gas infrastructure.

Kazakhstan would develop and create "a new technological line for the production of environmentally friendly hydrogen and its optimal mixing with natural gas, the creation of a new highly efficient 'gas-hydrogen fuel' for use in gas turbine thermal power plants and others," the strategy read. Pilot projects for hydrogen and hydrogen blends could be carried out in housing and communal buildings, it added. The wisdom of using hydrogen or hydrogen blends for space heat, especially in a domestic setting, has come under fire from independent experts on the grounds of efficiency, Safety, and affordability. In addition, the strategy places a strong emphasis on research and development work and international collaboration, especially in the field of nuclear hydrogen.

https://www.hydrogeninsight.com/

PHILIPPINES

Incentives to boost hydrogen investments

The Department of Energy (DoE) has rolled out guidelines for hydrogen investment incentives in the Philippines. The move comes as part of the government's efforts to promote sustainable energy solutions and reduce dependence on traditional fossil fuels. The DoE announced the introduction of incentives for hydrogen investments through Department Circular No. 2024-01-0001, titled "Providing a National Policy and General Framework, Roadmap, and Guidelines for Hydrogen in the Energy Sector." According to the DoE's social media announcement, stakeholders involved in hydrogen production, distribution, research and development, infrastructure establishment, and hydrogen fuelling stations for transportation sectors will now enjoy various perks and incentives provided by the government.

Stakeholders engaged in projects aimed at producing, importing, and exporting green hydrogen and its derivatives for power generation are eligible for benefits under the Renewable Energy Act of 2008. These incentives include:

For stakeholders involved in applying hydrogen to the transport sector using fuel cells, incentives are available under the Electric Vehicle Industry Development Act. These include benefits provided by the Corporate Recovery and Tax Incentives for Enterprises (Create) Act for manufacturing and assembly of hydrogen fuel stations, importation of capital and equipment, and exemption from duties on completely built hydrogen fuel stations for eight years. Projects involving hydrogen and its derivatives from nuclear energy will undergo an evaluation process for incentives under the Energy Efficiency and Conservation Act.

https://energynews.biz

REPUBLIC OF KOREA

Growth in medical device patents

The Republic of Korea's medical device patents grew fastest among major countries, and the influence of the country's medical device patent ranked third in new technology therapeutics and diagnostic devices, according to a report. The Korea Health Industry Development Institute (KHIDI) said so in its latest report, "Trends in New Technology Patents in Medical Devices." Researchers Kim Min-ju and Han Seung-cheol from KHIDI's Industrial Statistics Team analysed medical device patents registered between Jan. 1, 2012 and Dec. 31, 2021, at five major patent offices. The five are the Korea Intellectual Property Office (KIPO), the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO), the European Patent Office (EPO), and the World Intellectual Property Organization (WIPO).

The report categorized new medical device technologies into "new therapeutic and diagnostic devices" and "new functional restoration/assistive and welfare devices." New therapeutic and diagnostic devices include therapeutic and therapeutic auxiliary devices, such as electronic drugs and digital therapies, diagnostic and in vitro diagnostic devices, and medical robots. New functional restoration/assistive and welfare devices include physical, sensory, and expression function restoration and auxiliary devices, human-implantable medical devices, such as prosthetic devices and artificial joints, and new materials.

From 2012 to 2021, 68,272 patents were filed in the new technology medical device area. The yearly total doubled from 4,260 in 2012 to 8,975 in 2021. Patents related to new therapeutic and diagnostic devices totalled 53,129, accounting for 77.8 percent of all patents in the new medical device field. The number of patents related to therapeutic and diagnostic devices increased by 1.8 times, from 3,577 in 2012 to 6,466 in 2021. Patents related to new functional restoration/assistive and welfare devices totalled 15,143, an increase of 3.7 times from 683 in 2012 to 2,509 in 2021. Patents in new therapeutic and diagnostic devices had the highest average annual growth rate of all KIPO patents, especially in the last five years (2017-2021); they marked a growth rate of 10.7 percent, higher than that of other national patent offices.

Regarding the status of new medical device patents by applicant nationality, Korean applicants filed 2,225 patents for new therapeutic and diagnostic devices and 2,501 patents for new functional restoration/assistive and welfare devices, totalling 4,726 patents. This represented an average annual growth rate of 12.3 percent and 20 percent, respectively, the highest excluding China. The leading Korean patent applicants include Samsung Electronics, with 159 patents for new therapeutic and diagnostic devices, and DIO, with 135 patents for new functional restoration/assistive and welfare devices.

According to the analysis of patent indicators of the leading applicants (nationalities) in new therapeutic and diagnostic devices in 12 major countries, the Republic of Korea ranked third in the patent impact index (PII), although the country was ranked lower in the number of patents (12th) and patent competitiveness (11th).

https://www.koreabiomed.com

Big companies increased R&D investment in 2023

Big companies in the Republic of Korea increased their investments in research and development (R&D) activities last year despite decreased earnings, a corporate data tracker said. Their combined R&D investments rose 9.4 percent to 73.42 trillion won ($54 billion) in 2023 from 67.14 trillion won a year earlier, according to a recent survey of 224 firms by the data tracker CEO Score. They suffered declines in sales and operating profit due to an economic slowdown but they executed their planned R&D spending for future growth, the survey showed, reports Yonhap news agency.

Samsung Electronics topped others in terms of the value of R&D investments. It spent 28.35 trillion won last year, up 14 percent from a year ago. The country's top 10 conglomerates, including LG Electronics, SK hynix, Hyundai Motor, LG Chem, Hyundai Mobis, and Kakao were among the 224 companies. They accounted for more than 70 per cent of the overall R&D investments by the surveyed firms, CEO Score said.

https://www.thestatesman.com

Investment plan for AI and semiconductor

The Republic of Korean President Yoon Suk Yeol has unveiled plans for a 9.4 trillion won ($6.94 billion) investment in artificial intelligence by 2027, signalling a strengthening of the nation's position in cutting-edge semiconductor chips. This initiative includes a separate 1.4 trillion won fund dedicated to nurturing AI semiconductor firms as the Republic of Korea moves to keep pace with global rivals like the United States, China, and Japan, all of whom are developing and strengthening their semiconductor supply chains.

Semiconductors are the backbone of South Korea's export-driven economy, with chip exports surging to a 21-month high of $11.7 billion in March, comprising nearly a fifth of the nation's total exports. "Current competition in semiconductors is an industrial war and an all-out war between nations," Yoon told a meeting of policymakers and chip industry executives.

The investment strategy requires a significant expansion of research and development in AI chips, particularly artificial neural processing units (NPUs) and next-generation high-bandwidth memory chips. Moreover, the Republic of Korean authorities are committed to fostering the development of next-generation artificial general intelligence (AGI) and safety technologies.

https://www.businesstoday.in

SRI LANKA

Agri-tech innovations utilizing drones

Sri Lanka is transforming the agriculture industry through the use of tech innovations like high-resolution imagery, ground heat mapping, and more detailed data gathering making use of drones. Drones in agriculture have become a powerful tool for monitoring crops and livestock by delivering more expansive and higher-resolution imagery and enabling land imaging, surveying topography and boundaries, soil and irrigation monitoring spraying needs, and collecting soil and water samples. With the aim of revolutionizing agriculture, the Bank of Ceylon has stepped in to provide financial support for the first 100 agriculture drone pilot projects in Sri Lanka. Agricultural drones allow farmers to monitor crop and livestock conditions from the air to keep watch for potential problems and help optimise field management. With risks from supply chain disruptions, weather, crop disease, and other threats, farmers, ranchers, and other small business owners in agriculture industries are increasingly turning to technology like agricultural drones for help, a senior official of the agriculture ministry said.

Sri Lanka recently witnessed a groundbreaking moment in its agricultural sector as the first 100 agriculture drones took flight at Sooriyawewa KDU Southern Campus ground, marking a significant leap forward in modernising the country's farming practices. The financial initiative, spearheaded by the Bank of Ceylon, provided a loan facility for the importation of 250 drones aiming to revolutionise Sri Lanka's agriculture by supporting to introduce cutting-edge technology to enhance productivity and efficiency.

https://sundaytimes.lk

THAILAND

National AI strategy outlines 6 projects

Building an artificial intelligence (AI) workforce and the creation of a Thai large language model (ThaiLLM) are among the six proposed flagship projects under the second phase of the national AI strategy and action plan. Chai Wutiwiwatchai, deputy chairman of the National AI Policy and Action Plan Steering Committee, said a new National AI Committee is pending appointment by Prime Minister Srettha Thavisin and plans to begin implementing the second phase for 2024-27. Mr Chai estimated the six projects would require a total budget of 1.5 billion baht, of which 1 billion is to develop 30,000 AI-skilled workers from engineers and beginners.

The National Electronics and Computer Technology Centre (Nectec), which acts as secretary of the steering committee, recently hosted a closed hearing where organisations related to the AI plan offered details of the proposed projects. Tiranee Achalakul, president of the Big Data Institute, said Travel Link is the institute's AI project to combine tourism data with AI to recommend tourism attractions. "We will use generative AI to make a tourism chatbot," said Ms Tiranee.

Nakarin Amarase, senior vice president for external affairs at Siam Commercial Bank, said the use of AI to strengthen the fraud detection system is essential to reduce losses from financial fraud. From March 17, 2023, to Feb 29, 2024, losses from cybercrime totalled 27 billion baht from an average of 645 cases per day, he said. Using AI to analyse users who have multiple SIM cards and suspicious bank transactions can help freeze suspicious transactions before damage occurs, said Mr. Nakarin. This effort requires collaboration from police, the Anti-Money Laundering Office, the Bank of Thailand, telecom operators, the Thai Bankers' Association, and the Digital Economy and Society Ministry, he said.

Kobkrit Viriyayudhakorn, president of the AI Entrepreneur Association of Thailand, said ThaiLLM is an important project. The project is expected to require a budget of 120 million baht to create an open-source ThaiLLM foundation and chatbots to offer information on health, travel, and the environment. "We aim to employ 590 AI workers for the project and encourage the creation of Thai AI startups, reducing both costs and reliance on foreign AI. AI is the national infrastructure for secure technology," said Mr Kobkrit. Mr. Chai said Nectec is also responsible for developing a biometric identification AI testing centre, while the Electronic Transactions Development Agency plans to upgrade its AI governance clinic to an AI governance centre.

Putchapong Nodthaisong, secretary-general of the Office of the National Digital Economy and Society Commission, said the commission's fund can support some of these projects, such as the fraud detection system and ThaiLLM foundation. Wiboon Rugsancharoenphol, committee secretary of the Innovation One fund, under the Federation of Thai Industries (FTI), said during 2024-25, AI can improve productivity in the manufacturing sector by using machine vision technology to find defective products and enhance quality assurance in the process. He said the FTI will promote the pilot use of CiRA CORE technology in 50-60 small-scale factories, targeting electronics and food. The project is estimated to cost 20 million baht.

CiRA CORE is a platform that allows users to create algorithms or applications such as deep learning to facilitate learning and memory for a system. For example, it can be trained to do industrial tasks. Once the learning process is complete, it can instruct a robot to do such tasks in various industries. The FTI is also targeting AI energy optimisation to help manufacturers reduce their carbon footprint, supporting exports under the EU's Carbon Border Adjustment Mechanism.

https://www.bangkokpost.com

UZBEKISTAN

Legislation in accordance with WTO requirements

Uzbekistan has adopted amendments aimed at coordinating national legislation with the agreements of the World Trade Organization (WTO), marking a crucial step in facilitating trade and intellectual property rights within the country, Legal Information *reports*.

In an effort to align the national intellectual property system with the WTO Agreement on Trade-Related Aspects of Intellectual Property Rights, several measures have been introduced:

- **Use of Patents:** Specific circumstances have been outlined wherein the government may allow the use of patents without the permission of the owner, with provisions for compensation.
- **Compulsory Licensing:** Provisions have been made for obtaining compulsory licenses for the use of industrial property objects, with norms set for compensatory payments to patent owners.
- **Dispute Resolution:** Clarifications regarding the burden of proof in disputes arising from patented methods have been provided.
- **Trademark Registration:** The statute of limitations for cancelling registered trademarks due to unfair competition has been eliminated.
- **Equal Opportunity:** Equal opportunities for domestic and foreign applicants in the state registration of intellectual property objects have been ensured, with unified patent duty amounts for non-residents and residents.

Additionally, the legislation provides support for companies producing original medicinal products. Provisions have been made for the protection of results obtained from pre-clinical and clinical trials conducted during the creation of medicinal products. Compensation to the right holder is ensured even in cases of natural disasters, accidents, epidemics, and other emergency situations where industrial property objects are utilized.

https://daryo.uz

VIET NAM

Patents growth rate nears 10% a year

The average annual growth rate of patent applications and utility solutions was 9.8 percent per year in the last ten years with Vietnamese entities filling 7,560 applications, according to the Intellectual Property Office of Vietnam, while foreign entities filed a total of 60,517 patent applications. According to a report by the office, in 2014, Vietnamese entities filed only 487 patent applications compared to 3,960 by their foreign counterparts. Last year, the number of applications filed by Vietnamese entities increased to 991, while those filed by foreign entities rose to 8,469. However, the total number of utility solutions filed by Vietnamese entities over the past decade was more than 1.3 times higher than those filed by foreign entities with an annual growth rate of 12 per cent in comparison to the same figure by foreign firms of 9.4 percent.

During the last ten years, Vietnamese entities filed a total of 399,017 trademark registration applications, while foreign entities submitted only 83,803 applications with the number of trademarks awarded to Vietnamese entities reaching 200,856, compared to 56,908 awarded to foreign entities, said the report. Regarding applications for rights of use and ownership submitted over the past decade, from 2014 to 2023, there were 1,805 applications by industrial property owners. There were also 11,757 applications for transfer of ownership by industrial property owners.

https://vietnamnews.vn

Digital infrastructure plan for 2021-2030

Comprehensive plans are in place to rejuvenate and advance Việt Nam's information and communications infrastructure. The Ministry of Information and Communications on Friday announced details of the information and communications infrastructure planning for the period 2021-2030, with a visionary outlook extending to 2050, which was recently approved by Prime Minister Phạm Minh Chính. This plan outlines Việt Nam's ambitious objectives to establish the groundwork for a digital government, foster a thriving digital economy, and cultivate a connected digital society.

The envisioned information and communications infrastructure encompasses a cohesive framework that integrates various components, including the postal network, digital infrastructure, information technology industrial infrastructure, national digital transformation platforms, and security assurance systems. This interconnected network is pivotal for ensuring the integrity and security of all information within the system.

The plan aims for significant advancements in digital infrastructure by 2025. It envisions ubiquitous access to fibre optic cable for households, ensuring that 100 percent have access when needed. It sets goals for smartphone ownership among the adult population, access to high-speed Internet for technological hubs and government agencies, integration of IoT in essential infrastructure, and the adoption of cloud computing services by Vietnamese businesses.

Simultaneously, the plan entails deploying and investing in two to four additional international telecommunications cable lines. It also outlines the establishment and deployment of national data centres, including at least three national multi-purpose data centre clusters, regional multi-purpose data centre clusters, and one or two regional data centres catering to the needs of financial centres in Việt Nam, the region, and internationally.

Looking ahead to 2030, the focus shifts towards substantial improvements in fixed broadband access network infrastructure. Additionally, the plan aims to extend the coverage of 5G mobile broadband networks to 99 percent of the population, with an emphasis on advancing next-generation mobile networks. Furthermore, the target is set for 100 percent of state agencies, state-owned enterprises, and over 50 percent of the population to utilise cloud computing services provided by domestic enterprises. To support these initiatives sustainably, the plan calls for the development of large-scale data centre clusters adhering to green standards.

https://vietnamnews.vn

National hydrogen strategy

Viet Nam has recently approved its national hydrogen production strategy, seeking international investors to establish a production ecosystem in the country for both green and blue hydrogen meant for domestic and export markets. The country aims to achieve a production capacity of 100,000-500,000 tons of hydrogen per annum by the end of this decade, scaling up to generate 10-20 million tons per annum (mtpa) by the year 2050, using both renewable energy and carbon capture technologies. Along with global exports, the country targets domestic consumption of hydrogen in sectors such as transportation, power generation, and heavy industries, thereby meeting about 10 percent of Vietnam's cumulative energy demand by 2050.

Viet Nam has also vowed to gradually develop the hydrogen energy market in sync with its roadmap for energy transition in critical sectors such as power production, transportation including road, rail, waterway, air, and industries such as steel, cement, chemical, oil refining, and so on, along with commercial and residential energy needs. The Ministry has also noted that it will deploy projects that "take advantage of existing infrastructure" and those that create "mechanisms and legal corridor for businesses that produce and use fossil energy to actively convert to producing and using hydrogen energy".

The Vietnamese government, which is striving to achieve net zero by 2050, is considering hydrogen as a key clean energy source for its climate goals on decarbonization and energy transition. The country is reported to have assigned specific tasks to various ministries and local agencies for the effective deployment of its hydrogen strategy by adjusting provincial plans and policy changes to encourage hydrogen use and tap capital from domestic and international sources.

https://etn.news

Technology scan

Green hydrogen technologies

ASIA-PACIFIC

AUSTRALIA

Breakthrough process to slash green hydrogen costs by 40%

Sunshine Hydro, known for its pioneering Superhybrid technology that enables carbon-free energy, says it has discovered a breakthrough process to substantially lower the cost of producing green hydrogen. By harnessing the ultra-efficient electrolysers developed by Australian renewable energy manufacturer Hysata, Sunshine Hydro's Superhybrid technology is now capable of delivering clean hydrogen up to 40% cheaper than previously achievable.

Hysata's proprietary electrolysis technology optimises energy consumption, reducing the power needed per kilogram of hydrogen produced by 20%. This breakthrough process raises the bar for the entire sector, ensuring a sustainable and more efficient production pathway. Sunshine Hydro has separately developed ways of better utilising fast-acting electrolysers, including those developed by Hysata. The Sunshine Hydro technology supports the smooth operation of pumped hydro systems, balancing generation profiles and driving down hydrogen production costs by up to 20%, depending on seasonal patterns.

Achieving 24/7 carbon-free electricity requires the application of pumped hydro energy storage as part of the mix. To provide grids with round-the-clock and seasonal energy to power data centres, industry, and other power-demanding applications, a hydrogen electrolyser can be matched with pumped hydro turbines in such a way that they support the variable load even though needed using renewable energy sources.

Six years of extensive research at Sunshine Hydro reveal the indispensable role of hydrogen electrolysers in supplying continuous, carbon-free electricity. Importantly, the solution is designed to respond flexibly to energy market conditions. During peak periods when prices surge, energy can be temporarily redirected from hydrogen production to meet market demand.

Sunshine Hydro's innovative approach yields up to a 20% reduction in hydrogen production costs. Coupled with Hysata's efficient electrolysers, cumulative cost reductions reach up to 40%.

By pairing these advancements with clean energy generation, these two Australian innovations are poised to transform its energy landscape and play a crucial role in the nation's green energy and industry independence.

https://esdnews.com.au

CHINA

Device for producing green hydrogen

A group of Chinese scientists has developed a strategy that uses the energy of seawater and fresh water to efficiently produce "green" hydrogen, *Azernews* reports, citing foreign media outlets. This technology is a promising solution for producing clean fuel hydrogen to reduce carbon dioxide emissions in the energy sector. Researchers at Fudan University have developed a high-performance ion exchange membrane and a tandem of electrodes that will be installed in river mouths to collect osmotic energy and accelerate hydrogen production.

According to a study published in the journal *Nature Sustainability*, the integrated device demonstrates consistent and rapid release of alkaline hydrogen over 12 days under conditions of an artificial salinity gradient. The researchers said the study provides a viable way to produce hydrogen from renewable sources.

https://www.azernews.az

Green hydrogen from wastewater

Green hydrogen may soon be a matter of waste recycling in major cities, as researchers from the Hong Kong University of Science and Technology have created what they describe as an "ultra-fast" green hydrogen production method using municipal wastewater. The research team tested a modular forward osmosis-water splitting (FOWS) system that integrated a thin-film composite FO membrane for water extraction with alkaline water electrolysis. Published in the open-source journal *Nature*, the team's research demonstrated the system was capable of generating high-purity hydrogen directly from wastewater at a rate 14 times faster than state-of-the-art electrolysis, with very low energy consumption compared to industry standards as well.

"Using wastewater effluent is crucial for sustainable H2 production in regions where seawater is unavailable or freshwater resources are scarce, especially as H2 projects are rapidly expanding amid the foreseeable intensified worldwide water stress," the paper reads.

The team's findings also point to a 46% reduction in capital costs associated with water treatment compared to traditional processes, with the potential to capture both additional energy produced during the process, and clean water from the hydrogen cells themselves as by-products of the technology. All in all, the research could lead to wastewater-based green hydrogen production that is cleaner, cheaper, and more efficient.

https://www.proactiveinvestors.com.au

INDIA

Indigenously built hydrogen electrolyser

Larsen & Toubro (L&T) commissioned its first indigenously manufactured electrolyser at the Green Hydrogen Plant at A M Naik Heavy Engineering Complex in Hazira, Gujarat, the company stated in an official statement. Featuring a rated power capacity of 1 MW (expandable to 2 MW), this electrolyser can produce 200 Nm3/Hr of hydrogen. It is equipped with two stacks and an Electrolyser Processing Unit (EPU) ML-400, which is indigenously manufactured and assembled, adhering to the latest international standards, and offers exceptional flexibility and thermal stability. The electrolyser will now undergo rigorous testing to optimise its performance, and in turn, paving the way for full-fledged manufacturing of electrolysers.

This pioneering accomplishment signifies L&T Electrolysers' foray into domestic electrolyser manufacturing, underscoring the company's steadfast dedication to propelling sustainable energy solutions, the company added. L&T Electrolysers Ltd, a newly incorporated entity of L&T, is focused on manufacturing pressurised alkaline electrolysers using the technology from McPhy Energy, France.

Subramanian Sarma, Whole-time Director & Sr EVP (Energy), L&T, said: "The indigenously manufactured electrolyser marks a transformative leap towards clean energy, positioning us to lead not only in the domestic market but also globally. This advancement significantly bolsters our offerings across the value chain, showcasing L&T as a global force in the clean energy space".

L&T Electrolysers plans to leverage its upcoming giga-scale facility in Hazira to meet the growing demand for green hydrogen, maximizing product localization through enhanced local supply chain, and automation for cost-competitiveness. L&T Electrolysers has been allocated a significant 300 MW/annum capacity under the Production Linked Incentive (PLI) of the National Green Hydrogen Mission, launched by the Government of India's Ministry of New and Renewable Energy (MNRE) and implemented by the Solar Energy Corporation of India (SECI).

https://www.thehindubusinessline.com

ISRAEL

Green hydrogen using renewable energy

A group of researchers from the Technion Faculty of Materials Science and Engineering has presented a new technology for producing green hydrogen using renewable energy. Their breakthrough was recently published in *Nature Materials*. The novel technology embodies significant advantages compared to other processes for producing green hydrogen, and its development into a commercial technology is likely to reduce the costs and accelerate the use of green hydrogen as a clean, sustainable alternative to fossil fuels.

Several years ago, Technion researchers presented an innovative and efficient electrolysis technique that doesn't require a membrane and sealing to separate the two parts of the cell, since the hydrogen and the oxygen are produced at different stages of the process, unlike in regular electrolysis where they are created simultaneously.

This novel process, called E-TAC, was developed by Dr. Hen Dotan and Dr. Avigail Landman under the supervision of Prof. Avner Rothschild and Prof. Gideon Grader. They partnered with the entrepreneur Talmon Marco to fulfil the process's potential and develop commercial applications.

https://techxplore.com

JAPAN

The catalyst for green hydrogen production

Scientists from Japan's RIKEN Centre for Sustainable Resource Science (CSRS) have advanced a catalyst for producing green hydrogen. The custom-made catalyst enables the green and sustainable extraction of hydrogen from water. By manipulating the catalyst's 3D structure, the CSRS team has significantly improved its stability and lifetime by nearly 4,000%.

The researchers developed the novel **manganese oxide (MnO2) catalyst**, enhancing reaction stability by over 40 times through lattice structure modifications. By increasing planar oxygen in the 3D lattice, stronger bonds with manganese were formed, significantly boosting catalytic stability. Testing four manganese oxide variants, the highest achieving 94% planar oxygen maintained critical oxygen evolution in acid for a month at 1000 mA/cm2, transferring 100 times more charge than previous studies.

In PEM electrolyser tests, they sustained water electrolysis for about six weeks at 200 mA/cm2, producing hydrogen at a rate ten times greater than prior non-rare metal catalysts. Despite the need for longer-term stability at industrial scales, the researchers anticipate feasible real-world applications contributing to carbon neutrality. They hope their findings can spark interest in sustainable hydrogen as a viable tool in the renewable energy arsenal against climate change.

https://www.innovationnewsnetwork.com

AI technique promotes green hydrogen production

A National Institute for Materials Science (NIMS) research team has developed an AI technique capable of expediting the identification of materials with desirable characteristics. Using this technique, the team was able to discover high-performance water electrolyser electrode materials free of platinum-group elements—substances previously thought to be indispensable in water electrolysis. These materials may be used to reduce the cost of large-scale production of green hydrogen—a next-generation energy source. The research was published in *ACS Central Science*.

This NIMS research team recently developed an AI technique capable of accurately predicting the compositions of materials with desirable characteristics by switching prediction models depending on the sizes of the datasets available for analysis. Using this AI, the team was able to identify new, effective OER electrocatalytic materials from about 3,000 candidate materials in just a single month. For reference, a manual, comprehensive evaluation of these 3,000 materials was estimated to take almost six years.

These newly discovered electrocatalytic materials can be synthesized using only relatively cheap and abundant metallic elements: manganese (Mn), iron (Fe), nickel (Ni), zinc (Zn), and silver (Ag). Experiments found that under certain conditions, these electrocatalytic materials exhibit superior electrochemical properties to ruthenium (Ru) oxides—the existing electrocatalytic materials with the highest OER activity known.

These results demonstrated that this AI technique could be used to expand the limits of human intelligence and dramatically accelerate the search for higher-performance materials. Using the technique, the team plans to expedite its efforts to develop new materials—mainly water electrolyser electrode materials—to improve the efficiency of various electrochemical devices contributing to carbon neutrality.

https://phys.org

REPUBLIC OF KOREA

Low-cost catalyst for green hydrogen production

Electrolysis is a process that uses electricity to create hydrogen and oxygen molecules from water. The use of proton exchange membrane (PEM) and renewable energy for water electrolysis is widely regarded as a sustainable method for hydrogen production. However, a challenge in advancing PEM water electrolysis technology is the lack of efficient, low-cost, and stable catalysts for oxygen evolution reaction (OER) in acidic solutions during PEM water electrolysis.

While iridium-based catalysts are a potential solution, metallic iridium is rare and expensive in nature. Alternately, oxides of ruthenium (RuO_2) offer a more affordable and reactive option, but they also suffer from stability issues. Therefore, researchers are exploring ways to improve the stability of the RuO_2 structure to develop promising OER catalysts for the successful implementation of hydrogen production technology.

Now, in a recent study published in the *Journal of Energy Chemistry*, a group of researchers, led by Professor Haeseong Jang from the Department of Advanced Materials Engineering at Chung-Ang University, has developed a promising OER catalyst.

Denoted as SA Zn-RuO_2, the catalyst comprises RuO_2 stabilized by single atoms of zinc. Elaborating on their study, Prof. Jang says, "We were motivated by the need to find efficient and cost-effective alternative electrocatalysts for OER in PEM water electrolysis. Based on our study, we propose a dual-engineering strategy involving single atom Zn doping and the introduction of oxygen vacancies to balance high catalytic activity with stability during acidic OER."

The researchers synthesized SA Zn-RuO_2 by heating an organic framework with ruthenium (Ru) and zinc atoms, forming a structure with oxygen vacancies (missing oxygen atoms that positively alter the properties) and Zn-O-Ru linkages. These linkages stabilize the catalyst in two ways: by strengthening the Ru-O bonds and providing electrons from zinc atoms to protect ruthenium from overoxidation during the OER process. Furthermore, the improved electronic environment around the ruthenium atoms lowers the energies needed for molecules to stick to the surface, thus lowering the energy barrier for the reaction.

The resulting catalyst was more stable, with no apparent fall in reactivity, and significantly outperformed commercial RuO_2. Moreover, it required less extra energy (low overpotential of 213 mV compared to 270 mV for commercial RuO_2) and remained functional for a longer period (43 hours compared to 7.4 hours for commercial RuO_2).

Due to its improved stability and features, the newly proposed SA Zn-RuO_2 catalyst has the potential to influence the development of cost-effective, active, and acid-resistant electrocatalysts for OER. This, in turn, could help in reducing costs and enhancing the production of green hydrogen, aiding in a shift toward cleaner energy sources and advancements in sustainable technologies.

https://phys.org

Catalyst enhances hydrogen generation efficiency

Researchers from Pohang University of Science and Technology have devised a novel catalyst aimed at enhancing the efficiency of reactions using contaminated municipal sewage to produce hydrogen—a green energy source. Their research was recently featured in *Advanced Functional Materials*.

In pursuit of increased efficiency in the urea oxidation reaction, the team created a catalyst known as nickel-iron-oxalate (O-NFF). This catalyst combines iron (Fe) and oxalate on nickel (Ni) metal, resulting in an expansive surface area characterized by nanometre-sized particles in fragment form. This unique property enables the catalyst to adsorb more reactants, facilitating an accelerated urea oxidation reaction.

In experiments, the O-NFF catalyst devised by the team successfully lowered the voltage required for hydrogen generation to 1.47 V RHE (at 0.5 A/cm^2) and exhibited a high reaction rate even when tested in a mixed solution of potassium hydroxide (1 M) and urea (0.33 M) with a Tafel slope of 12.1 mV/dec. The researchers further validated the catalyst's efficacy by confirming its promotion of the urea oxidation reaction through photoelectron/X-ray absorption spectroscopy using a radiation photon accelerator.

https://phys.org

Solar hydrogen production technology

A joint research team at the Ulsan National Institute of Science and Technology (UNIST), led by Professor Lee Jae-sung, Professor Jang Ji-wook, and Professor Seok Sang-il from the Department of Energy and Chemical Engineering and Professor Lim

Han-kwon from the Graduate School of Carbon Neutrality, announced that it has developed a green hydrogen production technology utilizing solar energy, which boasts high efficiency, durability, and scalability.

The research team addressed the drawbacks of perovskite solar cells and significantly increased the size of the photoelectrodes by 10,000 times, enhancing the practicality of the technology. Solar hydrogen technology is an ideal green hydrogen production method that utilizes solar energy, the most abundant renewable energy source on Earth, to electrolyze water and obtain hydrogen.

The UNIST research team adopted perovskite as the material for the photoelectrode, which is efficient and relatively inexpensive. Perovskite solar cells are a research and development field led by professors at UNIST, including Professor Seok Sang-il, who participated in this study.

The research team manufactured the most UV-stable perovskite by using formamidinium instead of the conventional methylammonium as the cation in perovskite. It also ensured stability in water by completely sealing the contact surface with water using nickel foil. Typically, photoelectrodes for research and development are small, less than 1 square centimetre in size, while practical-scale ones need to be scaled up to 1 square meter, requiring about a 10,000-fold increase. During the scale-up process, hydrogen production efficiency tends to decrease, necessitating techniques to minimize this reduction.

To scale up the photoelectrode, the research team employed a module-based design wherein small photoelectrodes are interconnected and arranged in a consistent size. Similar to stacking blocks, small photoelectrodes are repeated horizontally and vertically to manufacture large-area photoelectrodes. With this scaled-up module, the research team achieved a solar-to-hydrogen conversion efficiency of over 10 percent, meeting the minimum requirement for commercialization. This efficiency level represents the world's highest efficiency for large-area photoelectrodes.

The findings of this study were published online in *Nature Energy*, one of the top academic journals in the field of energy, on Jan. 23. The research was conducted with support from the Ministry of Science and ICT's Climate Change Response Project and the BrainLink Project.

https://www.businesskorea.co.kr

EUROPE

SWEDEN

New hydrogen producing method

Researchers in Sweden unveiled a new concept for producing hydrogen energy more efficiently, splitting water into oxygen and hydrogen without the dangerous risk of mixing the two gases. Developed at KTH Royal Institute of Technology in Stockholm, the new method decouples the standard electrolysis process for producing hydrogen gas, which splits water molecules by applying an electric current. In contrast with prevailing systems, it produces the resulting oxygen and hydrogen gases separately rather than simultaneously in the same cell, where they need to be separated by membrane barriers.

That separation eliminates the possibility of the gases mixing with the risk of explosions, says researcher Esteban Toledo, a Ph.D. student at KTH who co-authored the paper published today in *Science Advances* along with Joydeep Dutta, professor of applied physics at KTH. It also eliminates the need for rare Earth metals. The two researchers patented the system, and a company, Caplyzer AB, was formed through KTH Innovation to scale the technology. Dutta says the hydrogen gas Faradaic efficiency was shown to be 99 percent. The researchers also report that lab tests showed no apparent electrode degradation as a result of long-term tests, which is important for commercial applications.

Producing hydrogen from water always generates oxygen. A typical alkaline electrolyser has a positive and negative electrode paired up inside a chamber of alkaline water, separated by an ion-permeable barrier. When an electric current is applied, water reacts at the cathode by forming hydrogen and negatively charged hydroxide ions, which diffuse through the barrier to the anode to produce oxygen. But the barrier causes resistance, and if the electric charge fluctuates, the risk of an explosive mix between oxygen and hydrogen is heightened.

Toledo says re-conceptualizing water electrolysis sets the stage for a more reliable form of green energy production, incorporating intermittent sources such as solar or wind. "Since we don't risk mixing the gases, we can operate over a wider range of input power," he says. "It's much easier then to couple with renewable energies that generally provide variable power."

The simultaneous production of gases is circumvented by replacing one of the electrodes with a super capacitive electrode made from carbon. These electrodes alternately store and release ions, effectively separating hydrogen and oxygen production.

When the electrode is negatively charged and produces hydrogen, the supercapacitor stores energy-rich hydroxide (OH) ions. When the direction of the current is swapped, the supercapacitor releases the absorbed OH, and oxygen is produced at the now-positive electrode.

https://techxplore.com

THE NETHERLANDS

Green hydrogen breakthrough

Researchers from the University of Twente have revealed in a new study that they have made notable advances in understanding the behaviour of tiny bubbles (micro- and nanobubbles) on electrodes during the water electrolysis process; a process that is vital to green hydrogen production. The tiny bubbles that form on electrodes are a nuisance to the electrolysis process. They block the flow of electricity and lower the efficiency of the overall reaction. These bubbles are problematic because less efficient electrolysis means more waste and higher green hydrogen production costs.

The researchers tried to understand exactly how the micro- and nanobubbles form on the electrodes and stick to them. The goal of gaining this understanding was to ultimately get rid of the bubbles to prevent them from impeding the hydrogen process.

The University of Twente researchers, led by Detlef Lohse, developed a theory that lets them successfully predict the electric current density that is necessary to allow the nanobubbles to grow uncontrollably and detach, thereby freeing the electrode to produce more hydrogen.

Their research builds upon the Lohse-Zhang model, an established stability theory for surface nanobubbles. The major difference is that the new research expands to include the electrolytic current density to predict the behaviour of the tiny bubbles. With this improved knowledge, the hope is that scientists and engineers can work toward detaching bubbles from electrodes. This is not only good news for water electrolysis for improved green hydrogen production, but also for other systems, such as in catalysis, where gas bubbles can form.

The study, “Threshold current density for diffusion-controlled stability of electrolytic surface nanobubbles” has been published in *Proceedings of the National Academy of Sciences*.

https://www.hydrogenfuelnews.com

UNITED KINGDOM

Steam-based hydrogen production

A new electrolyser cell that can withstand high temperatures will help cut the cost of hydrogen production and move society towards greener forms of energy, its developers have claimed. Led by researchers at Robert Gordon University (RGU) in Aberdeen, in collaboration with the University of Surrey, the team designed, built, and tested electrodes used in solid oxide steam electrolysis (SOSE) for waste steam generated from nuclear power plants. SOSE systems operate at 600-900°C, so the cell’s cathode, electrolyte, and anode layers were manufactured with thermal spray and dip coating techniques. The RGU team said other advances were made in materials and arrangement. The research showed that the tubular electrolyser cell provides improved performance, meaning the design has a higher hydrogen production rate compared to existing cells.

Lead investigator Professor Nadimul Faisal said: “Developing electrolyser cells with enhanced hydrogen production, and their scalable manufacturing, can play an important role in enabling not only eco-friendly development but also cost-effective, reliable, and sustainable opportunities. This project has the potential to advance technology to produce green hydrogen, and thus we will exploit the outcomes and commercialise the product.”

https://www.imeche.org

NORTH AMERICA

USA

Hydrogen from solar power and agricultural waste

University of Illinois Chicago engineers have helped design a new method to make hydrogen gas from water using only solar power and agricultural waste, such as manure or husks. The method reduces the energy needed to extract hydrogen from water by 600%, creating new opportunities for sustainable, climate-friendly chemical production. In a paper for Cell Reports Physical Science, a multi-institutional team led by UIC engineer Meenesh Singh unveils the new process for green hydrogen production.

The method uses a carbon-rich substance called biochar to decrease the amount of electricity needed to convert water to hydrogen. By using renewable energy sources such as solar power or wind and capturing byproducts for other uses, the process can reduce greenhouse gas emissions to net zero. “We are the first group to show that you can produce hydrogen utilizing biomass at a fraction of a volt,” said Singh, associate professor in the department of Chemical Engineering. “This is a transformative technology.”

Recently, scientists have decreased the voltage required for water splitting by introducing a carbon source to the reaction. But this process also uses coal or expensive chemicals and releases carbon dioxide as a byproduct. Singh and colleagues modified this process to instead use biomass from common waste products. By mixing sulfuric acid with agricultural waste, animal waste, or sewage, they create a slurry-like substance called biochar, which is rich in carbon.

The team experimented with different kinds of biochar made from sugarcane husks, hemp waste, paper waste, and cow manure. When added to the electrolysis chamber, all five biochar varieties reduced the power needed to convert water to hydrogen. The best performer, cow dung, decreased the electrical requirement sixfold to roughly a fifth of a volt.

https://today.uic.edu

Green hydrogen production and efficiency

Founded on pioneering research conducted at Cornell University, Ecolectro has developed proprietary AEM electrolysers designed to significantly reduce the cost of green hydrogen production. This breakthrough positions Ecolectro, and subsequently green hydrogen, as a viable and economically competitive energy source.

Ecolectro, an emerging leader in green hydrogen generation, has hit best-in-class performance milestones using their AEM chemistry in membrane-based electrolysers. Ecolectro has achieved peak production rates of >4A/cm2 at current densities of <2.1V and has achieved cell efficiencies of >74% with high hydrogen production rates. The Company’s current density sets a benchmark within the AEM industry and matches the best cell efficiencies of most PEM electrolysis technologies. With this technical breakthrough, Ecolectro-powered electrolysers can provide green hydrogen at significantly lower costs. Ultimately, the company anticipates achieving further improvements with a target efficiency of an industry-leading 80% or more.

The production rate and efficiency achievements have been demonstrated using Ecolectro's proprietary hydrocarbon-based chemistry which avoids the use of any perfluoro-alkyl substances (PFAs), iridium-based catalysts, and Titanium based components in the plates and porous transport layers. These material innovations not only lead to an impressive 80% cost reduction compared to PEM-based stacks but they also significantly lower Ecolectro's carbon footprint and enhance the sustainability of operations, reflecting their commitment to environmentally responsible practices.

In addition to the performance milestones, the company has successfully scaled its electrolysers from the lab-scale to the pilot scale. They have deployed a pilot electrolyser at a utility company and have made green hydrogen on-site for further use.

https://www.prnewswire.com

Asia-Pacific's path to sustainable energy

Opportunities and challenges of green hydrogen technologies

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Abstract

The Asia-Pacific region, which encompasses major economies such as China, Japan, and the Republic of Korea, is undergoing rapid industrialisation and urbanisation, which are leading to significant energy and environmental challenges. Green hydrogen, produced using renewable energy sources, represents sustainable solutions. This paper examines the challenges of these technologies in the region, with a particular focus on technological advancements, national strategies, and regional cooperation efforts. Countries such as Japan, Australia, and the Republic of Korea are investing in green hydrogen infrastructure and policy support. The advantages for small and medium-sized enterprises (SMEs) include cost savings, sustainability, and the potential for new market opportunities. The future outlook is promising, contingent upon continued investments, technological innovations, and supportive policies. Regional cooperation will play a pivotal role in overcoming challenges related to the adoption of green hydrogen and green ammonia technologies, paving the way for Asia-Pacific to emerge as a pioneer in the field.

Introduction

The Asia-Pacific region is a geographically and economically diverse area, comprising some of the world's largest and fastest-growing economies. These include China, India, Japan, and the Republic of Korea. The Asia-Pacific region is confronted with significant challenges about energy security, environmental sustainability, and economic growth. The concurrent processes of rapid industrialisation, urbanisation, and population growth have led to an increased demand for energy, making the transition to sustainable energy systems a critical necessity (UNESCAP, 2022). The Asia-Pacific region, which is home to some of the world's largest energy consumers and carbon emitters, must address its reliance on fossil fuels to combat climate change effectively (IRENA, 2022). The Asia-Pacific region is particularly susceptible to the adverse effects of climate change, including rising sea levels, extreme weather events, and biodiversity loss (Climate Policy Info Hub, 2022). Consequently, there is a pressing need for the development of innovative and sustainable energy solutions to ensure long-term environmental and economic stability. Green hydrogen, produced using renewable energy sources, represents a promising solution to the aforementioned challenges. Green hydrogen is a versatile energy carrier that can be utilized in a multitude of applications, including power generation, transportation, and industrial processes. As a result, it is a pivotal component of the future energy landscape (IEA, 2021). Furthermore, green ammonia, produced from green hydrogen, represents another avenue for sustainable energy storage and transport (NREL, 2022). This article examines the potential, opportunities, and challenges of green hydrogen and green ammonia technologies in the Asia-Pacific region, emphasizing the significance of technological advancements, supportive policies, and regional collaboration.

Technology trends

Green hydrogen overview

Green hydrogen is produced through the process of water electrolysis, which employs renewable electricity to split water into hydrogen and oxygen. In contrast to grey hydrogen, which is derived from natural gas and is associated with significant CO_2 emissions, green hydrogen is a zero-emission fuel, as it utilizes renewable energy sources such as wind, solar, or hydropower. This makes it a crucial component in the transition to a sustainable energy system and the fight against climate change (U.S.DOE, 2021). The process of producing green hydrogen involves several key steps:

1. Renewable Electricity Generation: The generation of electricity from renewable sources is a topic of growing interest in the context of climate change. Energy derived from renewable sources, including wind, solar, and hydropower, is generated without the emission of greenhouse gases. Subsequently, the electricity is utilized to facilitate the electrolysis process.
2. Water Electrolysis: The process of water electrolysis is as follows: In the process of electrolysis, an electric current is passed through water (H_2O) to separate it into hydrogen (H_2) and oxygen (O_2). The most

common methods of electrolysis are proton exchange membranes (PEM), solid oxide electrolysis cells (SOEC), and alkaline electrolysers. Each method has its own set of advantages and specific applications, which are discussed in detail below (Gouws et al., 2024).

3. Hydrogen Storage and Distribution: The storage and distribution of hydrogen are crucial aspects of the hydrogen economy. Subsequently, hydrogen must be stored and distributed efficiently. This can be achieved through several different methods, including compression, liquefaction, and chemical storage in compounds such as ammonia or metal hydrides (Shin, 2022).
4. Utilisation: The utilisation of hydrogen is a crucial aspect of its storage and distribution. Green hydrogen can be employed in a multitude of applications, including fuel cells for transportation, as a feedstock for industrial processes, and as a direct fuel for heating and power generation. Its versatility renders it an appealing option for the decarbonisation of sectors that are challenging to electrify, such as heavy industry and long-haul transport (Shin, 2022).

National and international technological issues

National strategies and policies

A significant number of countries in the Asia-Pacific region have identified the potential of green hydrogen and green ammonia and are developing national strategies to support their development. Policies that facilitate research and development, provide subsidies for renewable energy projects, and establish regulatory frameworks for safety are crucial for creating an enabling environment for green hydrogen and green ammonia.

1. **India:** India aims to establish itself as a global hub for green hydrogen production with an annual production target of 5 million metric tons by 2030. The Indian government has committed significant investments and incentives for green hydrogen production and electrolyser manufacturing. The mission emphasizes innovation, public-private partnerships, and strategic international collaborations to advance green hydrogen technology and infrastructure development. (KIEP, 2024)
2. **Japan**: The Japanese government has established a goal of establishing a hydrogen society by 2030, as outlined in the country's Basic Hydrogen Strategy. The Japanese government has earmarked over ¥70 billion ($640 million) for hydrogen-related projects, including subsidies for hydrogen fuel cell vehicles and infrastructure. Additionally, Japan is pursuing international partnerships to ensure a reliable supply of green hydrogen and green ammonia. This includes agreements with Australia and Brunei for the importation of these resources (METI, 2022).
3. **Australia**: The Australian National Hydrogen Strategy presents a comprehensive vision for the large-scale production of hydrogen, capitalizing on the country's substantial renewable energy resources. The Australian government has pledged AUD 370 million ($280 million) in support of hydrogen projects through grants and investments. Initiatives such as the Hydrogen Energy Supply Chain (HESC) project have the objective of producing green hydrogen in Australia for export to Japan. This would demonstrate Australia's potential to become a significant exporter of green hydrogen and green ammonia (Austrade, 2022).
4. **The Republic of Korea**: The Republic of Korean Hydrogen Economy Roadmap aspires to position the country as a global leader in green hydrogen technology by 2040. The plan encompasses targets for hydrogen production, infrastructure development, and the deployment of hydrogen fuel cell vehicles. The government has announced plans to invest KRW 2.6 trillion ($2.2 billion) by 2025 to support green hydrogen and green ammonia projects. The objective is to develop a domestic production capacity of 5 million tons per year by 2040(MOTIE, 2022).
5. **China**: China has set ambitious targets for the development of green hydrogen and green ammonia as part of its 14th Five-Year Plan. These targets include the establishment of 1,000 hydrogen refuelling stations by 2025 and the deployment of 1 million green hydrogen fuel cell vehicles by 2035. Additionally, the government is investing heavily in research and development, with a particular focus on reducing costs and improving the efficiency of production and storage technologies (IEA, 2023).

Case studies

India's National Green Hydrogen Mission

India has launched an ambitious initiative to position itself as a global leader in the production and use of green hydrogen. (MNRE, 2024)

1. **Green Hydrogen Production Plants:** India is setting up several green hydrogen production plants across the country, taking advantage of its vast renewable energy resources, particularly solar and wind power. These plants aim to integrate renewable energy with hydrogen production to achieve large-scale green hydrogen production.
2. **Public-Private Partnerships:** The mission promotes partnerships between government and private sector stakeholders to stimulate investment and technology development in green hydrogen. Key industries such as steel, cement, and fertilizers will be targeted for decarbonisation through the use of green hydrogen.
3. **Export Potential:** India aims to become a significant exporter of green hydrogen by establishing trade partnerships with countries seeking to reduce their carbon footprint. Strategic collaborations with international stakeholders will be pursued to strengthen global green hydrogen trade networks.

Japan's Hydrogen Society Initiative

Japan has been at the vanguard of green hydrogen development, with its Hydrogen Society Initiative aiming to establish a comprehensive hydrogen supply chain. The initiative encompasses investments in green hydrogen production, distribution, and utilisation, which are supported by government policies and industry partnerships.

1. **Fukushima hydrogen energy research field (FH2R)**: This facility, which commenced operations in 2020, is one of the largest green hydrogen production sites in the world, with the capacity to produce up to 900 tons of green hydrogen annually through the use of solar power. The project exemplifies the integration of renewable energy and green hydrogen production on a large scale. FH2R serves as a model for other regions seeking to develop green hydrogen production capacities (NEDO, 2020).
2. **Toyota's hydrogen fuel cell vehicles**: Toyota has been a pioneer in the development of green hydrogen fuel cell vehicles (FCVs), with its Mirai model representing one of the first commercially available green hydrogen cars. Additionally, the company is engaged in the development of green hydrogen-powered trucks and buses. Pilot projects in Japan and other countries are demonstrating the potential of green hydrogen in the transportation sector (TOYOTA, 2024).
3. **Kawasaki Heavy Industries' hydrogen supply chain**: Kawasaki is spearheading a project to establish a hydrogen supply chain between Australia and Japan. This involves the production of green hydrogen and green ammonia in Australia and their transportation to Japan in liquid form. This project exemplifies the viability of international green hydrogen and green ammonia trade and underscores the prospect of regional collaboration in the advancement of green hydrogen economies (NEDO, 2023).

Australia's hydrogen roadmap

The Australian Hydrogen Roadmap delineates the country's strategic plan to become a significant contributor to the global green hydrogen and green ammonia market. The roadmap emphasizes the potential for Australia to utilize its abundant renewable energy resources to produce green hydrogen and green ammonia for domestic use and export (Austrade, 2022).

1. **HyResource project**: The objective of this project, situated in Western Australia, is to generate up to 100,000 tons of green hydrogen annually through the use of wind and solar power. The project serves to illustrate Australia's potential to export green hydrogen to countries such as Japan and the Republic of Korea, which are seeking to diversify their energy sources (CSIRO, 2024).
2. **Queensland hydrogen industry strategy**: The state of Queensland has developed a comprehensive hydrogen industry strategy, with a particular focus on the production, utilisation, and export of green hydrogen. The state government has pledged AUD 19 million ($14 million) in support of green hydrogen initiatives, including the establishment of a hydrogen industry development fund and the construction of green hydrogen refuelling stations (Queensland GOV., 2019).
3. **H2U Eyre Peninsula Gateway project**: The objective of this project is to develop a large-scale green hydrogen production facility in South Australia, with a particular focus on the production of green hydrogen for export to Asian markets. The project encompasses the construction of a 75 MW electrolyser powered by wind and solar energy, with the potential for expansion to 1,000 MW in the future (GSA, 2024).

The Republic of Korea's Hydrogen Economy Plan

The Republic of Korea's Hydrogen Economy Roadmap aspires to position the country as a global leader in green hydrogen technology by 2040. The plan encompasses targets for the production of green hydrogen, the development of infrastructure, and the deployment of green hydrogen fuel cell vehicles (IEA, 2020).

1. **Ulsan hydrogen town**: The pilot project integrates green hydrogen into residential and commercial energy systems, including hydrogen-powered buses, fuel cell systems for buildings, and green hydrogen refuelling stations. The project serves as a model for other cities in the Republic of Korea and the region (ULSAN, 2013).
2. **Hyundai's hydrogen fuel cell vehicles**: Hyundai is a global leader in the development of green hydrogen fuel cell vehicles (FCVs), with its NEXO model representing one of the most advanced green hydrogen cars currently available. Additionally, the company is engaged in the development of green hydrogen-powered trucks and buses. Pilot projects in the Republic of Korea and other countries have demonstrated the potential of green hydrogen in the transportation sector (Hyundai, 2024).
3. **Korea Gas Corporation's hydrogen projects**: The Korea Gas Corporation (KOGAS) is investing in the development of green hydrogen production and distribution infrastructure. This includes the construction of green hydrogen refuelling stations and the establishment of a green hydrogen production facility using renewable energy sources. The company's objective is to produce 1.2 million tons of green hydrogen annually by 2040 (KOGAS, 2024).

Regional cooperation and future prospects

Regional cooperation must be established to overcome the challenges associated with the adoption of green hydrogen and green ammonia. Initiatives such as the Asia-Pacific Hydrogen Association facilitate collaboration among countries to facilitate the sharing of knowledge, technologies, and best practices.

1. **APAC hydrogen project**: This collaborative initiative involves multiple countries in the Asia-Pacific region working together to develop a regional green hydrogen supply chain. The project encompasses joint research and development initiatives and coordinated investments in infrastructure (GH2, 2024).
2. **ASEAN hydrogen task force**: The Association of Southeast Asian Nations (ASEAN) has established a task force to promote the development of green hydrogen and green ammonia technologies in the region. The task force's primary objectives are to facilitate collaboration between member countries, disseminate best practices, and develop regional standards and regulations for green hydrogen and green ammonia technologies (Hydrogen ASEAN, 2024).

Benefits of green hydrogen to small and medium scale enterprises (SMEs) in the Asia-Pacific region

Small and medium-sized enterprises (SMEs) in the Asia-Pacific region are poised to realize significant gains from the adoption of green hydrogen technologies. The aforementioned benefits encompass a spectrum of advantages, including operational cost savings and enhanced sustainability, as well as the creation of new business opportunities and regulatory compliance. The following paragraphs will outline the key ways in which green hydrogen can benefit SMEs in the region (ESCAP, 2024; Mavian et al., 2022).

Energy cost savings

Green hydrogen represents a cost-effective and reliable energy source for small and medium-sized enterprises (SMEs), particularly in areas with high renewable energy potential.

- **Local energy production**: Small and medium-sized enterprises (SMEs) have the potential to produce green hydrogen using locally available renewable resources, thereby reducing their dependency on expensive and volatile fossil fuel imports.
- **Stabilizing energy costs**: The use of renewable energy for hydrogen production allows small and medium-sized enterprises (SMEs) to mitigate the impact of fluctuating energy prices and to secure long-term energy cost savings.

Sustainable business practices

The adoption of green hydrogen can assist small and medium-sized enterprises (SMEs) in enhancing their sustainability profiles, which is becoming increasingly important for attracting customers, investors, and partners.

- **Carbon footprint reduction**: The transition to green hydrogen represents a significant opportunity for small and medium-sized enterprises (SMEs) to reduce their carbon emissions, thereby contributing to global climate goals and enhancing their environmental credibility.
- **Sustainability certifications**: The utilisation of green hydrogen can facilitate the attainment of sustainability certifications and labels by small and medium-sized enterprises (SMEs), thereby enhancing their marketability and competitiveness.

Energy security and reliability

- Green hydrogen represents a reliable energy source that can enhance the energy security of small and medium-sized enterprises (SMEs).
- A backup power supply is a system that provides power to a facility when the primary power source is unavailable. Hydrogen fuel cells can serve as a backup power source during grid outages, thereby ensuring uninterrupted business operations.
- Energy Independence: The generation of hydrogen on-site by SMEs can result in a reduction in their reliance on external energy suppliers and an enhancement of their energy independence.

Access to new markets and business opportunities

- The advent of the green hydrogen economy presents a plethora of new market opportunities and business prospects for small and medium-sized enterprises (SMEs).
- The production and services sector of the green hydrogen economy is a significant area of opportunity for SMEs. Small and medium-sized enterprises (SMEs) may enter the green hydrogen market by providing production, storage, and distribution services. This encompasses the establishment of small-scale hydrogen production facilities or the provision of hydrogen refuelling infrastructure.
- Technology and Innovation: Small and medium-sized enterprises (SMEs) may develop innovative technologies and applications for green hydrogen, including fuel cells, hydrogen-powered machinery, and other end-use applications.

Support from government policies and incentives

- The governments of the Asia-Pacific region are increasingly providing support for the adoption of green hydrogen through the implementation of various policies and incentives. One such incentive is the provision of grants and subsidies. Small and medium-sized enterprises (SMEs) may be eligible for government grants and subsidies to assist with the establishment of green hydrogen infrastructure and the adoption of hydrogen technologies.
- The implementation of policies that encourage the utilisation of renewable energy and low-carbon technologies can facilitate an environment conducive to the adoption of green hydrogen solutions by SMEs.

Collaboration and partnerships

Green hydrogen initiatives frequently facilitate collaboration between a diverse array of stakeholders, including small and medium-sized enterprises

(SMEs), large corporations, research institutions, and governments.

- **Collaborative projects**: Small and medium-sized enterprises (SMEs) may engage in collaborative projects and pilot programs, thereby gaining access to technical expertise, financial resources, and market networks.
- **Industry alliances**: The formation of alliances and partnerships with other companies and organisations can assist small and medium-sized enterprises (SMEs) in leveraging collective strengths and accelerating the adoption of green hydrogen.

Compliance with environmental regulations

The adoption of green hydrogen can assist small and medium-sized enterprises (SMEs) in complying with the increasing environmental regulations and standards (TRC, 2024).

- **Meeting emission targets**: Small and medium-sized enterprises (SMEs) may utilize green hydrogen to fulfil regulatory emission targets and circumvent penalties associated with non-compliance.
- **Corporate Social Responsibility (CSR)**: The adoption of green hydrogen can facilitate the advancement of corporate social responsibility (CSR) initiatives among small and medium-sized enterprises (SMEs), thereby demonstrating their commitment to sustainability and responsible business practices.

Enhanced competitiveness

The utilisation of green hydrogen can assist small and medium-sized enterprises (SMEs) in enhancing their competitiveness within the market.

- **Differentiation**: The adoption of green hydrogen by SMEs offers a means of differentiating themselves from competitors who rely on traditional energy sources. This can attract environmentally conscious customers and investors.
- **Innovation and efficiency**: The utilisation of hydrogen technologies has the potential to drive innovation and enhance operational efficiency, thereby leading to cost savings and the generation of superior product offerings.

Future outlook

The future of green hydrogen and green ammonia in the Asia-Pacific region appears promising, with an increase in investments, technological innovations, and supportive policies. Continued efforts to address economic and infrastructural challenges will be crucial for the successful integration of green hydrogen and green ammonia into the region's energy systems.

1. **Investment in research and development**: Ongoing investments in research and development must be made to enhance efficiency and reduce the costs associated with the production, storage, and distribution of green hydrogen and green ammonia. Governments and private companies must continue to provide financial support for innovative projects and to facilitate collaboration between research institutions and industry.
2. **Public awareness and acceptance**: It is imperative that the general public is aware of and accepts green hydrogen and green ammonia technologies if they are to be adopted on a widespread basis. Governments and industry must collaborate to disseminate information about the advantages of green hydrogen and green ammonia to the public, while also addressing any concerns related to safety and environmental impact.
3. **Policy and regulatory support**: The development of a green hydrogen and green ammonia economy is contingent upon the provision of robust policy and regulatory support. To facilitate the safe and reliable operation of green hydrogen and green ammonia infrastructure, governments must establish clear and consistent policies, provide financial incentives, and develop international standards and regulations.
4. **Regional cooperation**: Regional cooperation will play a pivotal role in overcoming the challenges associated with the adoption of green hydrogen and green ammonia. To facilitate the development of a robust and sustainable green hydrogen and green ammonia supply chain in the Asia-Pacific region, countries within this region must collaborate to share best practices, coordinate investments in infrastructure and research, and establish a unified approach to the advancement of these technologies.

Conclusion

The Asia-Pacific region stands to benefit significantly from the adoption of green hydrogen and green ammonia as transformative opportunities to achieve sustainable energy goals and combat climate change. By addressing the challenges of technology scale-up, commercialisation, and infrastructure development, countries in the region can fully realize the potential of green hydrogen and green ammonia technologies. The implementation of strategic policy frameworks, market incentives, and regional cooperation will be pivotal in facilitating the transition towards a future powered by green hydrogen and green ammonia.

Acknowledgment

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Unveiling India's green hydrogen economy

Opportunities and challenges

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Abstract

Fossil fuels have significantly impacted climate change, contributing extensively to greenhouse gas emissions. As energy is linked to 74% of the targets of the Sustainable Development Goals (SDGs), its critical role in global sustainability is evident. Renewable energy, particularly green hydrogen, has substantial potential to reduce these emissions and mitigate climate change. During the UN Summit in 2015, various countries, including those in the Asia-Pacific region, set ambitious climate action agendas. India, a key player in this region, has committed to achieving net zero carbon emissions by 2070. This article provides a comprehensive overview of India's green hydrogen initiatives and its efforts to achieve this target. It addresses several challenges critical to the development of a green hydrogen economy, including water, energy, and land footprints, cost-effectiveness, and material requirements. These factors are crucial for the holistic and responsible development of a green hydrogen economy in India.

Introduction

Climate change is one of the most pressing global challenges of the 21st century, characterized by significant alterations in weather patterns, rising sea levels, and increased frequency of extreme weather events. These changes are primarily driven by the excessive emission of greenhouse gases (GHGs), particularly carbon dioxide (CO_2) (IPCC, 2021).

Hydrogen is emerging as a crucial player in the fight against climate change due to its potential as a clean, versatile, and sustainable energy carrier. When produced using renewable energy sources, hydrogen can be a zero-emission alternative to fossil fuels. It can be used in various sectors, including transportation, industry, and power generation, thus contributing significantly to the reduction of GHG emissions (Sharma et al., 2023; Hren et al., 2023)

Globally, countries are investing in hydrogen research, infrastructure, and market development to accelerate the transition to a hydrogen economy (van Renssen, 2020). Different countries have set their target to achieve net zero carbon. In the Asia-Pacific region, several countries are at the forefront of adopting hydrogen to combat climate change. Japan has been a pioneer in hydrogen technology, with its Basic Hydrogen Strategy aiming to establish a "hydrogen society" by integrating hydrogen into its energy mix. The Republic of Korea is also making significant strides with its Hydrogen Economy Roadmap, which envisions the widespread use of hydrogen across various sectors. Australia, rich in renewable energy resources, is positioning itself as a major player in the global hydrogen market by investing in large-scale hydrogen production and export projects. China, with its vast industrial base, is focusing on scaling up hydrogen production and developing fuel cell technologies to reduce its carbon footprint.

The government of India also laid down the vision, intent, and direction for harnessing hydrogen energy by launching a National Hydrogen Mission for generating hydrogen from green power sources considering hydrogen as a beacon of hope for climate-neutral power generation and its important role in a successful energy transition. The Union Cabinet on 4th January 2023 announced an initial outlay of ₹19,744 crores ($2.3 billion), to produce 5 MMT (Million Metric Tonnes) per annum with an associated renewable energy capacity addition of about 125 GW by 2030 (National Green Hydrogen Mission report, 2023; Kar et al., 2023).

The major ministries in India responsible for energy and related matters include the Ministry of New and Renewable Energy (MNRE), the Ministry of Power (MoP), the Ministry of Petroleum and Natural Gas (MoPNG), the Ministry of Coal (MoC) and the Department of Atomic Energy (DAE). Ministry of Science and Technology (MoST), Department of Science and Technology (DST), Department of Biotechnology (DBT), Department of Scientific and Industrial Research (DSIR), Department of Atomic Energy (DAE), Ministry of Coal (MoC), Ministry of Earth Science (MoES), Ministry of Heavy Industries (MoHI), Ministry of New and Renewable Energy (MNRE), Ministry of Power (MoP), Ministry of Petroleum and Natural Gas (MoPNG) are main funding agencies. In addition, various Ministries have released draft green hydrogen policies at the state level and have issued several scheme guidelines under the Strategic Interventions for Green Hydrogen Transition (SIGHT) program. These initiatives aim to establish hydrogen

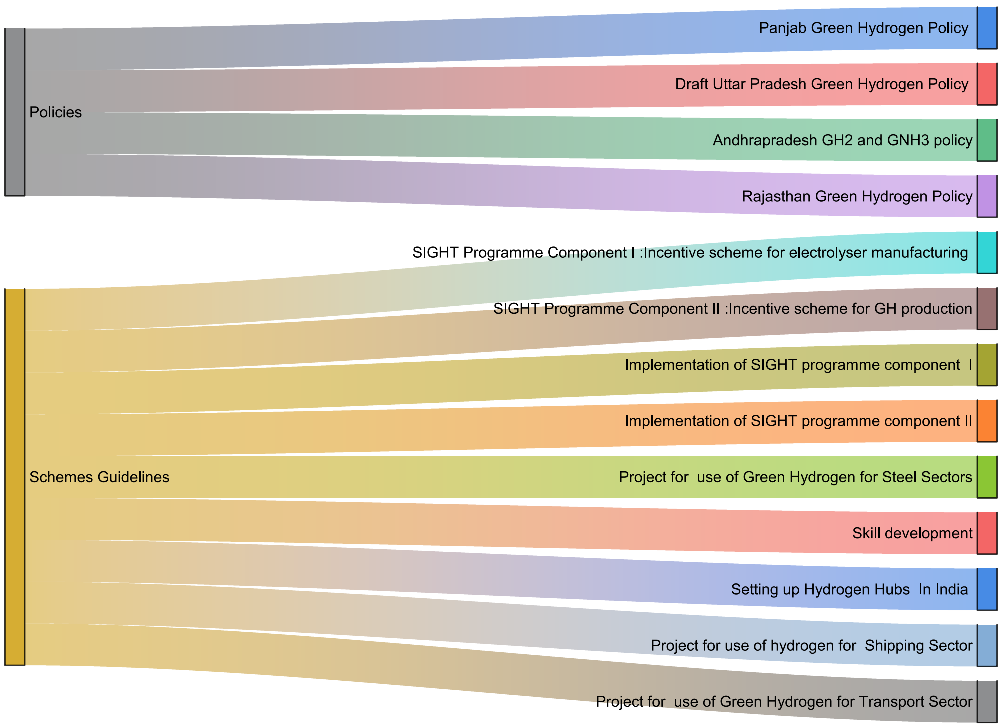

Figure 1a: State-level green hydrogen policy and scheme guidelines

(*Source*: created by author using data available on https://nghm.mnre.gov.in/)

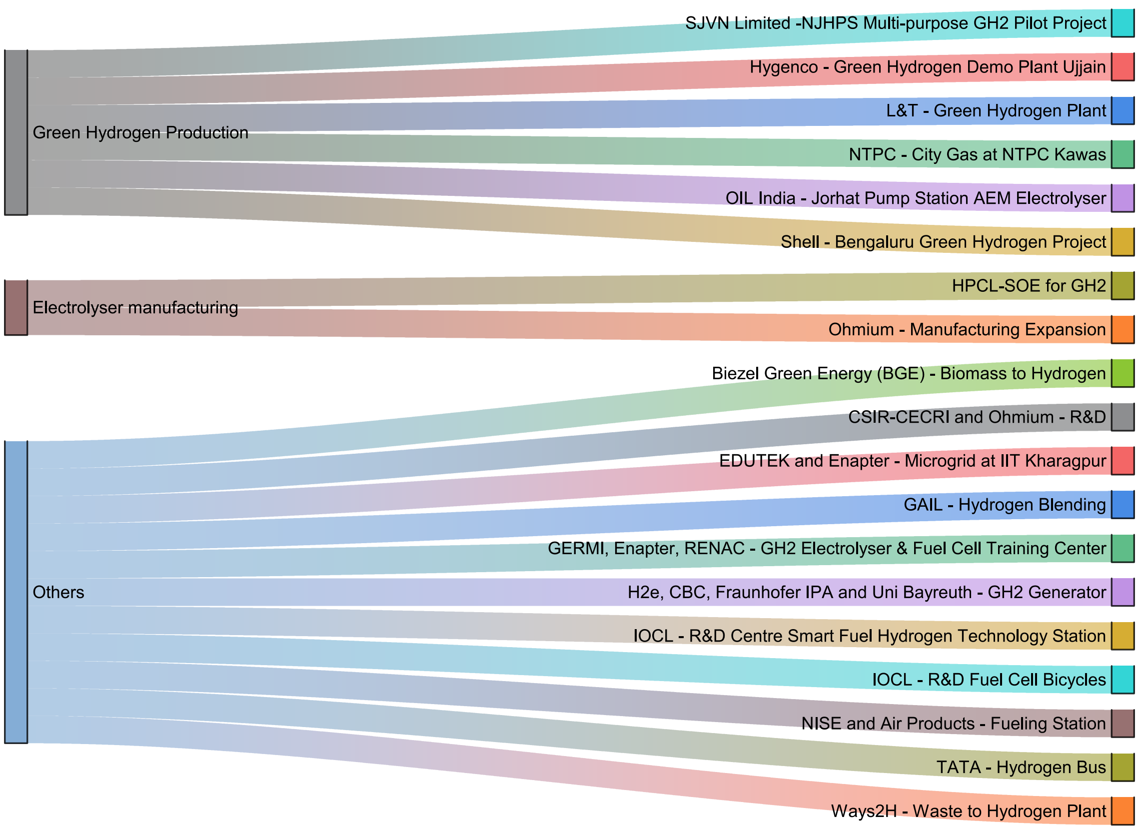

Figure 1b: Commissioned green hydrogen projects in India

(*Source*: created by author using data available on https://nghm.mnre.gov.in/)

hubs, develop relevant skills, and promote the use of hydrogen in various industries such as steel and iron. Furthermore, multiple green hydrogen and electrolyser manufacturing projects have been commissioned in collaboration with industries such as Shell, L&T, Ohmium, etc. (Figure 1a; 1b**)**.

India's green hydrogen economy: challenges and opportunities

The hydrogen economy holds great potential for a sustainable and clean energy future. However, it also presents certain challenges and risks that need to be addressed for "de-risking" the hydrogen economy. This section addresses the water, Energy, Land footprints, cost, and material challenges. This reveals some positive factors related to cost on one side but also addresses to look carefully the water energy land and material issues, important for the successful implementation of a hydrogen economy

Water footprint

Water demand for hydrogen production is achieved through electrolysis and renewable energy, 9 Liters of H_2O required for 1 kg of H_2 (Mehmeti, 2021). According to research, the demand for hydrogen in the renewable future scenario will be 2.3 x 10^{29} Kg or 2.3 Gt per year (Oliveria et al', 2021) For the electrolysis process, it will be 20.7 Gt per year of freshwater or 20.7 billion cubic meters or 20.7 x 1012 Liter, "which accounts for 1.5 ppm of Earth's available freshwater" (Beswick et al., 2021). However, water demand is remarkable in the case of energy production and power generation by fossil fuels. 251 billion cubic meters of freshwater were withdrawn by them, and 31 billion cubic meters were consumed (IEA,2017) Even if 20.7 billion cubic meters of H_2 production is totally consumed, it is still 33% less than the consumption by fossil fuels (Beswick et al., 2021). Moreover, as the energy industry moves more towards renewable technologies, fossil fuel energy sources themselves will become fossilized. As a result, employing hydrogen as a means of achieving a renewable energy society will result in significant water savings rather than expenditures.

As far as the Indian scenario is concerned, with electrolysis, India's whole hydrogen requirement would be around 54 x 10^9 Liters now, rising to around 270 x 10^9 Liters by 2050 (Hall et al., 2020). The overall usable water supply in India is 700 - 1,200 x 1012 liter, albeit this is decreasing due to overuse and climate change (Ramesh, 2021). According to this, electrolysis would utilize no more than 0.05 percent of India's total water supply. One shouldn't forget that agriculture acquires a major share of India's water consumption and with the changing climate and the growing urbanizing population, the force exerted on India's water crises will be high. Also, India's water is largely drawn from the monsoon, and it varies widely in accordance with the geography, time of year, season, and different years. Moreover, while many of us worry about rising sea levels, we ignore the role of subsidence, or where the land sinks as we pump out groundwater, as is happening in many coastal cities in India. When land sinks, saltwater can more easily push into groundwater

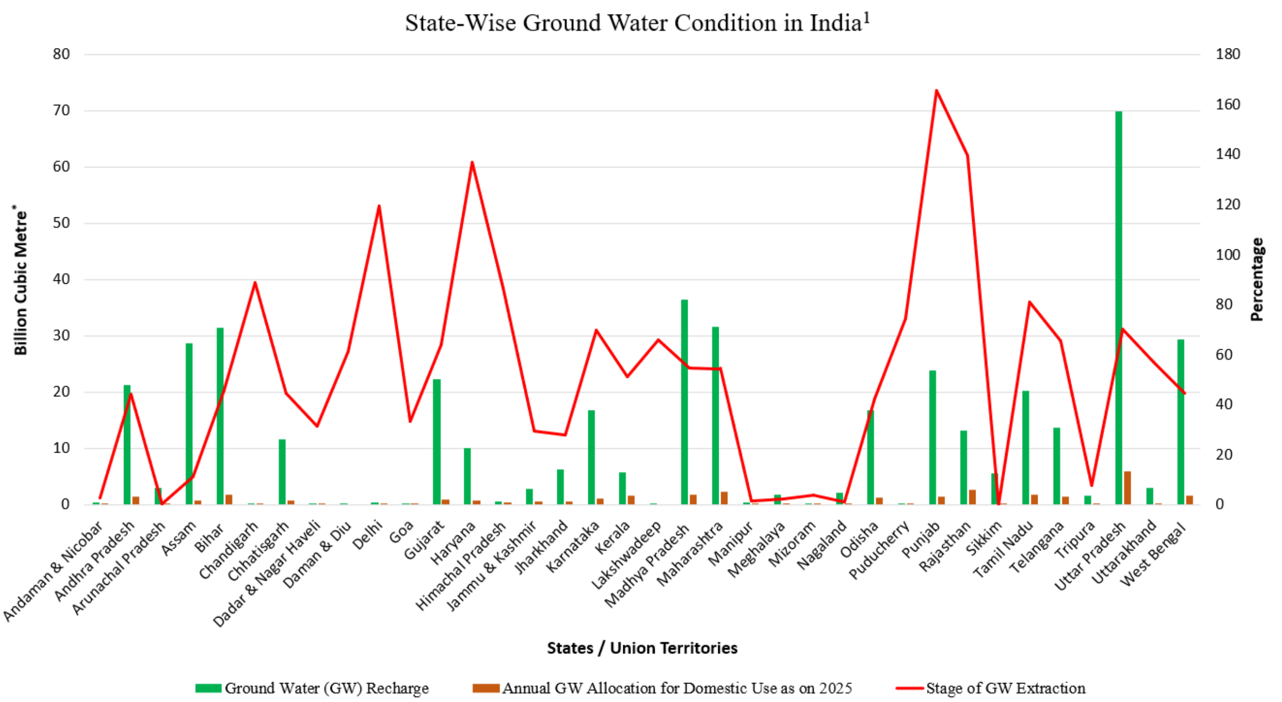

Figure 2: State-wise groundwater dynamics: recharge, domestic allocation, and extraction patterns in India (Source: Ground Water Year Book - India 2019-20, Central Ground water Board)

aquifers, reducing the supply of drinking water in coastal cities. Also, a warming climate also stresses every other facet of India's water conditions. Supply falls in a hotter climate as more water evaporates from reservoirs, especially during the summer and in drier geographies. So, in summer the electricity generated may be sufficient to power electrolyzes but the squabbles over shrinking water supply will intensify between Haryana, Delhi, Punjab, and Rajasthan (Figure 2) where the stage of ground water extraction is very high, i.e., more than 100%, which implies that in these states the annual groundwater consumption is more than annual extractable ground water resources. In the states of Himachal Pradesh, Tamil Nadu, Uttar Pradesh, and UTs of Chandigarh and Puducherry, the stage of ground water extraction is between 70-100%. In the rest of the states or UTs, the stage of ground water development is below 70% (CGWB 2019).

Further investigation would evaluate the specific water resources used and the sustainability of using the water, as competition and disputes among agriculture, industry, and cities over limited water supplies are already growing. Because water is utilized throughout the production supply chain and diverse production processes are highly interconnected, it is vital to measure water consumption across a fuel's life cycle to comprehend water-related consequences (CGWB 2019).

Land requirement

Recently, there have been studies exploring the implications of large-scale multi-gigawatt (GW) hydrogen production facilities, considering the national strategies of several countries. One such study conducted by the Institute for Sustainable Process Technology (ISPT) in the Netherlands focused on a detailed analysis of a 1 GW alkaline and PEM (Proton Exchange Membrane) plant. The study revealed that the land requirements for a PEM electrolyser plant were approximately 13 hectares (0.13 km^2), while an alkaline electrolyser plant required about 17 hectares (0.17 km^2). However, these land requirements could potentially be reduced with more compact designs, with estimates of 8 hectares for PEM and 10 hectares for alkaline electrolysers (ISPT 2020).

Most of the space needed for these plants (65%-75%) is dedicated to the electrolyser building and the electrical equipment, such as switchgears and transformers, while the hydrogen processing section requires the least space. With this calculation, to produce 5 million tons (MT) of green hydrogen in India, an estimated land requirement of approximately 500,000 acres is needed (IRENA Report 2020).

Energy footprints

Energy footprints play a pivotal role in evaluating the viability of hydrogen production. Figure 3 illustrates varying energy requirements across different hydrogen production methods. Water electrolysis emerges as significantly more energy-intensive compared to steam methane reforming. (Martínez-Rodríguez A and Abánades A 2020).

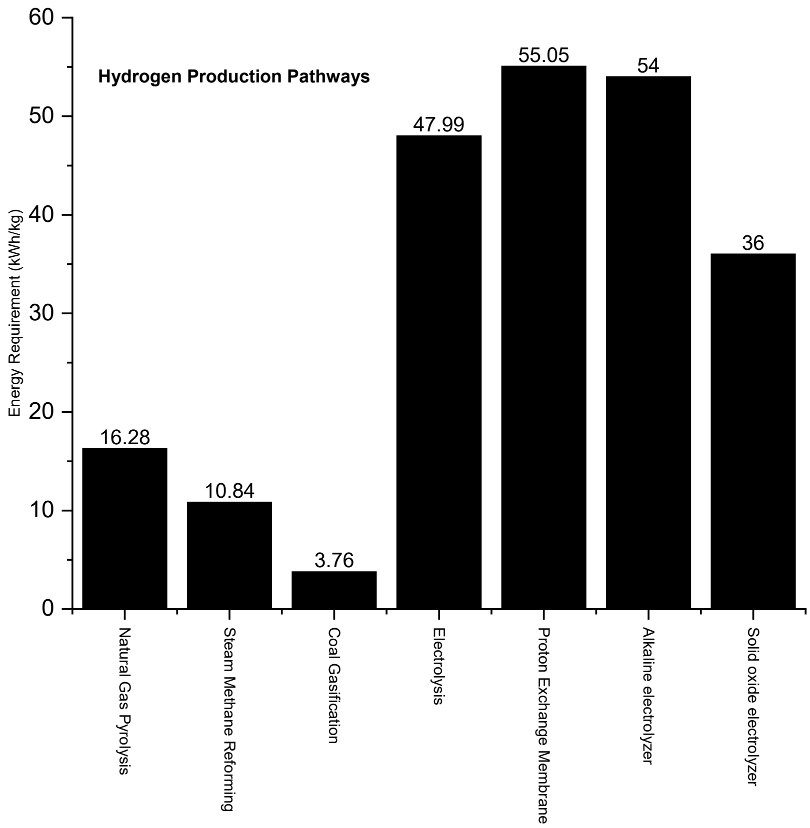

Figure 3: Energy requirements for various hydrogen production pathways

(*Source*: created by author using data from Martínez-Rodríguez A and Abánades A 2020)

Cost-effectiveness

The success of any technology depends on public acceptance. Hydrogen as an energy carrier offers advantages like a high energy density like gasoline, unlike fuel cell EVs. Hydrogen fuel cell vehicles have strong potential to achieve sustainable development goals (Harichandan et al. 2023).

Li and Taghizadeh-Hesary (2022) found that a hydrogen-powered sedan can cover 100 km on 1 kg of hydrogen, while 8-9 litres of petrol are needed for the same distance (costing ~9.21–9.79 USD). With hydrogen costing ~13 USD per kg, its price is comparable to conventional fuels (Figure 4 A & 4 B). This suggests hydrogen fuel has strong potential for societal acceptance in India (Jayakumar et al. 2022, Agarwal et al. 2023).

Awareness about the research advocates the usage of hydrogen fuel, which has great potential in the significant reduction of CO_2 emission, as the carbon emissions of conventional fossil fuel-based vehicles are much higher i.e. 307 g/km than hydrogen production using renewable energy i.e. ~ 42.5 g/km. This scenario will help in the mass acceptance of hydrogen production using renewable energy. The estimated reduction in costs of hydrogen will be 50% by 2030 and it will see an increase in demand up to 5-fold by 2050. India produces 6.7 Mt of H_2 per year and there is an output prediction by The Energy and Resources Institute (TERI) that is going to exceed 11.7 Mt by 2030 (Mehmeti et al. 2018).

The inclusion of the social cost of CO_2 remediation to quantify the extra costs associated with carbon emissions that are not automatically reflected in market prices will help better compare the costs and benefits of hydrogen fuel.

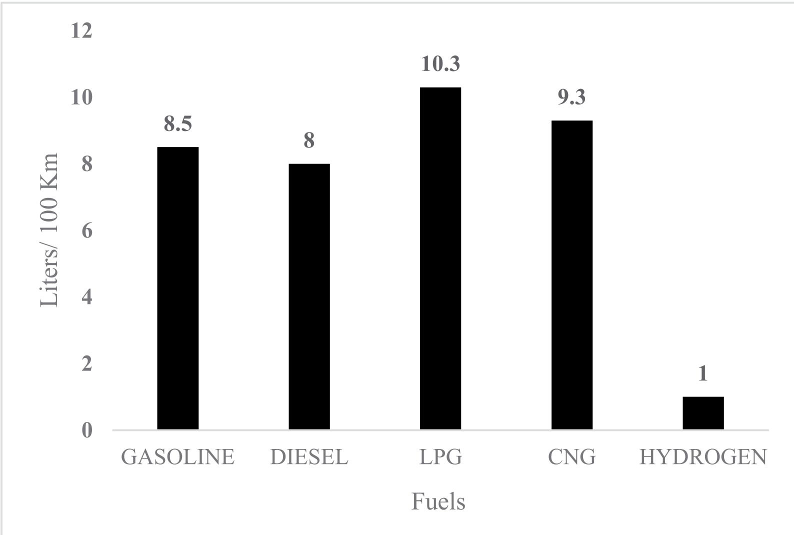

Figure 4A: Fuel consumption (liters per 100 km) for various fuel types

(*Source*: created by author using data from Li and Taghizadeh-Hesary. 2022)

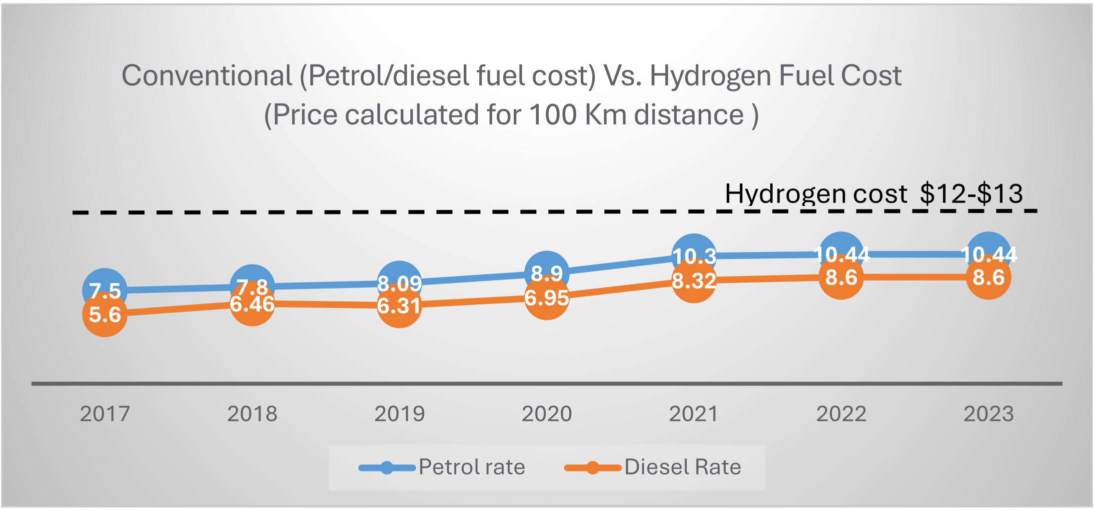

Figure 4B: Annual price trends of various fuels compared to hydrogen per 100 km distance

(*Source*: Created by the author using Li and Taghizadeh-Hesary 2022 data)

Material sustainability and sufficiency

The electrolyser supply chain faces risks due to the regional concentration of critical minerals and metals. For example, PEM electrolysers rely heavily on Platinum and Iridium from South Africa, while China dominates the supply of solid oxide electrolysers. This poses a potential supply chain risk for manufacturers. By 2030, the cost of PEM and PEMFCs is projected to be $80 per kW (Jayakumar et al., 2022). Collaboration with stakeholders is crucial to addressing raw material dependencies (Kiemel et al., 2021). Hydrogen production via sustainable electrolysis is vital for achieving Sustainable Development Goal 7. The growth in global electrolyser demand necessitates an assessment of critical raw material availability, as their scarcity could hinder expansion (Li and Baek, 2020).

To mitigate risks associated with materials like platinum, research is focused on alternative catalysts such as RuO_2, TiO_2, Ni, and Co-Ni alloys. High entropy alloys (HEAs) can also improve mineral sustainability. Improving PEM electrolyser efficiency, currently under 10%, to a target of 77% or higher is essential for scaling up national hydrogen economies (Zhang et al., 2021; Baum et al., 2022).

Conclusions and recommendations

In India, the annual hydrogen requirement through electrolysis is estimated at 54 billion litres, potentially rising to 270 billion litres by 2050 (Hall et al., 2020). Given the intense competition for water resources among agriculture, industry, and urban areas, especially in regions with high groundwater extraction rates, careful management and strategic planning are imperative. To ensure sustainable growth in hydrogen production, we need to regularly check critical raw materials and water resources. Researching alternative catalysts such as RuO_2, TiO_2, Ni, and Co-Ni alloys will reduce our reliance on scarce materials like platinum and iridium. We must also improve PEM electrolyser efficiency to make hydrogen production more effective. Educating the public about the benefits of hydrogen as a clean energy source will encourage acceptance and support. Governments and industries must collaborate to create policies and partnerships that handle raw material needs and build hydrogen infrastructure. These steps will help us transition efficiently and sustainably to a hydrogen-based renewable energy future.

Recommendations for de-risking hydrogen transition to achieve net zero carbon economy

The hydrogen economy has immense potential for a sustainable and clean energy future, but it also comes with challenges and risks that need to be addressed for successful implementation. To ensure a smooth transition to a hydrogen-based economy, India must develop a de-risking strategy. Key areas to focus on include:

Technological development: One of the key aspects of de-risking the hydrogen economy is advancing the development and deployment of hydrogen technologies. This involves conducting extensive research and development to enhance the efficiency, reliability, and safety of hydrogen production, storage, and utilization technologies. By investing in technology development, potential risks associated with scalability, cost-effectiveness, and performance can be minimized.

Infrastructure development: Establishing a robust and widespread hydrogen infrastructure is crucial for the successful implementation of the hydrogen economy. India needs to strategically plan and develop infrastructure

Figure 5: Illustrating recommendations for de-risking the hydrogen economy

so that the risk of inadequate availability and accessibility of hydrogen can be mitigated.

Safety and regulations: Developing comprehensive safety guidelines, standards, and regulations specific to hydrogen technologies to create a secure environment for hydrogen-related activities.

Market development: Efforts towards creating a viable market for hydrogen and its applications. like incentivizing the adoption of hydrogen technologies through supportive policies, financial mechanisms, and market incentives. By creating a favourable market environment, the risk associated with the initial commercialization and market acceptance of hydrogen technologies can be reduced.

International collaboration: global collaboration among governments, industry stakeholders, and research institutions in sharing knowledge, best practices, and resources can accelerate the development and deployment of hydrogen technologies. Collaborative efforts must address challenges related to harmonizing standards, ensuring cross-border trade of hydrogen, and optimizing the global hydrogen supply chain.

By implementing these de-risking strategies, India's transition to a hydrogen economy can be facilitated with reduced uncertainties and potential pitfalls. It enables India to address technical, economic, social, and environmental challenges proactively, ensuring a smooth and successful transformation towards a sustainable energy future powered by hydrogen.

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Sub-national drivers of India's green hydrogen development

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Abstract

India's national government has offered strong support for the development of green hydrogen as part of the country's clean energy transition. However, much of the actual progress in this transition will depend not on national but subnational governments. This paper argues that India's subnational governments have significant potential to capitalise on diverse natural resource endowments while creating jobs and growing the local economy when promoting green hydrogen. At the same time, the national government will need to offer direct and indirect support to address technological, financial, and institutional constraints when promoting green hydrogen at the subnational level. The paper conducts case studies of three Indian states, namely Gujarat, Jharkhand, and Kerala, to examine developments in the hydrogen sector at the sub-national level. The paper then recommends a six-point plan to strengthen the multi-level collaboration needed to capture the full benefits of green hydrogen. The plan consists of the following: 1) tailoring skill development programme to support the green hydrogen ecosystem; 2) closing infrastructure gaps; 3) incentivising off-takers; 4) attracting investment and enabling public-private partnerships; 5) encouraging research and development (R&D); and 6) promoting co-innovation. These six points can help India realise its potential while addressing the attendant limitations of a green hydrogen transition.

Introduction

India's National Green Hydrogen Mission (MNRE, 2023) is strategically important to the country's clean energy transition. The mission is rooted in the realization that hydrogen has considerable potential to decarbonise hard-to-abate sectors like industry, transport, and power generation. It further reflects the need to invest significantly in becoming a global hub for green hydrogen production, usage, and export (Government of India, 2023b); this financial commitment is apparent in the initial outlay of $2.3 billion in 2023 for the Green Hydrogen Mission (PIB, 2023)—a figure that is expected to increase more than 100% by 2024 (ET, 2024). At the same time, the mission also underlines that green hydrogen cannot only contribute to international decarbonisation efforts but foster economic growth and innovation.

Though there are several reasons that the mission is viewed as important, questions are often raised about the capacity of the green hydrogen industry to grow at not simply the national but sub-national levels. More concretely, many subnational governments are keen to develop a green hydrogen ecosystem. However, they may also lack the infrastructure and market support to contribute to those efforts. It is against this backdrop, that this paper argues that India's subnational state governments can tailor green hydrogen plans to suit local conditions and resources. The paper also contends that it will be critical to recognise that some states may need financial, institutional, and technological support from the national government. A mix of direct resource transfers (i.e. block grants) and indirect enabling reforms (i.e. tax incentives), along with overseas technology support, will be critical in this regard. Pulling off this delicate balancing act will require viewing the transition through a multilevel lens.

Toward a multilevel perspective

This paper will use a multilevel perspective to understand factors contributing to the green hydrogen transition, drawing on ideas from sustainability transitions and multilevel governance

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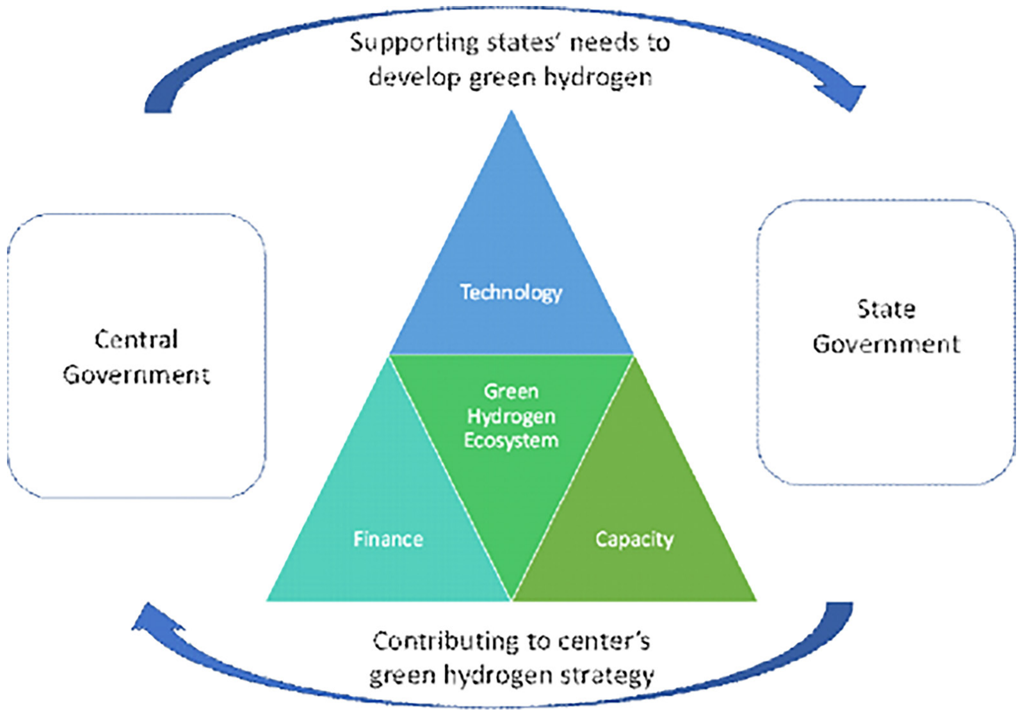

Figure 1: Multilevel governance for green hydrogen ecosystem

Source: Authors

(Betsill and Bulkeley, 2006; Geels and Schot, 2007; Bulkeley and Betsill, 2013; Markard, Geels, and Raven, 2020). A core insight of this work literature is that delivering public goods requires leveraging the skills and assets of central, state, and lower level governments-as evidenced by other public goods such as health and education (Moeko Saito-Jensen, 2015). In short, it necessitates cooperative power-sharing arrangements among all levels of government (NITI Aayog, 2018; Kandpal and Okitasari, 2023).

Research has shown that a top-down climate agreement is unlikely to trigger the systemic changes for a 1.5° C degree future (Osofsky, 2010), but subnational governments can initiate these transformative changes (C40 Cities, Sustainia and Realdania, 2017). This is because subnational authorities often possess local knowledge and motivation needed for their climate solutions (C40 Cities, 2015), linking these solutions to development benefits like jobs and industries (Rabe, 2007; Puppim de Oliveira *et al.*, 2013). However, subnational governments may lack the capacity to effectively implement and scale up these climate solutions (Burch, 2010; Corfee-Morlot *et al.*, 2009).

For simplicity, this paper emphasises the collaboration between national and subnational governments, granting subnational governments autonomy for innovative and locally appropriate solutions, and national support for implementation and scaling (Corfee-Morlot *et al.*, 2009). India's green hydrogen ecosystem will require crafting an effective multilevel power-sharing agreement (Figure 1), leveraging states' natural resources while also addressing technological and financial gaps (Gupta, Kumar and Kumar, 2023; Abhyankar *et al.*, 2023). A successful green hydrogen transition will require collaboration and cooperation among all levels of government, (Dutt, 2023), strengthening both stake and national development targets.

Tracking green hydrogen development plans by the Indian states

The Indian government's initiatives for clean energy prompted the hydrogen market to grow. The country's renewable energy plans are driving investment in the hydrogen sector, particularly in the transportation sector as fuel cell vehicles and hydrogen-powered buses are becoming more promising. States like Kerala, for example, are using hydrogen for water transport. Public-private partnerships are also fostering innovation and expanding the hydrogen energy landscape. Despite challenges like infrastructure development and cost, some states are emerging as major players in the hydrogen economy.

This section examines subnational initiatives and their alignment with India's National Hydrogen Mission, focusing on Gujarat, Jharkhand, and Kerala. In Gujarat, invaluable insights, focusing on policy impacts and business environment, came from Gujarat Energy Research and Management Institute, Indian Institute of Technology (IIT) Gandhinagar, and representatives from industry and the state government. In Jharkhand, discussions with the Jharkhand Renewable Energy Development Authority and the Central University of Jharkhand centred around state policies and capacity. In Kerala, interviews with policymakers, power utilities, and developers helped understand the ambitious green hydrogen goals and challenges.

The assessment was structured into three key subsections: estimated potential, challenges, and strategies. The estimated potential section evaluates each policy, financial resources, technology, and human resources. The challenges section showcases the limitations like renewable energy constraints, technological gaps, and financial hurdles. The strategies section reviews the state's long- and short-term policies for hydrogen development. Together, these sections provide a comprehensive overview of green hydrogen evolution across the studied states.

Case study 1: Overview of state-level developments in green hydrogen in Gujarat

Gujarat, India's third most industrialised state, aims to produce 3 Million Tonnes per Annum (mtpa) of green hydrogen by 2030 and 8 mtpa by 2035 (Government of Gujarat, 2023a). Gujarat, known as the petroleum capital of India, is committed to achieving its net zero target.

Estimated potential

Gujarat has significant green hydrogen potential, thanks to its renewable energy resources, industrial base, and the potential for economic growth. As of March 2023, the state has 21.6 GW of installed renewable energy capacity, with a target of reaching 100 GW by 2030 (Government of Gujarat, 2023b).

The private sector, like Reliance Industries Limited and Adani Group, is involved in setting up green hydrogen production infrastructure in Gujarat, aiming for 99.8 GW of renewable power and 4 million metric tonnes of green hydrogen production annually by 2030. Another company, L&T, is aiming to generate high-purity green hydrogen (99.99%) planning for 15% hydrogen blending with natural gas (LiveMint, 2023). The state government also signed agreements with Ocior Energy in February 2023 to build a facility in Kutch to generate 1 million tonnes of green hydrogen and ammonia per annum.

Gujarat is actively involving industry and implementing strategies to support green hydrogen development, including land allocation and stakeholder consultations. The state aims to create new revenue streams by exporting green hydrogen, which will also strengthen its role in the global hydrogen market.

Challenges

Gujarat faces multiple challenges in developing a hydrogen economy, particularly the lack of adequate and modern electrolysis capacity. It is also crucial to expedite the installation of more renewable energy infrastructure and storage facilities. Despite these challenges, developer's interest in green hydrogen is growing as the government is encouraging public-private partnerships. This optimistic outlook promises future developments and benefits for off-takers.

A critical challenge for the state is the lack of capacity and skilled human resources in the green hydrogen sector. Our research highlights the need for regulators, industrialists, developers, researchers, academicians, original equipment manufacturers (OEMs), and other industry participants to discuss and explore the obstacles, technology readiness level, cost optimisation, and the gap in the existing landscape.

An interviewee from a government organisation estimated around INR 8-10 lakh crore (roughly 100-120 billion USD) investment in the green hydrogen sector over the next 15 years in the state's green hydrogen sector. Yet, more investments are needed in this ecosystem including industry, academia, and research. Furthermore, R&D of storage technologies receives less attention since tenders favour high-readiness projects. More focus is needed on infrastructure, demand creation, R&D, and capacity-building programs.

Strategies

The state government aims to create an ecosystem for small and medium enterprises (SMEs) in the green hydrogen value chains by providing incentives such as capital subsidies and stamp duty waivers. Industry and academic insights assert continuous government support for the green hydrogen industry.

A key measure is the state government's readiness to allocate land for setting up renewable energy for green hydrogen production. The Gujarat Power Corporation Limited has already allotted 1,99,000 hectares of land in the Kutch-Banaskantha border areas for green hydrogen production to several companies including Reliance, Adani, Torrent Power, ArcelorMittal Nippon Steel India and Welspun Group.

The plan for developing a green hydrogen hub is an important milestone. The government has identified key players in the production, storage, transportation, and end use, including plans for electrolyser plants and storage facilities. It is expected that the industrial sectors like steel, fertilisers, and refineries will be primary consumers, aligning perfectly with the national targets.

Case study 2: State-level developments in green hydrogen in Jharkhand

Jharkhand hosts several major industries, like iron and steel, cement, mining, transport vehicles, and fertilisers, which can be potential consumers and producers of green hydrogen. Committed to promoting green hydrogen. The state has formed a task force and signed agreements for green hydrogen projects. The task force evaluates global best practices in hydrogen utilization and intends to develop a roadmap for (Bisoee, 2023), to develop 5,000 MW solar power capacity, incentivising land leasing for solar farms' green power generation (Deogharia, 2021).

Estimated potential

Two key drivers underpinning Jharkhand's strategic promotion of green hydrogen are deployment and manufacturing. The deployment driver aims to stimulate green hydrogen demand across sectors, including transport, industry, power, and agriculture. Concurrently, the manufacturing driver seeks to position Jharkhand as a hub for green hydrogen production and supply chains (The Pioneer, 2023). This dual focus stimulates demand and aligns with the state's broader economic goals. Jharkhand, with substantial reserves of critical minerals such as graphite, is poised to emerge as a promising manufacturing hub. Graphite, essential for batteries, fuel cells, and high-tech applications, complements the green hydrogen industry, supporting livelihoods, and job creation, and leveraging the state's renewable energy potential and industrial base.

The Jharkhand Task Force on the Green Hydrogen Mission oversees state-level initiatives, comprising officials from the Energy and Forest departments, NTPC, CCL, and Tata Steel, with technical support from CEED (Centre for Energy and Environment Development). This collaboration guides policy execution, ensures departmental coordination, and enhances industry partnership (CEED, 2023). The Departments of Mines and Geology, and Industries engage stakeholders to develop Jharkhand's green hydrogen ecosystem. Simultaneously, the Department of Energy serves as the nodal agency for state-level renewable energy projects.

Jharkhand actively engages with industries to shape strategies for green hydrogen production and utilisation. A significant milestone is the formal approval of the *"Hydrogen Fuel Project "* in Jamshedpur, marking the launch of production of over 4,000 hydrogen internal combustion engines and 10,000 battery systems. Subsequent phases of the project will expand into advanced chemistry batteries, hydrogen fuel cells, and hydrogen fuel delivery systems in collaboration with TCPL Green Energy Solutions Private Ltd. (Ray, 2023).

Additionally, Tata Steel's trial of injecting hydrogen into the 'E' Blast Furnace at its Jamshedpur Works is another milestone in sustainable steelmaking in India (Tata Steel, 2023). The trial explores the viability of hydrogen as a fuel source, providing crucial insights for future green hydrogen initiatives.

Jharkhand's green hydrogen initiatives present possibilities for remarkable growth, supported by several projects such as Tata Steel's trial and collaboration with TCPL Green Energy Solutions. The state also aims to attract developers by leveraging its industrial strength offering a business-friendly environment with transparent rules and streamlined processes for green hydrogen projects.

Challenges

Jharkhand faces challenges inherent in the nascent stage of entering the green hydrogen sector. Creating a comprehensive and supportive ecosystem tailored to the state's unique context is crucial, coupled with the need for developing robust renewable energy sources to power electrolysis. Ensuring access to cutting-edge electrolyser technology and fostering local manufacturing capabilities are key priorities for Jharkhand's green hydrogen journey.

Developing effective storage solutions for intermittent renewable energy sources and building an efficient hydrogen transportation network presents a complex task. Balancing innovation, safety, and environmental sustainability is essential for a conducive environment. The state also emphasises the importance of R&D plans to fund R&D initiatives that address the specific challenges in green hydrogen production.

Strategies

The green hydrogen task force envisions a pivotal role in Jharkhand's future administrative landscape by fostering stakeholder collaboration. However, administrative frameworks must adapt to the evolving green hydrogen landscape, integrating industry, academia, and governmental insights for effective policy implementation in the future.

Jharkhand can also leverage the Eastern Zonal Council in Ranchi to become a hub for green hydrogen trading. This involves creating a coordinating body within the Council to promote inter-state collaboration, joint projects, shared infrastructure, and standardised regulations. Reinforcing the state's leadership in setting standards and ensuring fair trade practices.

With the capital-intensive nature of green hydrogen initiatives, Jharkhand is committed to providing adequate financial resources. The agreement Jharkhand signed with TCPL Green Energy Solutions Private Ltd (TCPL GES) to set up India's first Hydrogen Fuel Project in Jamshedpur (ET Online, 2023) signifies the state's initial foray into this domain, paving the way for scaled-up operations in hydrogen combustion engines, advanced chemistry batteries, fuel cells and delivery systems.

Jharkhand's commitment to green hydrogen is evident in its "Solar Energy Policy 2022," aiming to achieve a cumulative solar power capacity of 4 GW by 2027 (Government of Jharkhand, 2021). The policy includes plans for 3 GW of utility-scale solar projects, comprising solar and non-solar parks, floating solar, and canal top solar projects (Government of Jharkhand, 2021), aiming to encourage private investors and integrate solar power advancements into its green hydrogen landscape.

Case study 3: Kerala's green hydrogen development strategy and progress

The Kerala government views green hydrogen as crucial to achieving its target of 100% renewable energy by 2040 and net-zero status by 2050 (Government of Kerala, 2023a). The state envisions green hydrogen replacing grey hydrogen in refineries and the fertiliser industries, powering heavy transports and boats, blending with natural gas for heating, and enabling sustainable aviation fuel. The state aims to leverage its abundant natural resources, renewable energy potential, freshwater, and access to ports to become a green hydrogen production centre.

Estimated potential

Kerala plans to tap domestic and export markets for green hydrogen. Although the state has a small industrial base, it has several refinery and fertiliser units like Fertilisers and Chemicals Travancore Limited (FACT) and Bharat Petroleum Corporation Limited (BPCL) Kochi Refinery, with substantial demand for hydrogen (NITI Aayog, 2022). Kerala focuses on early-stage deployments in heavy transport and is also exploring other sectors, like energy storage, on an experimental basis.

Kochi, with its industrial base and access to the Cochin Port, has significant potential to become a green hydrogen hub. The state government has partnered with India Hydrogen Alliance (IH2A), to evaluate the Kochi Green Hydrogen Hub (KGH2), including building a green hydrogen plant and zero-emission transport options (IH2A, 2022). This project has been selected for funding support under the Hydrogen Valley Innovation Cluster of the union government (Kondul, 2024).

The export market offers tremendous opportunities, particularly with EU countries setting ambitious green ammonia targets. India's cheap renewables and the fully integrated national grid offer significant competitive advantages for domestically produced ammonia, and some Indian firms are already securing supply contracts. Most large-scale projects target external markets. The Vizhinjam port, India's first trans-shipment port, has the potential as an export-oriented green ammonia hub, with infrastructure development plans underway. Kerala has already received significant proposals for setting up export-oriented green Hydrogen and green ammonia production plants (Arushi Koundal, 2023).

Electricity costs, which account for more than 60% of the final cost of green hydrogen, make cheap renewable electricity vital for attracting investments. Kerala aims to ramp up its renewable energy capacity through floating solar plants and pumped hydro storage, taking advantage of its vast reservoirs and unproductive lands. The potential for floating solar and pumped hydro stands at 6,500 MW and 11,000 MW respectively, supported by small hydro projects and vast freshwater resources.

Challenges

As green ammonia is three times costlier than grey ammonia, fertiliser companies are unlikely to absorb costs without explicit government support. While fertiliser and refinery industries are crucial for green hydrogen scale-up (Kowtham Raj, Pranav Lakhina, 2022; Challa *et al.*, 2023), they face subsidy-related constraints. Refineries also depend on government push as public sector undertakings dominate the sector. Bharat Petroleum Corporation Limited (BPCL) has shown interest in establishing green hydrogen production at the Kochi refinery, but no projects have yet been finalised. Developers emphasised the need for hydrogen purchase obligations (HPO) to accelerate the green hydrogen market.

In the transport sector, Kerala focuses on hydrogen internal combustion vehicles due to the lower retrofitting costs. However, their efficiency is much lower than fuel cells. Further, Green hydrogen's role in heavy transport and energy storage remains unclear there are cheaper alternatives like battery storage.

Another key issue is the lack of testing and certification facilities. This is an area where modest government investment can have a significant impact by reducing project risks and costs and by accelerating local manufacturing of components.

The state also faces challenges in harnessing its renewable resources. Kerala currently imports about 76% of its electricity and has low renewable penetration. Much of Kerala's renewable potential lies within forest reserves, but developing these areas poses environmental implications.

According to the interviewees, risk perception of green hydrogen projects among financiers has decreased significantly in recent years but remains a challenge for projects without secured purchase agreements.

Strategies

Kerala is in the final stages of announcing a green hydrogen policy targeting 30% green hydrogen blending by 2027 reducing Green Hydrogen costs to USD 1/kg, and achieving 100% Green Hydrogen/Ammonia in all hydrogen applications by 2040 (Government of Kerala, 2023b). The state's strategy for scaling up Green Hydrogen includes developing Hydrogen hubs and small-scale projects dispersed across the state, including Green Hydrogen Valleys in Kochi and Thiruvananthapuram, aiming for private-investment-led growth. Kerala allocated INR 200 crores (USD 24 Million) for green hydrogen development in 2023-24 through Viability Gap Funding (VGF), equity, and loans, with other potential incentives like electricity duty concessions and priority project clearances (RenewableWatch, 2023).

A high-level steering committee, with the Agency for New and Renewable Energy Research and Technology (ANERT) as the nodal agency, oversees Kerala's green hydrogen scheme. ANERT has constituted a project management unit to promote investment and support implementation, aiming at large-scale projects and aggregating demands for scale economies (Government of Kerala, 2016). The state plans to implement a few pilots using the union government's PLI scheme and will create sector-specific roadmaps and strategic investment to expedite renewable energy project deployments and forge partnerships.

The States' role in accelerating a green hydrogen transition

The case studies of Gujarat, Jharkhand, and Kerala underscore the pivotal role that Indian states play in advancing the national hydrogen industry. These cases demonstrate the various approaches the states may consider as part of the green hydrogen policies.

The cases further demonstrate that the states align with India's national hydrogen targets and develop comprehensive policies for the hydrogen sector's growth. Effective implementation, rigorous monitoring and enforcement, and addressing the challenges in production, technology, infrastructure, and investment will be critical to meet these targets.

Gujarat emphasises electrolysis-driven hydrogen, Jharkhand on manufacturing, and Kerala on ambitious green hydrogen targets, all aligning with the national objective of transitioning to a low-carbon economy. However, challenges include developing efficient and cost-effective production, and technological and infrastructural barriers. Additionally, considerable R&D investments will be necessary to remain technologically competitive.

With regard to the challenges associated with developing hydrogen, there could be some concerns. Kerala's State Electricity Board notes that inadequate distribution networks and outdated transmission infrastructure are major hurdles (KSEB, 2019), underscoring the need for improved energy infrastructure and grid expansion to support the hydrogen industry.

Table 1: Shared potential, common challenges, and strategies

Potential	Challenges	Strategies
▪ Many Indian states have huge RE potential. ▪ Existing industrial bases in many states can help advance hydrogen production and create demand. ▪ The presence of industries will help states develop domestic and overseas partnerships. ▪ States in the coastal region could benefit from overseas export opportunities. ▪ Evolving policy and governance apparatus will help accelerate the hydrogen sector. ▪ States will need to work together to develop the hydrogen industry as they have specific competitive advantages in terms of resources – land, RE potential, water as well as technology and finance access.	▪ Accessibility and affordability of advanced technology remain the key hurdles to states. ▪ The lack of testing and certification facilities is a common challenge across states. ▪ Need centre-state coordinated efforts to rope in off-takers. ▪ Production cost remains a key hurdle in attracting off-takers. ▪ Land acquisition for RE projects remains another major concern in many states. However, states like Gujarat have already shown significant progress. ▪ Clean water availability can be a concern in certain regions.	▪ There is an emphasis on public-private partnerships. ▪ Financial incentives continue to be the common element in strategies to attract investments. ▪ Many states are progressing on green hydrogen policies and building nodal agencies/ institutions. ▪ Efforts are seen to align policies with industries to develop a hydrogen ecosystem. ▪ States with geographic advantage and proximity to ports focus on becoming green hydrogen hubs.

Source: Based on assessment done by IISD and WRI researcher teams

All three states are exploring various funding mechanisms, including international investments, public-private partnerships, and multilateral lending agencies, aligning with the national objective for green hydrogen projects. However, convincing financiers, especially those without secured purchases, remains challenging. Clear and robust mechanisms to attract and retain investments are crucial.

The diversification of end-use sectors, as recognised by Gujarat, Jharkhand, and Kerala, aligns with India's national strategy. However, harnessing the market potential, especially for sectors with low hydrogen demand is challenging. States need innovative solutions to aggregate demands and secure off-takers to achieve economies of scale and meet India's national hydrogen industry targets.

International collaboration is also crucial for achieving these targets. States can facilitate collaborations by acting as intermediaries in the country to accelerate collaboration on three fronts, such as technology, finance, and capacity development. Possible areas include sharing electrolyser technology, advancements in transport and storage solutions, and securing financial support. In this context, the agreements with the EU and Japan can be of potential benefit to India's hydrogen sector development. Japan, with its focus on hydrogen and climate strategies and numerous patents for hydrogen technology (Ungria, Rodriguez, and Burattini, 2023) can be a good option for Indian exports and a source of technology access. India's agreement with Germany to establish a hydrogen task force aims to foster cooperation in the production, utilisation storage, and trade of green hydrogen (Shetty, 2022). Green hydrogen from India could cater to the growing demand for green hydrogen in the European countries that adopted a hydrogen strategy.

Developing the hydrogen ecosystem in Indian states also demands collaboration with overseas investors and technology leaders. Co-innovation (Janardhanan, 2020)–collaborative development of technologies- can be an effective approach, particularly with states that lack adequate technical know-how but possess the potential to generate investment. Although the central government controls foreign policy, there is a growing emphasis placed on para-diplomacy–involving subnational entities in foreign policy. This can enhance technology, finance, and capacity development. Utilising mechanisms such as sister city partnerships and Exclusive Economic Zone (EEZ) ties can expedite these efforts.

Conclusion and recommendations

The case studies highlight the importance of sub-national governments in supporting the national green hydrogen mission. To achieve this, a comprehensive strategy strengthening the state's capacity to develop a hydrogen ecosystem is required. A set of six recommendations outlining specific actions to support 'capacity development, strengthening hard and soft infrastructure, incentivising off-takers, inviting more investment, strengthening technology and promoting international collaboration' is listed below:

1. ***Tailor skill development programme to suit the hydrogen ecosystem***: To strengthen the hydrogen ecosystem, a skilled workforce plays a key role. Programmes need to be in place to ensure that the workforce is capable of contributing to the design, operation, and maintenance of the green hydrogen ecosystem. For this, the support of the national government will be important for the state governments.
2. ***Close the infrastructure gap***: As renewable energy production expands; transmission and distribution infrastructure must be strengthened. For example, the aggregate technical and commercial loss in power systems is about 44% of the generation in Jharkhand, about 15% in Gujarat, and 16% in Kerala (Government of India, 2023a). States must also focus on strengthening the governance mechanism to support this transformation and ensure the readiness of domestic technologies. Centre-state collaboration as well as engagement with overseas technology partners will be crucial.
3. ***Incentivise off-takers***: Implementing adequate financial mechanisms to incentivise off-takers will encourage the hydrogen industry's growth. Subsidies and tax credits along with mechanisms similar to Renewable Purchase Obligations (RPO) (MNRE, 2010) to mandate hydrogen purchases for high-consuming sectors can help in this regard.
4. ***Attract investment, and encourage PPP***: States need to attract and facilitate investment from stakeholders in the hydrogen sector. This demands policies to encourage public-private partnerships and legal and governance structures.
5. ***Encourage R&D***: Lack of access to affordable technologies, in the production, transportation, and storage of hydrogen, has been critical in many states. This demands specific initiatives to support R&D to support the technology-intensive green hydrogen industry.
6. ***Promote co-innovation***: Co-innovation and co-production with overseas partners need institutional support for joint research, manufacturing, and scaling up technologies. The central government may promote para-diplomatic engagement between Indian states and overseas counterparts through sister-city initiatives to bridge the technology gap.

By focusing on these elements, national and state governments together can overcome challenges and foster a vibrant green hydrogen ecosystem in India.

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Note: This paper is based on the IGES Discussion paper (2024) titled 'The Role of Sub-National Governments in India's Green Hydrogen Transition: A multilevel perspective'. This paper largely confines its analysis to the information available until December 2023.

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Prospects of low-carbon hydrogen development in Russian Federation

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Abstract

Russia is a major player in the market of traditional hydrogen and hydrogen-containing products. Having an energy sector with a low carbon footprint (a large share of hydroelectric and nuclear power plants), the country attaches great importance to the development of technological competencies in the field of low-carbon hydrogen. The article discusses the current state and problems of the energy complex for isolated objects and settlements in the Arctic regions of Russia. Several cases, including the International Arctic station "Snowflake" and the Sakhalin hydrogen test site, show options for using hydrogen technologies in energy and transport.

Introduction

The hydrogen industry not only plays a significant role in many industries in the world such as chemical, oil refinery, metallurgy, etc. but also be considered an important part of future energy transition in the energy sector and transport. The world hydrogen industry is not limited only to the energy transition but also plays an important role in such industries of the Asia-Pacific region as the chemical industry (production of ammonia, nitrogen fertilizers, methanol), oil refining (hydro-refining and hydrocracking), metallurgical industry and several other industries. The role of hydrogen and hydrogen-containing products (ammonia and methanol) in energy and transport remains modest, but there is a growing trend.

To assess the possible role of hydrogen in the decarbonization of the industry, it is enough to mention that the effect of just replacing high-carbon hydrogen with low-carbon hydrogen can exceed 500 million tons of CO_2 (more than 1% of current global emissions), a significant reduction in carbon emissions can also be achieved by expanding the use of hydrogen in metallurgy, as well as in the transport and energy sectors.

Nowadays, many large projects in the world combine renewable energy sources (RES) and hydrogen production, transportation, and hydrogen usage as fuel for various types of transport. Hydrogen energy is one of the key areas in decarbonization programs' implementation and achieving carbon neutrality - hydrogen can be obtained from low-carbon sources and its use as an energy carrier does not lead to greenhouse gas emissions.

Approaches to determining the carbon footprint of hydrogen

Table 1 shows the assessment of the carbon footprint of hydrogen depending on the method of its production (and production) and the presence, if necessary, of measures for recycling the carbon dioxide obtained during the production of hydrogen [Karasevich V., Elistratov V. (2024)]. The Table uses the world's most popular colour classification of hydrogen. Based on the Table, in addition to natural hydrogen (we propose to consider it carbon neutral) and green hydrogen (hydrogen produced using renewable electricity or by steam conversion or pyrolysis of biomethane), low-carbon hydrogen can also include yellow hydrogen (hydrogen produced by electrolysis due to the use of electricity from nuclear power plants), turquoise (hydrogen produced by pyrolysis of methane), and blue (hydrogen produced by steam reforming of methane with carbon dioxide capture and storage/usage).

In some cases, along with the electricity source, other factors can play a significant role in the carbon footprint of the hydrogen produced. In general, as can be seen from the formula below, the total carbon footprint of hydrogen production E can be represented as the sum of the carbon footprint of the preparation of deionized water (E_W, significant if sea and ocean water desalination technologies are used, absent in the chemical process during methane pyrolysis), the carbon footprint of electricity (E_P, its consumption is maximum during the electrolysis of water, it is also present in all methods of hydrogen production discussed in the article) or feedstock (E_F in the case of natural gas and coal during steam reforming and coal gasification) and the carbon footprint of logistics (E_L when the need to transport both water or initial fuel or electricity, and when transporting hydrogen) minus compensated carbon emissions (E_C, for example, when burying CO_2 in steam reforming of methane).

$$E = E_W + E_P + E_F + E_L - E_C$$

The current carbon footprint of water E_W is high in those countries that actively use desalination plants powered by non-renewable electricity (for example, from power systems with a large share of coal or heavy oil power plants), a high carbon footprint of logistics E_L can be in cases where hydrogen is planned to be delivered to isolated settlements over long distances using vehicles on traditional fuels.

Table 1: Colour code of hydrogen [Karasevich, Elistratov (2024)]

Colour of H_2	Description	Carbon footprint, kg CO_2 / kg H_2
White	Natural hydrogen	No data
Yellow	Water electrolysis, nuclear power $H_2O \rightarrow H_2\uparrow + O_2\uparrow$	0.5–2.5
Brown	Coal gasification (CG) + Water gas shift (WGS) $C\downarrow + 2H_2O \rightarrow CO_2 + 2H_2$	14.4–25.3
Grey	Steam methane reforming (SMR) + WGS $CH_4 + 2H_2O \rightarrow 4H_2\uparrow + CO_2\uparrow$ By-product hydrogen	10.7–16.0
Blue	SMR +WGS +CO_2 capture and storage (CCS) CG + WGS + CCS	3.0–5.9 0.8–5.2
Purple	Methane pyrolysis $CH_4 \rightarrow C\downarrow + 2\ H_2\uparrow$	0.5–2.5
Green	Water electrolysis (RES), biomethane pyrolysis, biomethane CMR + WGS	0.5–2.5

Current hydrogen situation

Global production and consumption of hydrogen in 2022 was approximately 95 million tons [IEA Global Hydrogen Review (2023)]. The largest hydrogen-producing countries are China (25 million tons in 2021), the USA (10 million tons), India (6 million tons), and Russia (5.5 million tons) [Karasevich, Elistratov (2024)]. The main methods of its production are steam reforming of methane (62%) and coal gasification (19%, because of China); part of the hydrogen (18%) is obtained as a by-product of oil refining (Figure 1) [IEA Global Hydrogen Review (2023)]. The share of electrolysis hydrogen is less than 1%, but by 2030, according to International Energy Agency (IEA) estimates, it should grow by about 20 million tons (12 million tons from electrolysis hydrogen and 8 million tons from hydrogen produced by steam reforming of methane with carbon dioxide disposal). Hydrogen is mainly used in the chemical industry (52%, production of ammonia and nitrogen fertilizers, methanol), oil refining (43%), and metallurgy (5%, direct reduction of iron from iron ore). The share of hydrogen in low-carbon energy and transport was less than 1% or approximately 40 thousand tons. At the same time, according to IEA forecasts, the share of hydrogen in the electric power industry and transport will significantly increase.

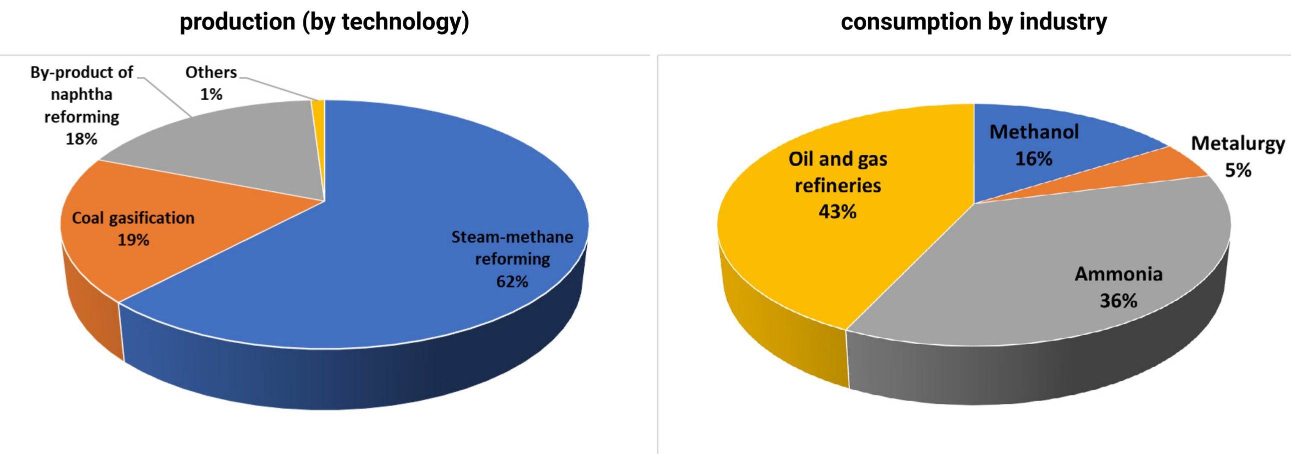

Figure 1: World hydrogen production [IEA Global Hydrogen Review (2023)]

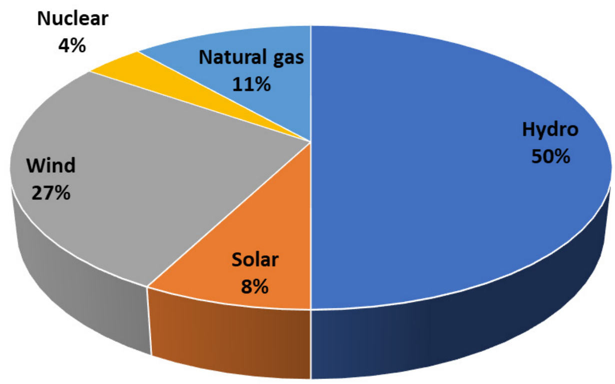

Figure 2: Russian low-carbon hydrogen projects: by source of energy [Russian Atlas of low-carbon and carbon-free hydrogen and ammonia production projects, Ministry of Industry and Trade (2022)]

Hydrogen in Russia

The climate goals adopted by Russia after the signing of the Paris Agreement provide for the expansion of the use of energy resources with a low carbon footprint to be climate-neutral by 2060. Hydrogen may be one of the promising universal low-carbon energy carriers. As both a source of energy storage and fuel for heat/electricity generation and for vehicles, low-carbon hydrogen can play an important role in reducing the carbon footprint of the Russian economy.

Currently, Russia produces more than 5 million tons of traditional hydrogen annually and is one of the five leading hydrogen producers in the world (after China, USA, EU-27, and India). More than 1 million tons of hydrogen is exported annually as part of hydrogen-containing products (ammonia, methanol, nitrogen fertilizers). Hydrogen is mostly produced and consumed locally by chemical industry enterprises (primarily ammonia and methanol producers), oil refineries, and metallurgy (2 plants use direct iron reduction technologies). About 160 thousand tons of hydrogen annually are sold in cylinders or reservoirs.

In strategic hydrogen documents, great importance is given to the development of the country's technologies for the production, transportation, storage, and use of hydrogen, such as electrolysers with proton and anion exchange membranes, storage and transportation of hydrogen in metal hydrides, hydrogen energy storage systems, hydrogen fuel cells. Russian Government supports technologies development support through federal programs and publishes the catalogue "Russian Competencies of the hydrogen industry" which covers local manufacturers and organizations that are involved in hydrogen technology development [Catalogue "Russian Competencies of the Hydrogen Industry", Ministry of Industry and Trade of Russia (2022)].

In 2022 the Russian government issued a hydrogen and ammonia projects atlas [4] that consists of 41 hydrogen and ammonia projects (Figure 2). These projects plan to produce low-carbon hydrogen and don't cover current hydrogen production that is 100% grey. A brief analysis of these projects shows that most of them are in the conceptual stage and only a few projects are in the feasibility or development stage. Almost half of the projects plan to produce not only hydrogen but also ammonia. This can be explained by the good hands-on experiences of Russian companies in ammonia transportation and uncertainty over the feasibility of alternative transport options such as liquefied hydrogen or the use of Liquid Organic Hydrogen Carriers (LOHC).

Figure 2 shows that 50% of Russian hydrogen projects plan to use hydropower as energy for their hydrogen production. This is because Russia generates 16% of its electricity from power hydropower plants and hydro energy is the cheapest low-carbon energy to produce hydrogen and ammonia. Another 35% of projects plan to use solar or wind power, and 11% of projects plan to use natural gas with carbon capture and storage technologies.

Russian hydrogen pilot projects

Snowflake Arctic R&D station

Improving the quality of people's lives and protecting the environment are important issues for the Russian Arctic territory's development. The implementation of these issues requires the development of low-carbon energy in the Arctic regions. According to [5], in the Arctic zone of Russia, there are more than 520 settlements with a population of more than 300 thousand people; the total installed power capacity exceeds 1 GW (500 MW in settlements, 500 MW in mining enterprises) and heat capacity - 200 Gcal/h. For developing and testing technologies in Arctic conditions, the Moscow Institute of Physics and Technologies (MIPT) proposed to create "Snowflake", the International Arctic zero-carbon R&D station. [6].

The Polar International Arctic Station Snowflake (Figure 3), located 70 km north of Salekhard in the Yama-Nenets District, is a completely energy-autonomous complex that can operate for a full year. The station can accommodate 80 researchers simultaneously; the total area of residential and technical premises will reach 10200 m^2. The technical premises of the station will contain laboratories, power complexes, station engineering support systems, and workshops for various purposes.

In 2023, the project was approved by Glavgosekspertiza (the Federal Body

Figure 3: Arctic zero-carbon station Snowflake

that approves construction projects) of Russia; the station's construction is planned to begin shortly. Snowflake is created as a research complex for conducting Arctic climate interdisciplinary scientific research and full-scale testing in the fields of renewable and hydrogen energy, telecommunication, new models of construction technologies (primarily in terms of monitoring and thermal stabilization of soils), robotics for harsh climates, arctic medical products, solutions in the field of food safety.

The station will operate primarily on renewable energy sources (diesel power generation exists as a backup). Snowflake will get power from a local wind power plant with a capacity of up to 1,05 MW and solar power plants with a capacity of up to 300 kW. The station's heating will be carried out by heat pumps using low-grade heat from the neighbouring lake. The station also has lithium-ion batteries and a hydrogen storage unit that helps to pass through the time when there is a lack of electricity generated from renewable energy sources.

The station's hydrogen energy storage system consists of 100 m^3 hydrogen generators based on water electrolysis, hydrogen storage receivers with a total volume of up to 1200 m^3, and a 500-kW electrochemical power generator based on low-temperature fuel cells with a proton-exchange membrane. The station's hydrogen energy storage system consists of hydrogen generators based on water electrolysis, hydrogen storage receivers with a total volume of up to 1200 m^3, and an electrochemical electricity generator based on fuel cells with a power of up to 500 kW. The storage system also includes 2,5 MW lithium-ion energy storage devices with appropriate inverters. The total energy storage capacity will reach 80 MWh.

Sakhalin hydrogen pilot project

This project is a part of the Sakhalin hydrogen cluster that aims to create a new hydrogen energy industry in the region for low-carbon hydrogen export and the development of full-cycle hydrogen technologies and their consumption in the energy sector. The cluster also has two more projects: low-carbon hydrogen production using steam reforming of methane (blue hydrogen) with carbon dioxide capture technology and passenger rail service using trains powered by hydrogen fuel cells.

For the development of new hydrogen technologies and engineering solutions, MIPT and the Government of the Sakhalin Region, with the participation of companies and partner organizations (PJSFC Sistema, State Atomic Energy Corporation ROSATOM, PJSC «RusHydro», etc.), created a Centre hydrogen engineering with an experimental site in the Sakhalin region. The complex consists of 4 sites. Yuzhno-Sakhalinsk site consists of a 300-kW solar power plant, that provides energy for green hydrogen production. The hydrogen fuelling station will refuel experimental hydrogen equipment (hydrogen truck Ural and commercial vehicle Gazelle), hydrogen will also be supplied to power the cell tower in Ogonki village and for a mobile power station in Pushisty village.

Another test site of the complex is the energy-isolated village of Novikovo. It is planned to test the joint operation of a hydrogen energy storage system with a redox flow battery. Support-balancing functions (maintaining frequency and voltage in an isolated network) will be assigned to the lithium-ion module. Nowadays, the village's energy supply is provided by 2 wind turbines and diesel generation. The use of energy storage systems will make it possible to harmonize the production and consumption of electricity, significantly reduce diesel fuel consumption; to increase the share of renewable energy sources in the energy balance of the village.

Sakhalin complex will be in operation this year.

Hydrogen vehicles projects

During Soviet times, the development of hydrogen transport with an emphasis on the internal combustion engine was given great importance. For example, at the Olympic Games in Moscow, athletes were transported from the Olympic Village to sports venues using a hydrogen commercial vehicle "RAF". In 80-th, there was the TU-155 laboratory aircraft which used liquefied hydrogen as a fuel; liquefied hydrogen also was used as a fuel for the 2nd stage of a rocket engine.

Hydrogen Arctic all-terrain vehicle RUSAK **PJSFC Systema hydrogen ship site**

Figure 4: Russian hydrogen vehicles

In recent years, several Russian companies have been actively developing hydrogen cars and refuelling infrastructure. In July 2024, there were two new vehicle presentations: the hydrogen all-terrain vehicle “Rusak” (Figure 5, left), developed by MIPT with partner companies, and the hydrogen truck “Ural”, which arrived for trial operation at the Sakhalin test site. Previously, the companies “KAMAZ” (truck and bus), “GAZ “(bus and commercial vehicle Gazelle), and Research Automotive and Automotive Institute (NAMI, premium class car Auras) demonstrated their developments.

The all-terrain hydrogen arctic vehicle “Rusak K-10” was made Moscow Institute of Physics and Technologies with “Vezdekhody Severa”, “Kubo” and “Hydrogen Energy”. A five-axle vehicle has dimensions of 12 x 2.9 x 3.6 meters, weighs 12.5 tons, maximal speed of up to 60 km/h, and a load weighing up to 2.5 tons. Rusak is equipped with a hydrogen 120 kW fuel cell and lithium-ion batteries. Six cylinders have a total capacity of 1200 litres at 350 bar pressure, and the mass of hydrogen on board is approximately 30 kg. The vehicle operates on 180 kW permanent magnet synchronous electric motors. Rusak is capable of getting up to 400-500 km without refuelling.

So far, Russia has only one hydrogen gas station in the Moscow region. This year, an experimental hydrogen filling station should be operational in Yuzhno-Sakhalinsk (one of the facilities of the Sakhalin test site described above); one more hydrogen filling station will also be at the Snowflake Polar station.

Two Russian companies are developing hydrogen ships. Sitronics Group - a subsidiary of Sistema Public Joint Stock Financial Corporation - is testing a passenger hydrogen ship based on an electric vessel with an electrochemical generator. Figure 4 (right) shows the R&D fuel cell power unit for a ship made by PJSFC “Systema”’s Centre of Hydrogen Technologies jointly with Bauman Moscow State Technical University. Another hydrogen-powered vessel is in development at the Zelenodolsk shipyard named after A. M. Gorky in Tatarstan; it started in February 2023.

Conclusion

Russia has set goals to reach a low-carbon economy by 2060, and hydrogen is to play an important part in this transition. Current Russian hydrogen policies support hydrogen project development. The Russian government is devoted to creating in the country hydrogen technologies, equipment, and Research and Development potential.

Because of huge relatively cheap hydropower resources half of the announced projects plan to use this resource to produce hydrogen and ammonia, while the biggest announced and under feasibility study projects plan to operate with natural gas using carbon capture and storage technologies. The hydrogen industry of the country aims to create technological solutions along the entire hydrogen chain: hydrogen production, storage transportation, and usage in traditional (chemical, oil refinery, metallurgy) and innovative (low carbon energy and transport) industries.

For autonomous energy supply to isolated facilities and settlements in the Arctic and Far Eastern regions, several pilot projects are being implemented using low-carbon technologies based on renewable energy sources and energy storage systems. This will reduce energy supply costs by replacing diesel fuel, which is expensive in logistics, with local energy resources (primarily solar and wind energy), increase the reliability of the energy supply (there is no transport component), and reduce the negative impact of energy supply to objects/settlements on the environment. The engineering solutions that are developing for the Arctic make it possible to test advanced technologies and approaches to reliable low-carbon energy supply using hydrogen self-propelled energy systems. In the future, the developed technical solutions can be successfully replicated for other objects and settlements in the Arctic region of the Russian Federation.

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3. CatLog “Russian competencies of the hydrogen industry”, Ministry of Industry and Trade of Russia;
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Ocean thermal energy-driven development for sustainability

Prospects for green hydrogen in the Asia-Pacific region

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ABSTRACT

A major source of green hydrogen in the Tropics is none other than ocean thermal energy. The energy from the Sun, stored in the upper layer of the deep seas, could be extracted by applying the ocean thermal energy conversion (OTEC) technology to generate electricity fed through electrolysers, to generate green hydrogen. The global potential of OTEC is 9.3 TW (9,300 GW), almost one-half of which is within the Asia-Pacific Region. Once the potential within the Region is fully realised, it could fulfil the World demand of 650 million tonnes of green hydrogen by 2050, and at USD 3 per kg, valued at USD 1,950 billion annually. The required capital investment of USD 750 million per 100 MW gross OTEC plant capital could be recovered within 5 to 7 years.

Introduction

Ocean Thermal Energy is a major source of renewable energy in the Tropics. It is a secondary source of energy from the Sun that is stored in the form of heat energy in the upper layer of the deep seas. The heat energy could be extracted by pumping in the warm sea water at 27 degrees Celsius through the heat exchangers of an ocean thermal energy conversion (OTEC) plant, through which liquid ammonia, as a working fluid, is passed and transforms itself into a gaseous form that turns a turbogenerator to generate electricity. The ammonium vapour is converted back into the working fluid by pumping up cold seawater, through condensers, from about 800 metres deep where the temperature must be 7 degrees Celsius (C) or lower to 4 degrees Celsius. The ammonia in either form, liquid or gaseous form, is circulated in a closed-cycle plant system.

The generated electricity, if not taken up including the running of the OTEC plant, is fed into electrolysers to generate green hydrogen that is compressed and stored in gas cylinders that could be taken away for various applications.

The cold-water discharge off the condensers at about 10 degrees Celsius could be utilised for multiple applications including cooling off the servers of data centres, cooling of tropical soils for temperate crops; for the culture of high-value marine produce such as seaweed "*umi budou*", abalone, oysters, prawns, non-poisonous fugu fish; extraction of lithium for batteries; production of table sea-salts, and that of premium value mineral water.

The knowledge on the conversion of ocean thermal energy into electrical power was first discovered by Jacques Arsene d'Arsonval, a French Physicist, in 1881, although it had been revealed about 1260 years ago in Al-Quran, Chapter 24, verse 40 during the 609-632 AD period. D'Arsonval's student, Georges Claude[1], built the first OTEC plant, in Matanzas, Cuba in 1930. The system generated 22 kW of electricity with a low-pressure turbine. The plant was later destroyed in a storm. Currently, three OTEC Plants are running with various capacities: 2x50 kW at Kumejima, Okinawa, Japan[2] and another, 210 kWg at Kona, Big Island, Hawaii, USA.[3] The first one has been running since 3 June 2013, officially opened by the Emperor of Japan, if not earlier. Figure 1 illustrates the past and present OTEC development and demonstration plants worldwide.

As illustrated in Figure 2, over 66 percent of these activities have been undertaken within the Asia-Pacific Region. As listed in Table 1, there are 36 countries that have the potential to develop OTEC projects within their respective exclusive economic zones, and perhaps beyond into the high seas.

Research and Development activities relating to OTEC in various parts of the World intensified as a response to the oil supply crisis, also known as the Arab Oil Embargo, in October 1973[4], with the most significant ones being carried out in "the Republic of Korea, Japan, India,

1 https://en.wikipedia.org/wiki/Ocean_thermal_energy_conversion

2 http://otecokinawa.com/en/

3 https://www.scientificamerican.com/article/hawaii-first-to-harness-deep-ocean-temperatures-for-power/

4 https://www.britannica.com/event/Arab-oil-embargo.

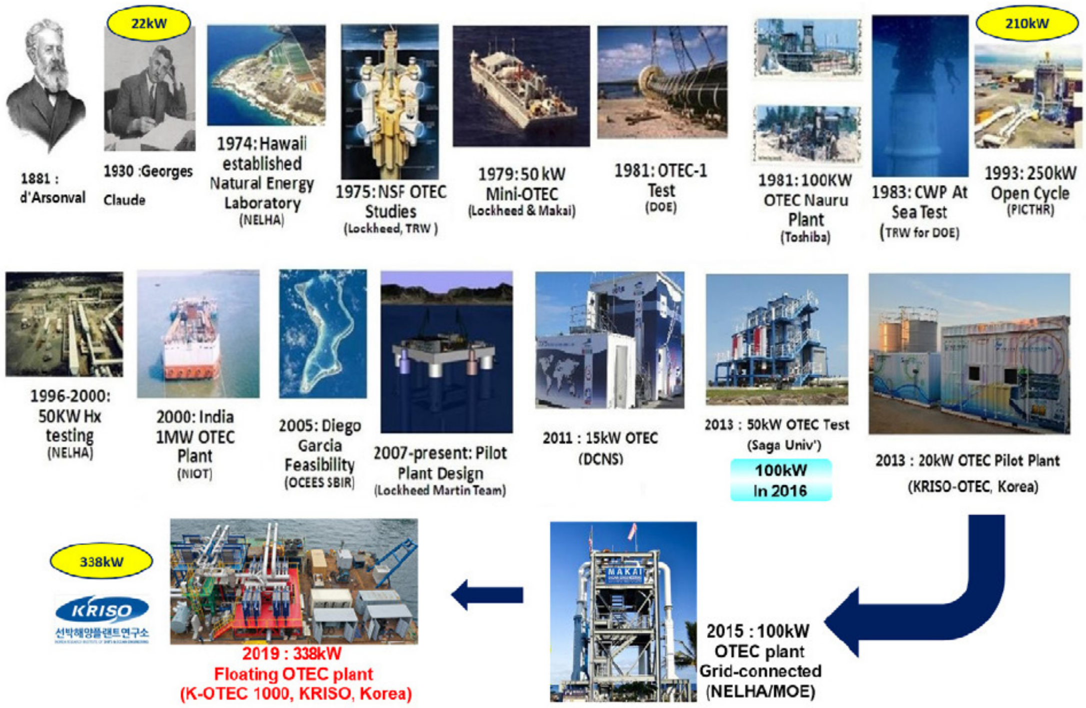

Figure 1: History of OTEC development and demonstration (after KRISO)

Ref: OES (2021), White Paper on Ocean Thermal Energy Conversion (OTEC). IEA Technology Programme for Ocean Energy Systems (OES), www.ocean-energy-systems.org. Page 13.

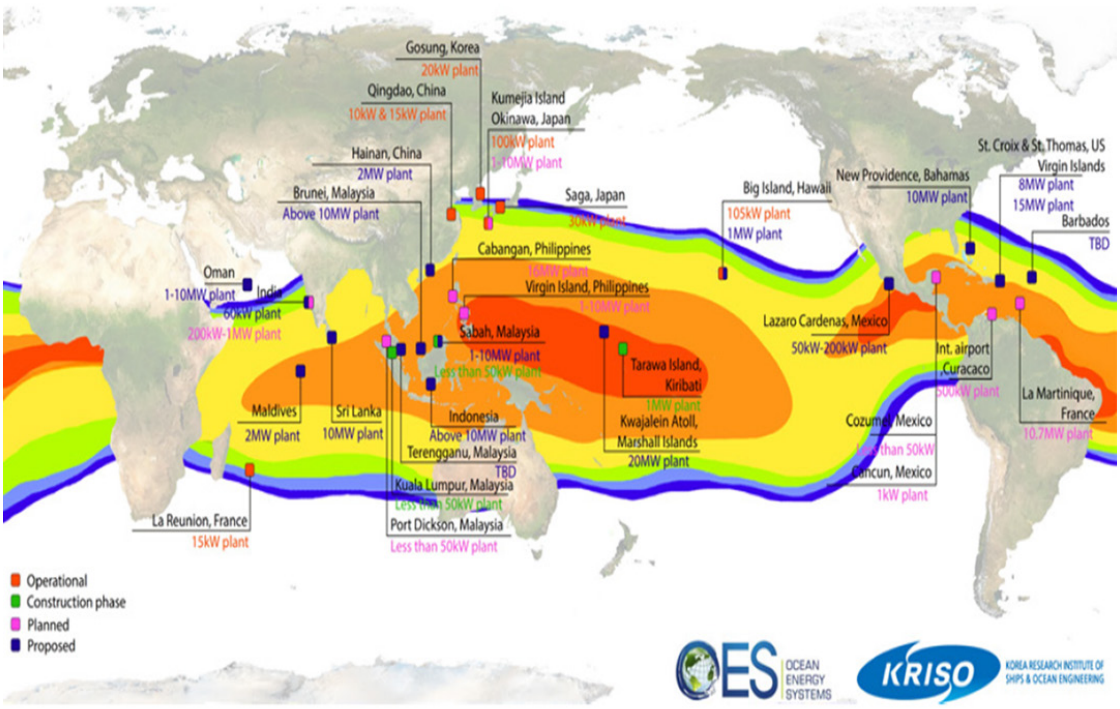

Figure 2: Present and future planned OTEC/SWAC projects around the world

Ref: OES (2021), White Paper on Ocean Thermal Energy Conversion (OTEC). IEA Technology Programme for Ocean Energy Systems (OES), www.ocean-energy-systems.org. Page 15.

Table 1: Countries within the Asia-Pacific region with OTEC potential within their respective exclusive economic zones and beyond

Australia	Malaysia	Cook Islands	Philippines
Bangladesh	Myanmar	Diego Garcia	PNG
Brunei Darussalam	PRC	Fiji	Samoa
Hong Kong, China	Thailand	French Polynesia	Samoa
India	Viet Nam	Guam	Seychelles
Japan		Hawaii	Solomon Islands
		Indonesia	Sri Lanka
		Kiribati	Taipei,China
		Maldives	Tonga
		Mauritius	Tuvalu
		Nauru	Vanuatu
		New Caledonia	Wake Island
		Northern Marianas	Wallis & Futuna Is.
		Okinawa	

PNG = Papua New Guinea, PRC= People's Republic of China.

Source: L. Vega. 2010. Economics of Ocean Thermal Energy Conversion (OTEC): An Update. Paper presented at the Offshore Technology Conference. Houston. 3–6 May.

France, China, Malaysia, and the USA."[5] In 2018, the Korean Research Institute of Shipping and Offshore Engineering (KRISO) commissioned its 338kW Floating OTEC Plant in Busan. The Roadmap for further development would be first: the installation of the proof-of-concept of a 2.5 MW floating OTEC plant that could be scaled up to 10 MW and up to 100 MW capacity.

Ocean thermal energy potential in the Asia-Pacific region

The ocean thermal energy potential within the Asia-Pacific Region could be said to have at least one-third of the global ocean thermal energy potential of at least 5,000 GW[6] up to 9,300 GW[7], that is about 4,000 GW (or 4 terawatts). Should this potential be fully realised, it could generate about 650 million tonnes of green hydrogen per year and that could fulfil the world demand for green hydrogen, as shown in Figure 3, in 2050.[8,9]

Table 2 outlines the annual electricity production of 100-MW OTEC Plant by country within the Region. The total generation is 32,720 GWh per year. However, it is said "[a] more modest OTEC scenario with a global potential of the order of 7 terawatts[10] shows little impact on the availability of local heat. As OTEC flow rates increase, the erosion of vertical seawater temperature gradients is much slower in 3-D ocean models, because any heat locally added to the system can be horizontally transported and redistributed at a relatively fast rate. It must be noted that the baseline commercial OTEC plant is sized at 100 MW, so 70,000 plants would correspond to 7 terawatts."[11]

Green hydrogen production at OTEC plants

Most potential sites of OTEC plants are at a distance far away from the nearest coastlines over 60 kilometres. Since the maximum net power

5 OES (2021), White Paper on Ocean Thermal Energy Conversion (OTEC). IEA Technology Programme for Ocean Energy Systems

6 Dr. Gerard Nihous at the University of Hawai'i led the implementation of a numerical model with state-of-the-art atmosphere-ocean coupling including ocean currents and thermohaline circulation to assess the environmental impact of thousands of plants. He essentially divided the OTEC resource region into 25 km x 25 km squares with a "100 MW/ΔT: 20 °C" plantship stationed in the middle of each square. His theoretical conclusions can be conservatively interpreted by stating, for example, that 50,000 plants (5 TW) could be installed with "acceptable" world-wide environmental impact.

7 Jia Y et al (2018), An evaluation of the large scale implementation of ocean thermal energy conversion (OTEC) using an ocean general circulation model with low-complexity atmospheric feedback effects. J Mar Sci Eng. https://doi.org/10.3390/jmse601001

8 Hydrogen Council (2020). Path to hydrogen competitiveness: A cost perspective. 75pp

9 PwC Global Hydrogen Assessment Demand 2050.

10 Rajagopalan & Nihous (2013)

11 ADB (2014). Page 23

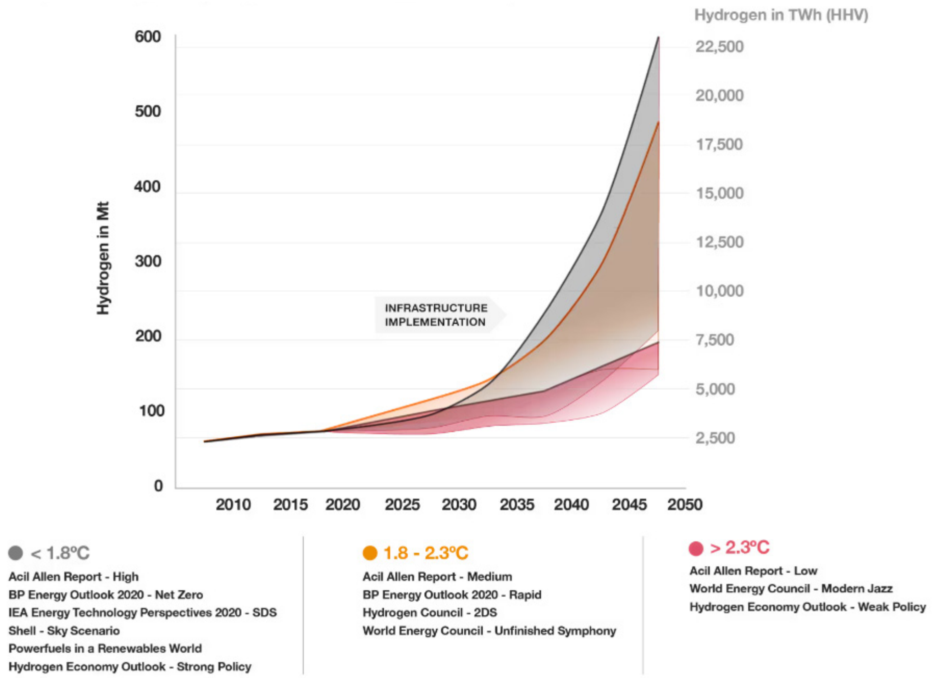

Figure 3: Range of hydrogen demand assessment by 2050

Source: PwC, https://www.pwc.com/gx/en/industries/energy-utilities-resources/future-energy/green-hydrogen-cost.html. 21 June 2024

Table 2: Annual electricity generation with 100-MW OTEC plant by country within the Asia-Pacific region

Region and Country	Appropriate Ocean Thermal Resource within Exclusive Economic Zone	Annual Production (gigawatt-hour)	Reference Longitude	Reference Latitude
Central and West Asia				
Pakistan	Too low	580	66	24°N
East Asia				
People's Republic of China	Yes	1,100	115°E	20°N
Pacific				
Reference Site (Hawaii)	Yes	1,040	158°W	21°N
Cook Islands, Rarotonga	Yes	1,040	160°W	22°S
Fiji	Yes	1,320	178°E	17°S
Kiribati, Tarawa	Yes	1,450	175°E	2°N
Marshall Islands, Majuro	Yes	1,430	170°E	7°N
Federated States of Micronesia	Yes	1,430–1,500	140°E–165°E	0°–10°N
Nauru	Yes	1,490	167°E	0.5°S
Palau	Yes	1,460	135°E	7°N
Papua New Guinea	Yes	1,230	145°E	10°S
Samoa	Yes	1,500	172°W	12°S
Solomon Islands	Yes	1,520	160°E	10°S
Timor-Leste	Yes	1,320	125.5°E	8.5°S

Tonga	Yes	980	175°W	22°S
Tuvalu	Yes	1,520	180°	5°–10°S
Vanuatu	Yes	1,370	165°E	15°S
South Asia				
Bangladesh	No	Not applicable	91°E	22°N
India	Yes	1,070	90°E	16°N
Maldives	Yes	1,130	72.6°E	3.1°N
Sri Lanka	Yes	1,090	82°E	8°N
Southeast Asia				
Brunei Darussalam	Yes	1,400	113.5°E	5.1°N
Cambodia	No	Not Applicable	103°E	11°N
Indonesia	Yes	1,200	100°E	5.1°S
Malaysia	Yes	1,410	114°E	6.1°N
Myanmar	Yes	1,080	93°E	18°N
Philippines	Yes	1,410	119°E	14°N
Thailand	Yes	1,150	97°E	7°N
Viet Nam	Yes	1,160	110°E	14°N

Note: Excludes land-locked developing member countries.
Source: Provided by G. C. Nihous using tools described in G. Nihous. 2010. Mapping Available Ocean Thermal Energy Conversion Resources around the Main Hawaiian Islands with State-of-the-Art Tools. *Journal of Renewable and Sustainable Energy*. 2 (043104).

that could be generated per site is about 64 MW up to 77 MW, it would not make much sense to transmit the generated power by sea cables to the nearest land. It is generally proposed the available power be converted into hydrogen by installing the required electrolysers and compressors on board the OTEC Plant platform, like a floating platform for storage offshore (FPSO). The generated hydrogen is compressed at 350 bars or 700 bars into gas cylinders that could be taken away for shipment.

Use of green hydrogen

In Malaysia, for instance, the bulk of energy, about 42 percent, is used in the transport sector which is highly dependent on petroleum products including diesel and liquid petroleum gas. The present state of hydrogen fuel cell vehicle (H2FCV) technology is so advanced that the running costs of such hydrogen-fuelled vehicles are already competitive. For instance, say, the retail price of green hydrogen is USD[12] 6 per kgH2. For every one kilogramme of hydrogen fuelling, say Toyota Mirai, it would cover 245 kilometres (km). Thus, the running cost of such a hydrogen-fuelled vehicle is RM 0.11 per km.

In contrast, for the same dollar, one could purchase[13] of 13,67 litres, say RON95[14], which is a highly subsidised petroleum product in Malaysia. For the most popular petrol-driven car in Malaysia, say model 2020 Perodua Myvi 1.3L G AT whose rated fuel consumption performance at 4.9 litres per 100 km, would cover 279 km, and its running cost is RM 0.10 per km. Thus, it is comparable to that of a premium hydrogen-fuelled vehicle.

Another application of green hydrogen is to support the development of standalone, off-grid, distributed renewable energy power systems. This is also to fulfil the aim of SDG 7 is to "ensure access to affordable, reliable, sustainable, and modern energy for all." At present, the Asia Pacific region, with almost 60% of the global population, still has around 455 million people who lack access to electricity, and 1.9 billion people are still dependent upon traditional solid fuels for cooking and heating.[15] Such decentralized solutions especially in remote and sparsely settled areas offer a cost-competitive alternative to grid expansion and can be rapidly deployed to meet levels of demand too low to justify grid investments.

12 $1.000 USD = RM4.669 MYR

13 https://www.wapcar.my/tools/fuel-cost-calculator. 20 July 2024. 2020 Perodua Myvi 1.3L G AT. 4.9 litres/100km

14 https://ringgitplus.com/en/blog/petrol-credit-card/petrol-price-malaysia-live-updates-ron95-ron97-diesel.html. 20 July 2024. MYR 2.05 per liter of RON 95.

15 https://www.google.com/search?q=population+without+electricity+in+Asia+Pacific&oq=population+without+electricity+in+Asia+Pacific&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQIRigATIHCAIQIRigAdIBCTQwNzQ4ajBqN6gCALACAA&sourceid=chrome&ie=UTF-8. 20 July 2024.

In addition, the productive uses in rural communities, such as solar water pumps, refrigerators, agro-processing machinery, and a wide range of equipment for microenterprises, contribute to socioeconomic development and improve quality of life. Together, these can increase incomes and raise productivity, contributing to job creation, the emergence of new enterprises, and economic growth. Those solutions are mostly provided increasingly by the application of mini hydropower and solar photovoltaic technologies and account for a third of total mini-grids installed.[16] These solutions could be further enhanced by installing the already widely available fuel cell technology with the availability of locally generated hydrogen by increasing the capacity of solar photovoltaic panels or that of hydrogen supplied from the nearest OTEC plants. By harnessing the power of the sun, though it would create a more sustainable energy future, it is not without challenges to the power distribution grid. This trend has reduced the demand for electricity from the grid during the day, as homes and businesses use energy produced by their rooftop solar systems. This means there is increased strain on the grid as it works to keep up with fluctuating supply and demand, which can create instability. Expressed graphically, the effect on the grid is known as the Duck Curve[17], and if it is not addressed, could potentially lead to power blackouts. One way to address this issue is to install the necessary hydrogen fuel-cells at strategic locations within any distribution network heavily fed by intermittent and fluctuating electricity supply.

The demand for green hydrogen will continue to grow, not only to fulfil the aim of Sustainable Development Goal 7: "affordable, reliable, sustainable and modern energy for all" by 2030, but also that of Sustainable Development Goal 13: Climate Action. In Malaysia, for instance, there exist a number of deepwater oil and gas (O&G) production fields including Malikai, Gemusut-Kakap, Kikeh, and Rotan from which their respective carbon dioxide (CO2) emissions could be captured and utilised in the production of green methanol. The required green hydrogen for such production could be produced from the adjacent OTEC plants that could co-exist with the nearby O&G platforms. About 277 tonnes per day of green methanol could be produced, through the hydrogenation process, by capturing 13.5 million standard cubic feet of CO2 produced therein, and the amount of green hydrogen required would be about 98 tonnes per day by investing in the necessary OTEC Plants of 204 MW capacity.[18] The quantity of CO2eq that could be offset[19] would be about 1.5 million tonnes per year, and that would attract some carbon credits of at least NZD 84 million per year.[20]

The economics of OTEC-hydrogen production

"Based on lessons learned with preliminary OTEC designs, model basin tests, experimental plants, and the know-how available from offshore engineering firms, it can be stated that no major technical issues remain for the implementation of OTEC."[21] The challenge now, other than raising the required financing, is to work out the levelized cost of electricity from various sizes of OTEC plants ranging from 1 MW to 2.5 MW and upscaled to 10 MW, 50 MW, and 100 MW. The cost of electricity accounts for 70 cent percent of the cost of hydrogen production.[22] It would take about 50 kilowatt-hours of electrical power to produce one kilogramme of hydrogen.[23]

As outlined in Table 3, based on the 50 MW OTEC Plant, the 2023 Levelized Cost of Electricity Production with commercial loans yield an upper limit of $0.378/kWh. With less expensive HXs the LCOE could be $0.256/kWh. Thus, the cost of electricity alone for OTEC-hydrogen production would be at least USD 12.8/kgH, or its total cost would be about USD 18.30/kgH. This is much higher than the current cost of production from other renewables, namely, solar PV, and wind.

As shown in Figure 4, the expected cost of hydrogen is to be not more than USD 2.50/kgH, and that of green hydrogen at USD 3.00/kgH as highlighted in Figure 5.

16 https://trackingsdg7.esmap.org/downloads. 20 July 2024. Page 11.

17 The Duck Curve refers to a graphical representation of electricity demand from the grid on days when solar energy production is high and demand in the grid is low. When plotted on a graph the lines and curves form a distinctly duck-like shape. Essentially, the Duck Curve represents the potential for power system instability, as the grid attempts to cope with extreme changes in demand across different parts of the day. https://www.synergy.net.au/Blog/2021/10/Everything-you-need-to-know-about-the-Duck-Curve. 20 July 2024.

18 Zulqarnain, et al (2023). Recent development of integrating CO2 hydrogenation into methanol with ocean thermal energy conversion (OTEC) as potential source of green energy, Green Chemistry Letters and Reviews, 16:1, 2152740, DOI: 10.1080/17518253.2022.2152740

19 CHUN Yoonyoung et al (2023)_LCA Evaluation for Hybrid-OTEC & Malaysia Model_8th Meeting of SATREPS-OTEC Programme_8 June 2023. [1MW OTEC=62.7 tonnes CO2eq]. 1MW coal-fired power-plant would emit about 7,577 tonnes of CO2eq. https://www.iea.org/data-and-statistics/charts/average-co2-intensity-of-power-generation-from-coal-power-plants-2000-2020. Accessed on 5 June 2023

20 The Carbon News NZU Index. $54.25/tonne. 19 July 2024.

21 IEA-OES (2024), Ocean Thermal Energy Conversion (OTEC) Economics: Updates and Strategies. www.ocean-energy-systems.org

22 https://www.powermag.com/overcoming-green-hydrogens-major-operational-cost-electricity/. Accessed 8 July 2024.

23 https://www.hydrogennewsletter.com/faq-general-green-hydrogen-knowledge/. Accessed 8 July 2024

Table 3: First generation 50 MW-class closed cycle OTEC plant: Current USD levelisation (constant annual cost)

Inputs in Blue		Output Red
System Net Name Plate:	**53.5 MW**	*SOA Components*
System Availability	**92.3%:**	*4-weeks downtime/module*
Site Annual Average Capacity Factor:	**100.0%**	*Design Selection*
Annual Electricity Production	**432,609 MWh**	
Daily Desalinated Water Production	**0.00 MGD**	
	0 m^3/day	
Installed Cost (CC):	$886.92 M	**16578 $/kW**
1st Year OMR&R:	**$48. 78 M**	*5.5% of CC*
I, interest {current-dollar discount rate):	**8.00%**	
ER, annual escalation (inflation) rate for entire period:	**3.00%**	*All elements*
N, system Life:	**15 years**	
Capital Payment		
Investment Levelizing Factor for I and N (Capital Recovery Factor):	11 .68%	
Levelized Investment Cost (CC*CRF):	**103.619 $M**	**"Annual Amortization"**
COE_{CC} : Fixed CC Component of COE	**0.240 $/kWh**	
OMR&R Costs		
Expenses Levelizing Factor for 1, N and escalation (ELF):	1.22	
Capital Recovery Factor, f(I,N):	11.68%	
Present Worth Factor accounting for inflation, f(I,ER,N):	10.5	
Levelized Expenses Cost (OMR&R *ELF):	**59.740 $M**	**"Annual Levelized OMR&R"**
$COE_{OMR\&R}$: Levelized OMR&R Component of COE	**0.138 $/kWh**	
Total (CC + OMR&R) Levelized Annual Cost of Electricity Production:	**163.359 $M**	
Total Levelized Cost of Electricity (no profit; no environmental or tax credits):		
$COE = CDE_{CC} + COE_{OMR\&R}$	**0.378 $/kWh**	

Ref: IEA-IOES (2024). Table 21, Page 31.

However, OTEC Technology, considered one of the 21 emerging and most impactful technologies in the 21st Century[24], has multiple streams of revenue. Other than electricity that could be converted into green hydrogen, it could generate multiple revenues by utilizing the discharge of cold deep-sea water off the OTEC Plant condensers, at 10 degrees Celsius, for the following applications:

- Cooling of the servers of data centres[25];
- Seawater air-conditioning;
- Cooling of tropical soils for temperate crops;
- Culture of value high-value marine produce, including abalone, oysters, fugu fish, and prawns; and that of seaweeds "*umi budou*", marine algae as a source of biofuels;

24 Academy of Sciences of Malaysia (2017). Science & Technology Foresight 2050. Pp: 92-93. https://www.akademisains.gov.my/asm-publication/eset-study-report/

25 An important new source of higher electricity consumption is coming from energy-intensive data centres, artificial intelligence (AI) and cryptocurrencies, which could double by 2026, to 1,000 TWh. The worldwide consumption in 2022 was about 460 TWh of electricity, almost 2% of total global electricity demand. IEA Electricity 2024. Analysis & Forecast 2026. Page 8.

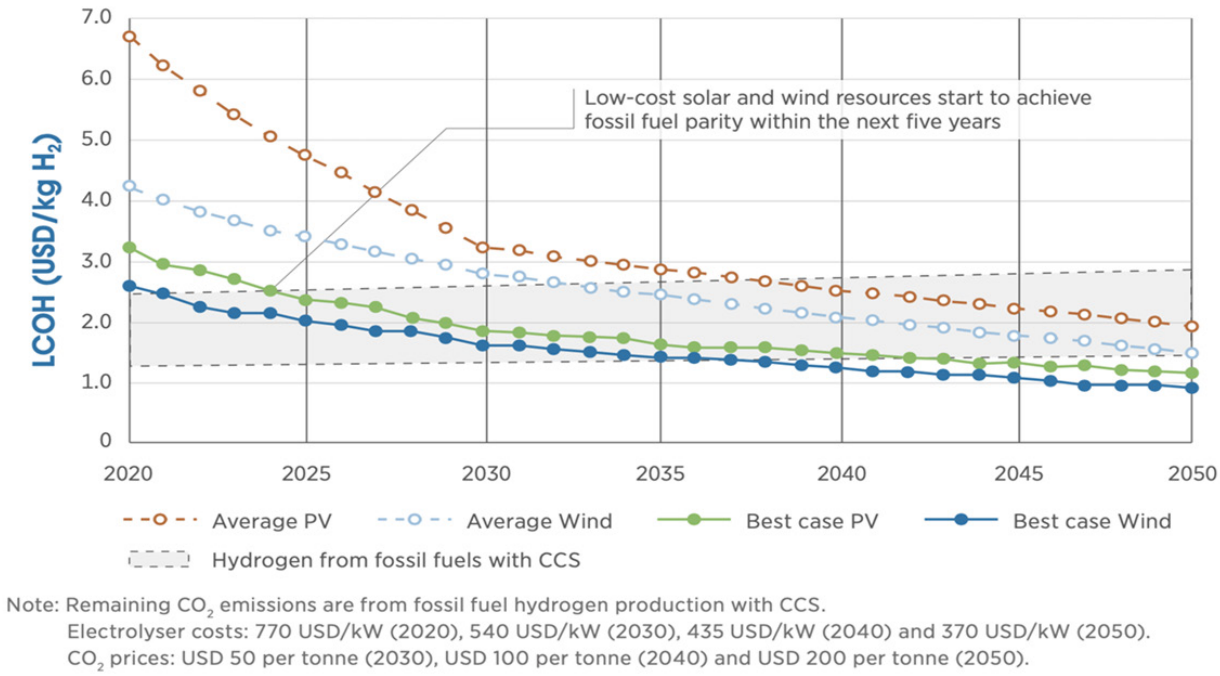

Figure 4: Hydrogen production costs from solar and wind vs fossil fuels

Source: IRENA (2019). Figure 14, p. 34. Adam Christensen (2020). Page 59.
Ref: IRENA (2019). Hydrogen: A renewable energy perspective. Tech. rep. Paris, Sept.
URL: https: //www.irena.org/publications/2019/Sep/Hydrogen-A-renewable-energyperspective.

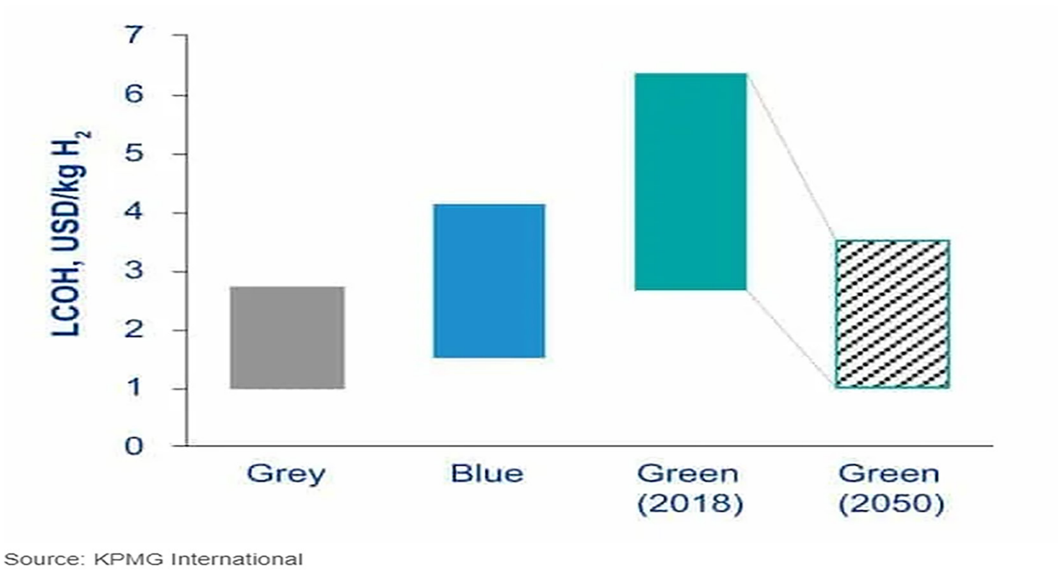

Figure 5: LCOH USD/kg H2 by type

Note: OTEC-generated green hydrogen could easily match the expected cost of USD 3/kgH2, or even lower, simply because the heavy initial investment of OTEC Plant could be absorbed by other OTEC revenue streams, including the production of premium value mineral water, and cooling of data centres.
Ref: https://carboncredits.com/doe-sets-eyes-on-cutting-clean-hydrogen-cost-1-kilo-by-2031/?utm_source=CarbonCredits.com&utm_campaign=8f4c8a920c-EMAIL_Carbon_Recap_11052024&utm_medium=email&utm_term=0_-8f4c8a920c-%5BLIST_EMAIL_ID%5D. 11 May 2024

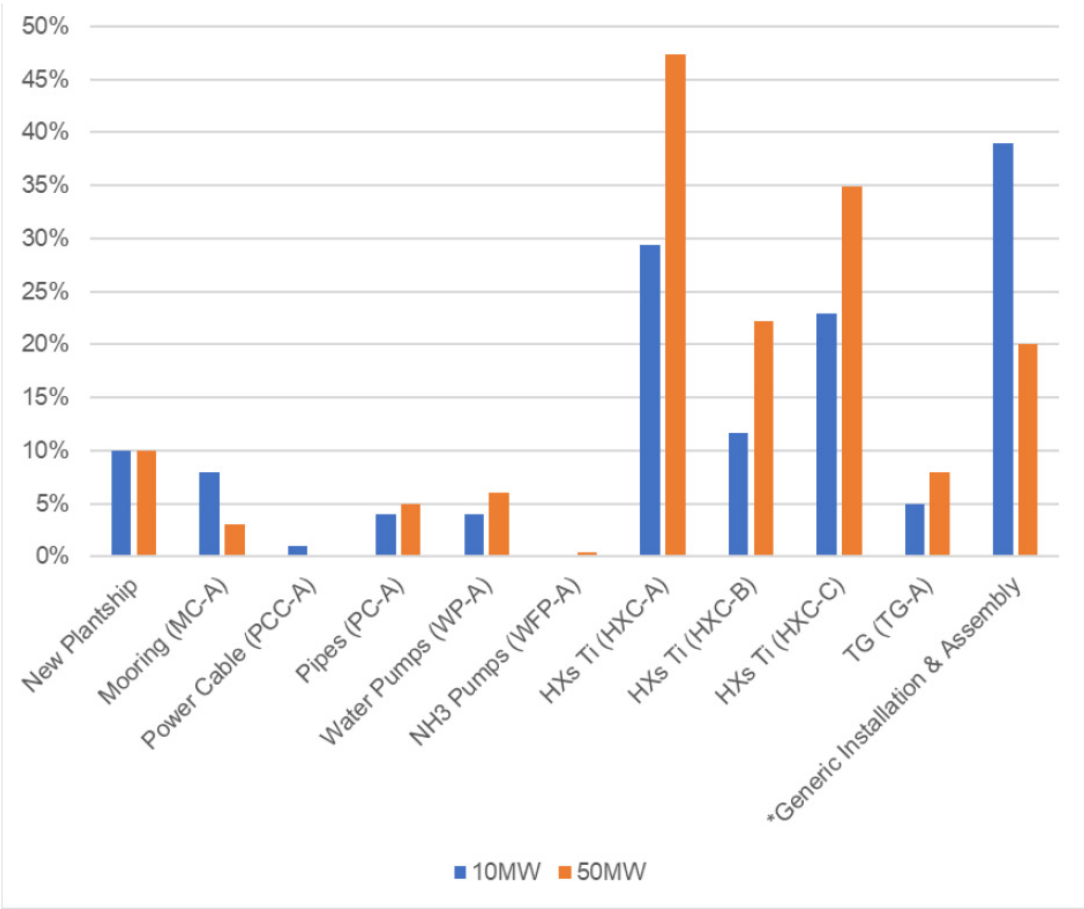

Figure 6: Closed cycle OTEC cost distribution with various heat exchanges

Ref: IEA-OES (2024), Ocean Thermal Energy Conversion (OTEC) Economics: Updates and Strategies. www.ocean-energy-systems.org. Page 11.

- Extraction of Lithium for batteries;
- Production of value high-value sea salts; and
- Sales of the raw deep-sea water (DSW) to produce premium value mineral water[26] that is beneficial to human health in reducing blood pressure, cholesterol, and obesity.

With such promising and attractive streams of revenues, the heavy capital cost of the said OTEC plant could be shared, if not totally absorbed, by the above spinoff industries[27] as such the cost of green hydrogen production by OTEC technology could be reduced from USD 18.30/kgH to USD 2.50/kgH and could match any other renewables or even fossil fuels.

Further R&D on OTEC technology

Even though OTEC Technology, not only meets all the 17 Sustainable Development Goals of the UN but also generates multiple streams of revenue (in value high-value food items, premium value mineral water, and highly desirable green hydrogen), the heavy capital cost of OTEC plant is still a major concern to all stakeholders. As shown in Figure 6, the costliest equipment is the Titanium Heat Exchanges [HXs Ti (HXC-A, B, C] that take up at least 25% up to 47% of the total capital cost of OTEC Plant, including its installation and assembly, as outlined in Table 4.

In addressing such an issue the Institute of Ocean Energy of Saga University of Japan and the University of Technology Malaysia (UTM) Ocean Thermal Energy Centre entered into an agreement to conduct joint research and development of Hybrid-OTEC experimental plant under the Science and Technology Research Partnership Programme for Sustainable Development (SATREPS) under the Science and Technology Agency

26 Among the notable brands are “Mahalo” and “Kona Deep” of Hawaii; and “YES” of Taiwan, China.

27 Other than cooling the data centres’ servers, these industries are already well established in Kumejima, Okinawa, Japan; Big Island, Hawaii, USA; and Goseong, Republic of Korea. A pilot plant in extracting Lithium from seawater has been set up at the Institute of Ocean Energy Saga University (IOES), Imari, Kyushu, Japan.

Table 4: Closed cycle OTEC cost estimates for major subsystems in 10MW and 50 MW plantship

	10.6 MW		53.5 MW	
Component	**$M**	**10 MW %**	**$M**	**50 MW %**
New Plantship	28.3	10%	84.5	10%
Mooring (MC-A)	22.0	8%	29.0	3%
Power Cable (PCC-A)	3.7	1%	4.2	0%
Pipes (PC-A)	10.9	4%	43.5	5%
Water Pumps (WP-A)	11.5	4%	57.5	6%
NH3 Pumps (WFP-A)	0.65	0.2%	3.4	0.4%
HXs Ti (HXC-A)	84.0	29%	420.0	47%
TG (TG-A)	13.5	5%	67.5	8%
***Generic Installation& Assembly**	111.8	39%	177.3	20%
TOTAL ($M)	**286.3**		**886.9**	
$/kW (w/ HXC-A)	**27,012**		**16,578**	
$/kW (w/ HXC-B)	**21,606**		**11,223**	
****Installation& Assembly***	***$M***		***$M***	
Mooring & Power Cable	*43.5*		*58.4*	
Pipes & Pumps	*8.0*		*34.8*	
Power Block	*33.2*		*57.0*	
Electrical & Controls	*27.1*		*27.1*	

The category "Installation and Assembly" is the same amount independently of HXs supplier and includes educated estimates associated with transportation to a generic site and equipment mobilization and demobilization.

Ref: IEA-OES (2024), Ocean Thermal Energy Conversion (OTEC) Economics: Updates and Strategies. www.ocean-energy-systems.org. Page 10.

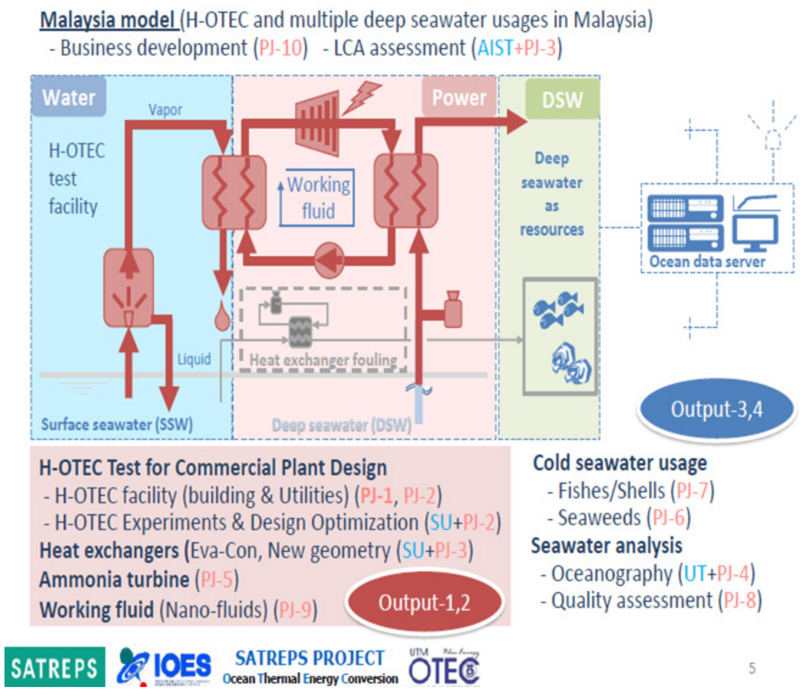

Figure 7: Malaysia-Japan SATREPS hybrid-OTEC project 2019-25 [Diagram after Yasunaga Takeshi]

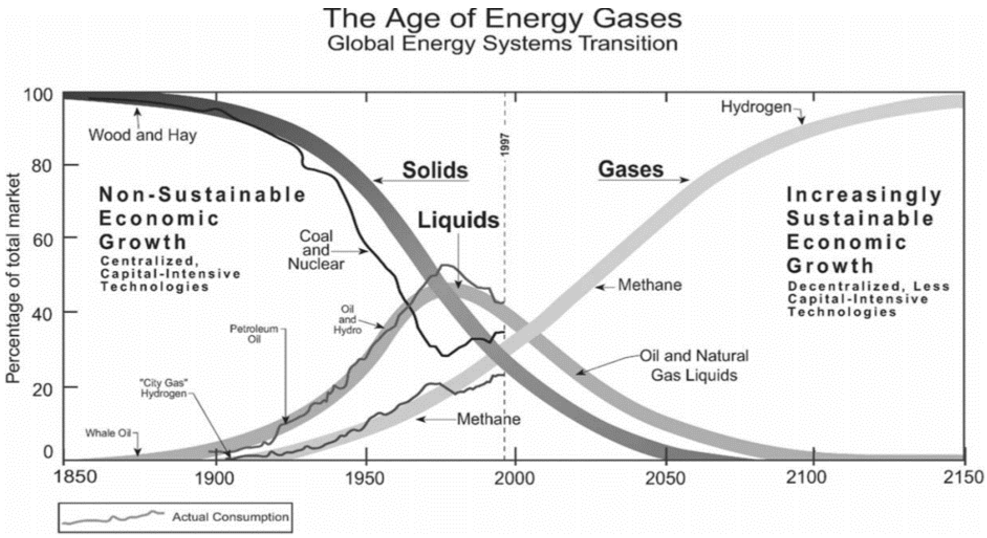

Figure 8: Global energy systems transition 1850-2150 [20]

[20] Hefner RA, GHK Company. The age of energy gases (Fig. 1). Adapted from Presentation at the 10th Repsol-Harvard Seminar on Energy Policy, Madrid, Spain, 3 June 1999. Oklahoma City, OK, 1999; Ausubel JH. Where is energy going? Ind Phys 2000; 16 –19.

of Japan (JST) with the support of Japanese International Cooperation Agency (JICA) and the Ministry of Higher Education of Malaysia (MoHE) for the period 2019-2024,25. As shown in Figure 7, the Hybrid OTEC plant of 3kW, said to be the first of its kind in the world, essentially consists of both the open-cycle and closed-cycle systems. Instead of using the Titanium-type heat exchanges as evaporators, the stainless-steel version is used. To prevent the biofouling of steel-type heat exchanges, water vapour is introduced through a vacuum chamber into which warm sea water is injected.

Another novel aspect of joint R&D is on the formulation and testing of nano working fluids injected with selected nano materials and selected surfactants. The purpose is two-fold: one is to improve the efficacy of the existing working fluids including ammonia, and another, the OTEC potential in shallow waters, that are less than 700 meters, could be harnessed.

Concluding remarks

Said Sheikh Zaki Yamani, the former Oil Minister of the Kingdom of Saudi Arabia, back in 1974: *"The Stone Age did not end for the lack of stone, and the Oil Age will end long before the world runs out of oil."*[28] This statement is followed by another: there shall be a transition from OPEC to OTEC.[29] Indeed, it has been projected over the period 1850-2150, as shown in Figure 8, the solid fuels had been phased out by liquid fuels in the mid-Seventies; the latter are being phased by gases, namely, methane by early this Century, and hydrogen is going to be the most dominant energy carrier by 2050.[30]

Acknowledgement

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2024

October 9-11, 2024
International Greentech & Eco Products Exhibition and Conference Malaysia (IGEM)
Kuala Lumpur, Malaysia
Contact:
Conference Secretariat
Tel: +603-8921 0800
Email: nursyamimi@mgtc.gov.my; khairol.naim@mgtc.gov.my
https://www.igem.my/

October 14-18, 2024
Asia-Pacific Ministerial Conference on Disaster Risk Reduction (APMCDRR)
Manila, Philippines
Contact:
Conference secretariat
Email: apmcdrr@un.org
https://apmcdrr.undrr.org/

October 18-20, 2024
2024 Asia Conference on Smart Grid, Green Energy and Applications (SGGEA 2024)
Suzhou, China
Contact:
Ms. Cici Xu, Conference Secretary
Tel: +852 95096877
Email: sggea_conf@163.com
http://www.sggea.net/

October 22-24, 2024
Asia Clean Energy Summit (ACES)
Singapore
Contact:
Ms. Nur Asyiqin
Project Executive
ACES Secretariat
Tel: +65 6338 8578
https://www.asiacleanenergysummit.com/home

November 9-11, 2024
2024 9th Asia Conference on Environment and Sustainable Development (ACESD 2024)
Osaka, Japan
Contact:
Miss Ching Cao
Conference Secretary
Tel: +86-13290000003
Email: acesd_conf@126.com
https://www.acesd.org/

November 11-13, 2024
Asian Summit on Global Warming and Climate Change (ASGWCC2024)
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Email: secretary@climatesummit2024.org
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2nd edition of Sustainability Environment Asia (SEA)
Kuala Lumpur, Malaysia
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Derrisen Sdn Bhd
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55200 Kuala Lumpur, Malaysia
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https://gwec.net/apac-wind-energy-summit-2024/

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2024 International Conference on Clean Energy and Smart Grid (CCESG 2024)
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December 02-04, 2024
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International Conference on Sustainable Energy and Green Technology 2024 (SEGT 2024)
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2025

January 17-19, 2025
2025 2nd International Conference on Smart Grid and Energy
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