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Institute for Essential Services Reform

Powering the Future:

An Assessment of Energy Storage Solutions and The Applications for Indonesia

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A global overview of energy storage system deployment and the adoption status in Indonesia

- ➢ Energy storage system (ESS) roles in power system and deployment trend
- ➢ Technology outlook
- ➢ Current adoption status in Indonesia and future adoption challenges

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Deep dive into the hydrogen development, an emerging technology and game-changer

- ➢ The Hydrogen technology development
- ➢ Challenges and opportunities of hydrogen implementation
- ➢ Enabling factors for hydrogen ecosystem development

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Further challenges and opportunities, along with the steps Indonesia needs to take

- ➢ Power and transportation sector coupling
- ➢ Domestic battery supply chain
- ➢ Recommendations

A global overview of energy storage system deployment and the adoption status in Indonesia

- ➢ Energy storage system (ESS) roles in power system and deployment trend
- ➢ Technology outlook
- ➢ Current adoption status in Indonesia and future adoption challenges

Frequently asked questions:

1. Why is energy storage necessary and what role does it play in the power system?
2. How far has the application of energy storage progressed globally?
3. What is the best energy storage technology?
4. What is the status of energy storage development in Indonesia?
5. What are the challenges and where are the opportunities for implementing energy storage in Indonesia?

While VRE will continue to be the main driver of ESS growth, the role of ESS has evolved beyond just supporting VREs, becoming a valuable grid asset both in front of and behind the meter

ESS to enable higher VRE penetration

Six phases of variable renewable energy integration

High phases:

- **Phase 6:** Secure electricity supply almost exclusively from VRE
- **Phase 5:** Significant volumes of surplus VRE across the year
- **Phase 4:** VRE meets almost all demand at times

Low phases:

- **Phase 3**: VRE determines the operation pattern of the power system
- **Phase 2:** VRE has a minor to moderate impact on the system
- **Phase 1:** VRE has no significant impact at the system level

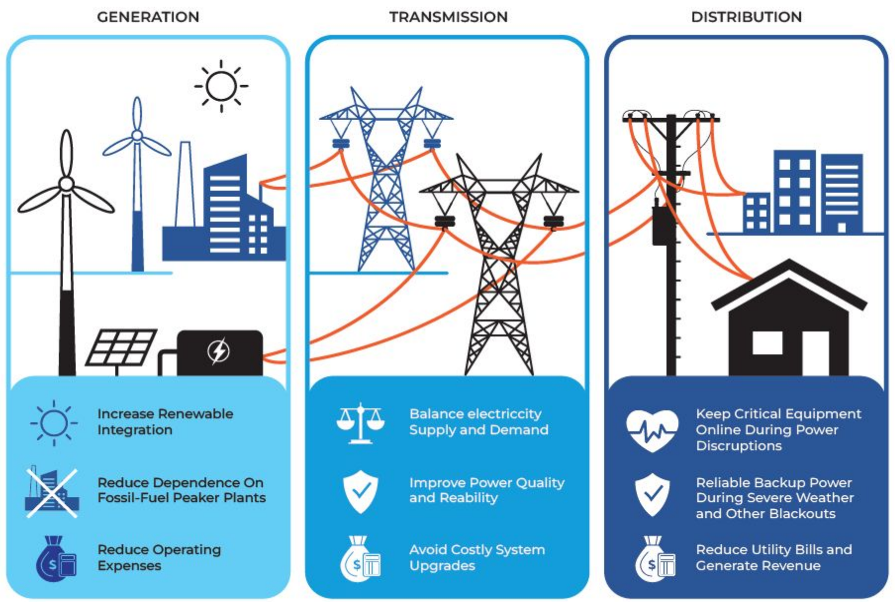
Phases 6–5: Long-duration or seasonal storage

Phases 4–3: VRE generation time-shifting energy storage

Phases 2–1: The implementation of energy storage to correct VRE output

Source : Adapted from IEA, 2024

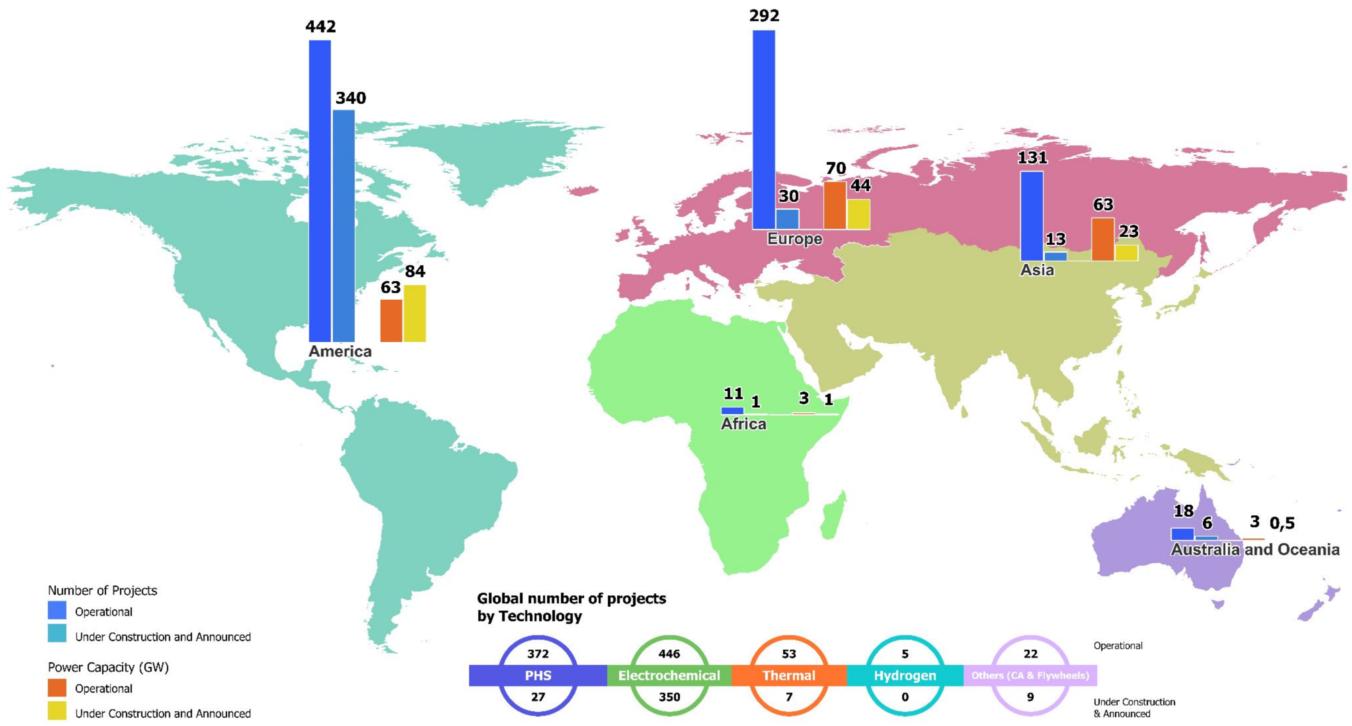
ESS roles in power system



Source : Adapted from Global X ETFs, 2022

Also helping to avoid conventional generator inefficient ramping and can be more cost-effective (30%) than operating a peaker gas plant

The global map of energy storages systems installation (capacity >1 MW)

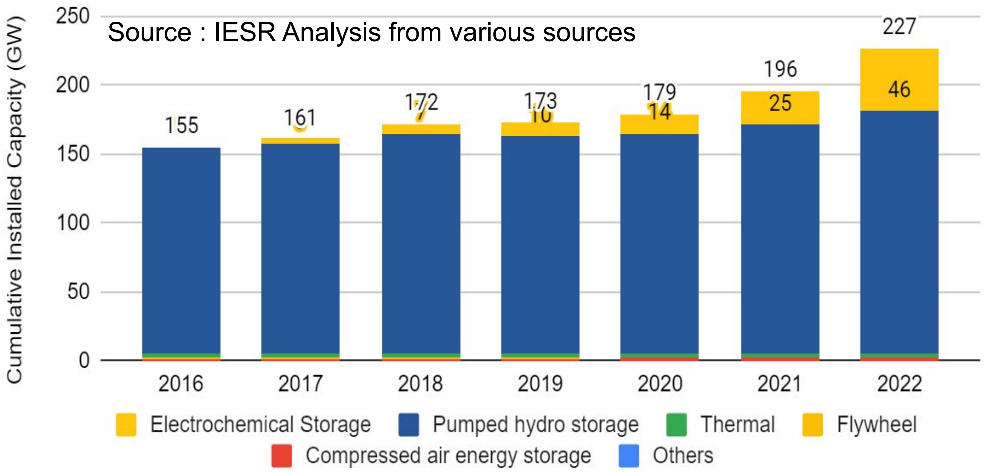


Source : IESR Analysis from U.S. DOE database, 2024

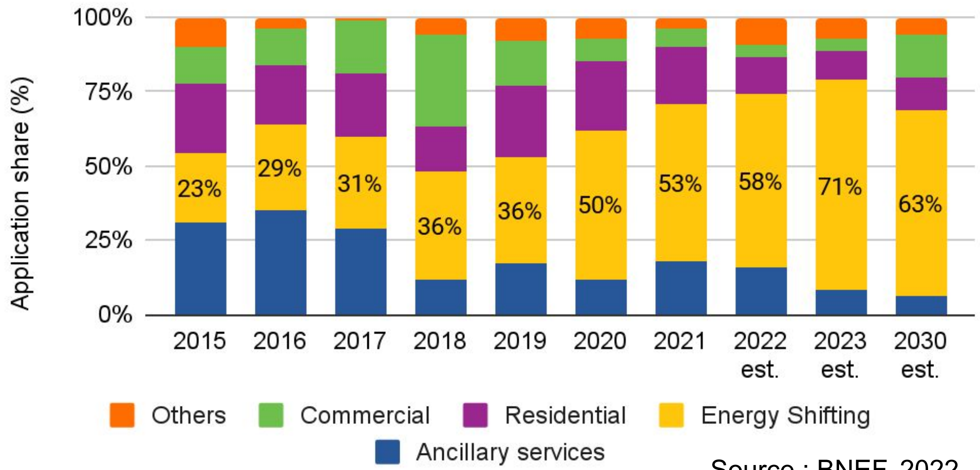
More than 2,000 ESS projects with various types of technology have been operated worldwide.

- The Americas have the highest number of ESS projects with capacities exceeding 1 MW, predominantly electrochemical technologies, with the USA as the leading installer
- Europe leads in total installed capacity, with many pumped hydropower storage systems installed across various countries.
- Although Asia has less than half the number of ESS projects compared to Europe, it has a similar total capacity, implying that the projects are generally developed on a larger scale.
- ESS projects totaling approximately **88 GW are reported to be under construction**, with an additional **64 GW announced** across five continents

Global energy storage systems capacity growth



Application mix of BESS projects (power output base)



Source : BNEF, 2022

Global energy storage has grown by about 41% over the past six years. Grid-scale ESS (in-front of meter) capacity installations, typically at the megawatt scale, have recently outpaced customer-sited (behind-the-meter) ones.

BESS is the fastest-growing technology, with installed capacity increasing more than tenfold between 2018 and 2023, reaching an estimated 86 GW.

The growth rate of ESS installations is expected to continue and accelerate if countries strengthen their commitment to achieving net-zero emissions by 2050. To meet the COP28 target of tripling renewable energy capacity by 2030, 1,500 GW of ESS installed capacity will be required.

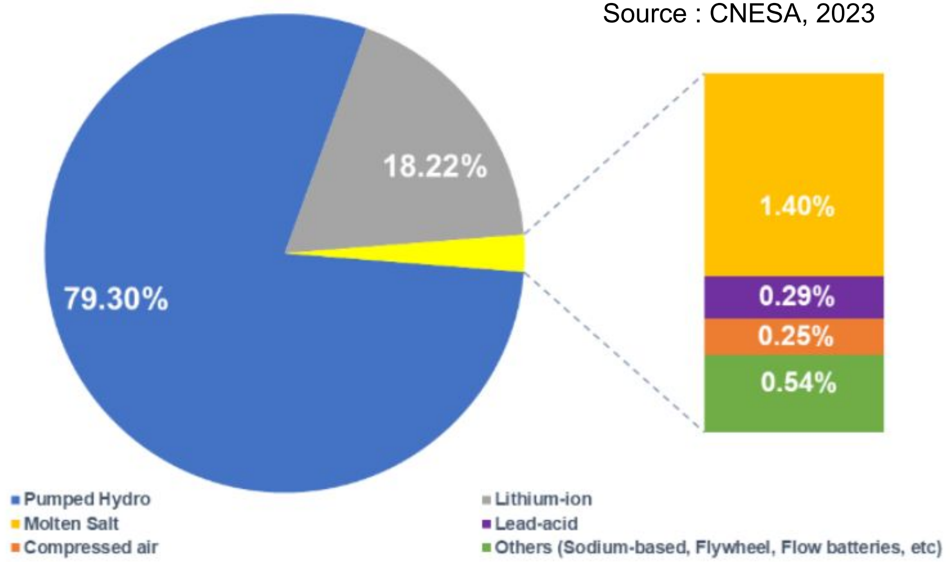
National-level support is expected to further boost storage investments in the coming years. China and the USA, projected to account for more than half of global storage deployments by 2030, are driving this growth through the 14th Five-Year Plan (FYP) and the Inflation Reduction Act (IRA), respectively.

In recent years, the ancillary services BESS market has reached saturation, while energy-shifting ESS capacity has grown to occupy more than half of the application mix. This trend is closely linked to the substantial increase in renewable energy deployment, driving the demand for longer-duration ESS.

Today's energy storage capacity share

Global energy storage market in power sector by 2023

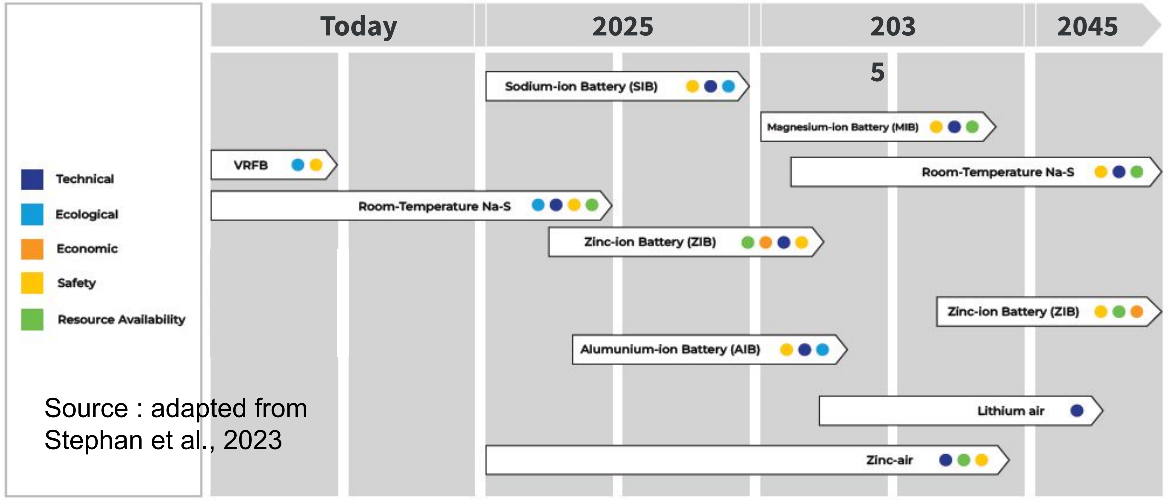
Source : CNESA, 2023



Mechanical storage still dominate, accounting for around 80% of global ESS capacity. While lithium-ion batteries (LIBs) lead electrochemical ESS, alternatives like sodium-ion and flow batteries are gaining attention

Emerging technologies market entry projection

Electrochemical energy storage technology development roadmap

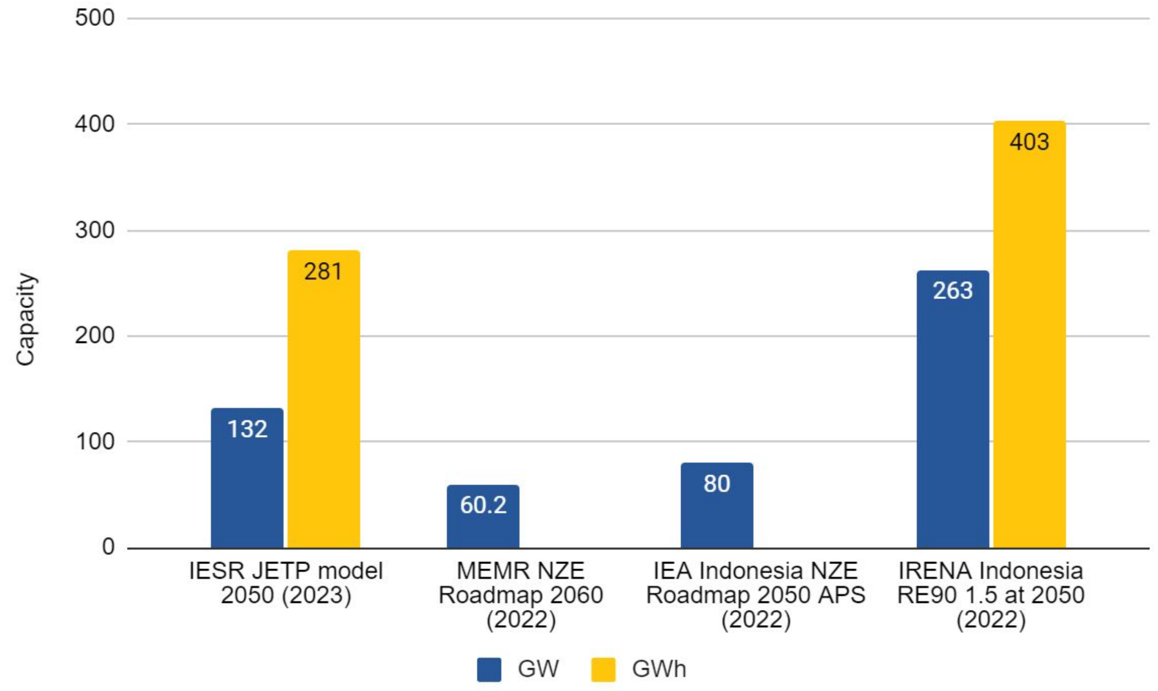


Source : adapted from Stephan et al., 2023

Non-lithium chemistries are projected to account for more than 10% of the stationary market by 2025, up from less than 5% in 2021.

Metal-ion batteries that replace lithium with sodium are expected to enter the ESS market first, capturing market share from LIBs before other metal-ion batteries follow.

Required energy storage capacity in different scenarios



ESS installed capacity in Indonesia by 2024 and the projected new capacity addition

Potential installed capacity by 2030: 33.7 GWh

25 MWh
Traced installed capacity by private sector and PLN

Around 10 MWh
from more than 20,000 APDAL (Government distributed storage)

Around 4.5 GWh
PLN pipeline Including Dedieselization and PHS plan

Around 29 GWh
electricity export solar PV + battery projects

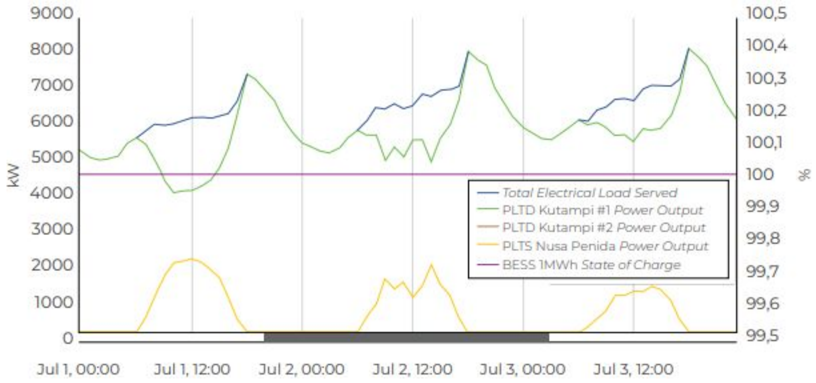
Source : IESR Analysis

- Indonesia's total cumulative installed energy storage capacity has reached around 35 MWh by mid-2024, primarily from BESS installations in distributed, isolated systems supporting solar PV generation. Installed energy storage capacity could exceed 30 GWh by 2030, based on announced projects.
- Some of ESS technology early adopters are private sectors and remote areas supported by grants for electricity access. Most private sector entities willing to invest in solar PV + BESS systems were those previously reliant on costly diesel generators.

Nusa Penida study case

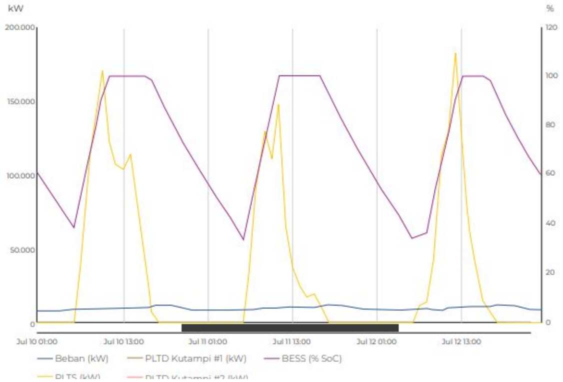
Source : IESR,2024

existing system profile



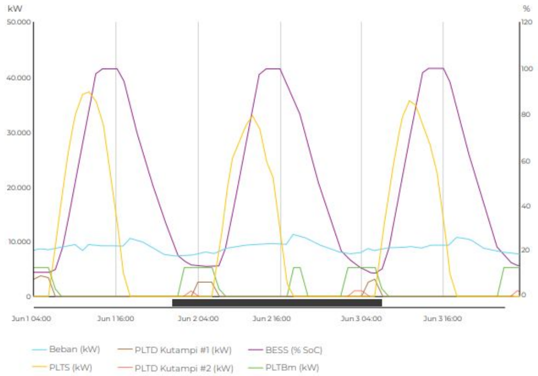
NZE roadmap by 2030

100% solar PV + BESS



Or

Solar PV + BESS + biomass



Two cases BESS utilization each by off-grid C&I solar rooftop system

- BESS in the resort has a longer duration to maximize the use of energy produced by VRE
- BESS in industrial microgrids has a short duration with large output capabilities, to provide an instantaneous power source for uninterrupted industrial processes
- Besides gaining a green label, installations in industries and eco-resorts, offer significant electricity cost savings.from fuel consumption reduction

Second-life battery utilization and redox flow battery pilot project

- Installing energy storage in the residential sector requires individual initiative and willingness due to the lack of rewards or promising investment schemes. Similarly, testing various types of energy storage through pilot projects involves high costs and uncertain results.

The summary of existing characteristics of power system in Indonesia and its influence to energy storage system adoption

Characteristics	Influence on ESS Adoption	Description
Low VRE penetration level and slow growth in the past few years	Demote	- The output variability of VRE at the current penetration level has no significant impact on grid stability, reducing the need for ESS to smooth VRE output. - VRE electricity production levels are still low and can be supplied to the grid. At higher levels, ESS will be needed to reduce VRE curtailment.
Low electricity load and peak load growth	Demote	- The capacity of non-VRE power plants (committed projects) has increased significantly, while the growth in electricity demand has been relatively low in recent years, hampering utilities' ability to invest in new grid assets. - The system load factor has been high, indicating a low need for ESS development as a peaker asset. - The installed fast-response generating capacity is already quite high.
High capacity of fast response generators in the pipeline	Demote/Neutral	- This limits the potential for additional development of ESS as an ancillary services provider. - ESS projects must be economically competitive with generating assets such as gas-fired power plants and conventional hydropower plants.
Several isolated systems with limited energy sources	Promote	- In certain remote areas, particularly those with limited energy resources and no grid connection, access to electricity is often restricted to lighting. - Electricity generation using a solar PV plus storage system can be more cost-effective than fossil fuel generators like diesel generators.
Inferior power system reliability and efficiency in smaller systems	Promote	- There is potential to increase system efficiency based on the low system load factor, particularly in several small systems. -The higher-than-average level of system interruptions in small systems suggests potential for ESS implementation as a backup power source or for deferring transmission and distribution (T&D) upgrades. -Systems with high VRE penetration levels are beginning to be impacted by the variability of VRE output.
Low flexibility in current generation mix to accommodate rapid VRE integration	Promote/Neutral	- The plan to significantly expand VRE capacity to reach the final net zero emissions (NZE) target will require large-scale, versatile energy storage to facilitate rapid VRE integration. - The number of existing grid assets that can be operated with flexibility is limited.

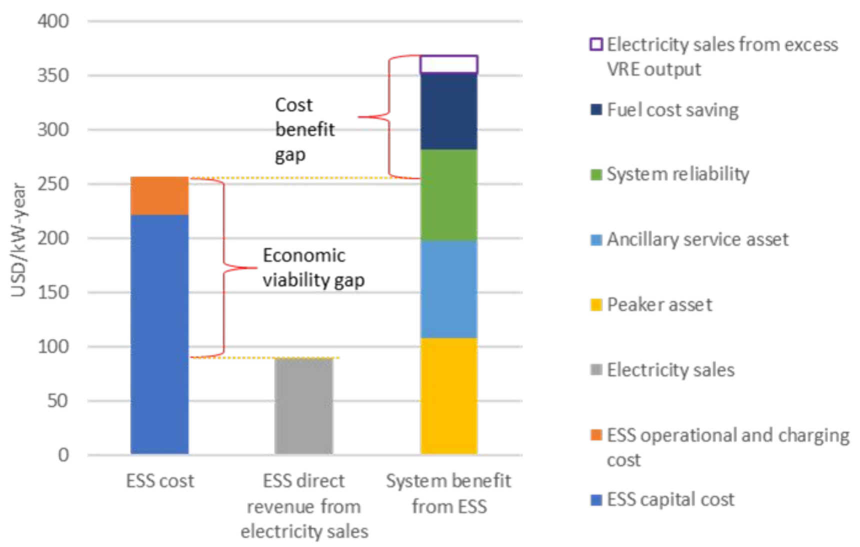
At present, the best opportunities for ESS deployment lie in smaller or isolated systems

ESS-related regulatory framework

Document type	Document	Remarks
Planning and/or ESS definition	MEMR's NZE Roadmap 2022	Sizable capacity target, limited ESS definition
	National Electricity Plan (RUKN) Draft 2023-2060	
	PLN's RUPTL (2021-2030)	
	MEMR Reg 9/2023 (RENSTRA 2020-2024)	Storage deployment plan beyond RUPTL
	Government Reg 25/2021	May need an update with detailed terms for ESS
Grid code	MEMR Reg 20/2020	May need adjustment with recent high VRE adoption plan
Others	MEMR Reg 12/2021 (Business certification)	Quite detailed. may need to be evaluated after the introduction of other new or updated regulations
	MEMR Reg 22/2021 (APDAL regulation)	

- Many essential policy frameworks have yet to be introduced.
- Previous long-term planning documents for the power sector do not fully recognize the unique versatility and value of different types of stationary ESS.
- The current market structure and regulations do not provide a sufficient enabling environment for ESS adoption.

Estimated system benefit of utility scale ESS compared to its costs



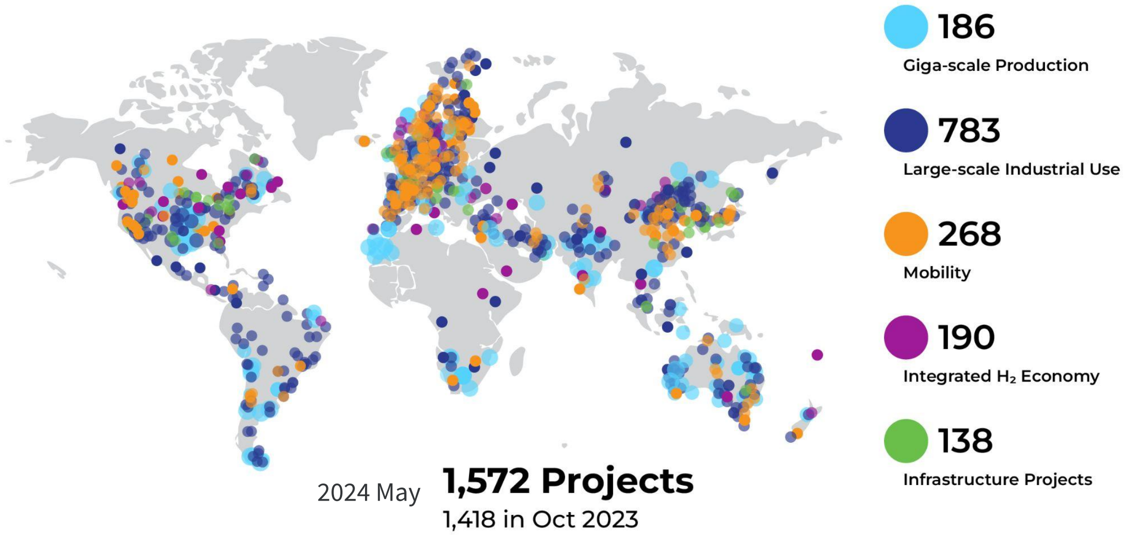
- Currently, there are no specific incentives or subsidies to encourage the expansion of ESS projects and reward early adopters.
- The total system cost benefits of integrating ESS should be considered when evaluating its economic viability, particularly at the utility scale in Indonesia.

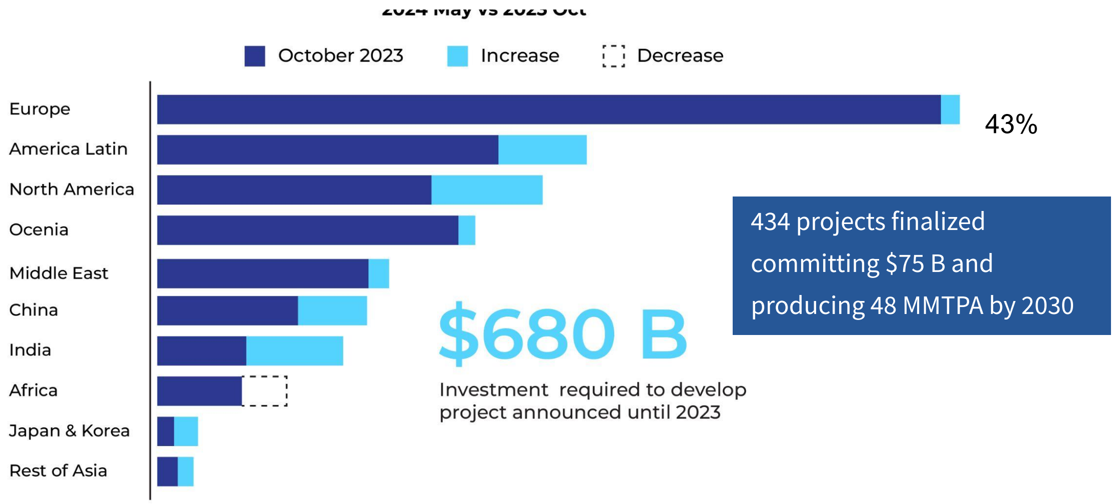
Hydrogen

Summary

- ➢ The Hydrogen technology development
- ➢ Challenges and opportunities of hydrogen implementation
- ➢ Enabling factors for hydrogen ecosystem development

The landscape of global hydrogen development as an emerging technology and game-changer

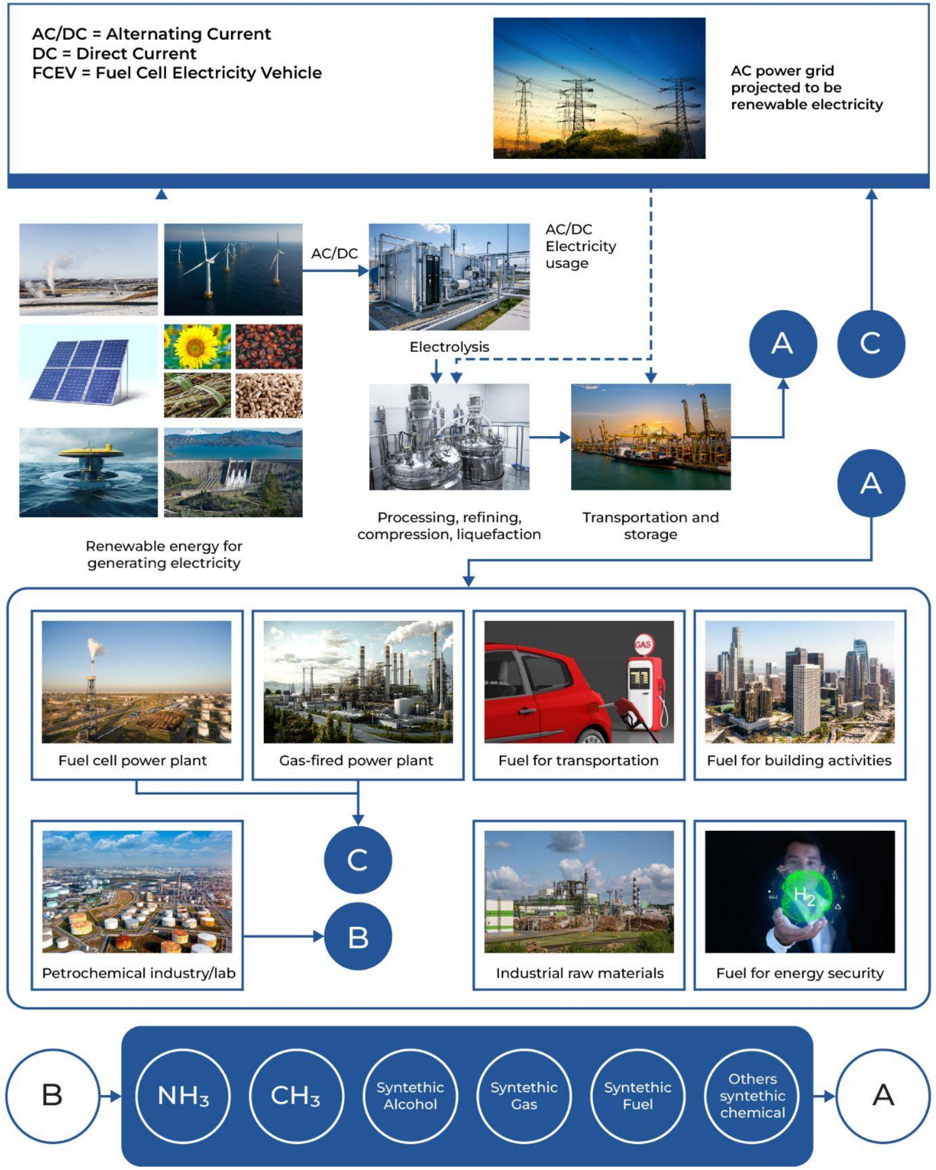




- Global hydrogen consumption is predicted to rise six- to eight-fold from 90 million ton/year in 2020 to 530–650 million ton/year in 2050 (IEA, WHA).
- Adopting low-emission hydrogen would cut at least 80 gigatons of CO_2e, or 19% of annual global GHG emissions (WEF, Hydrogen Council).
- By the end of 2023, nearly 50 countries had published their National Hydrogen Strategies, including Indonesia (Weltenergierat).
- Hydrogen utilization can create near-zero-emission energy, which is being pushed to be produced and utilized globally.
- The world is currently shifting towards low-emission hydrogen and renewable energy, making green hydrogen much more preferred.
- It appears that the present hydrogen production ecosystem is insufficient to accommodate these 2050 projections of global demand.
- Its scope, production, and use are limited by the fact that the infrastructure and technology needed to use it are still being developed as an emerging technology.

Source : *Hydrogen Council, 2024*

Sustainable, low-emission, green hydrogen as sustainable green energy storage

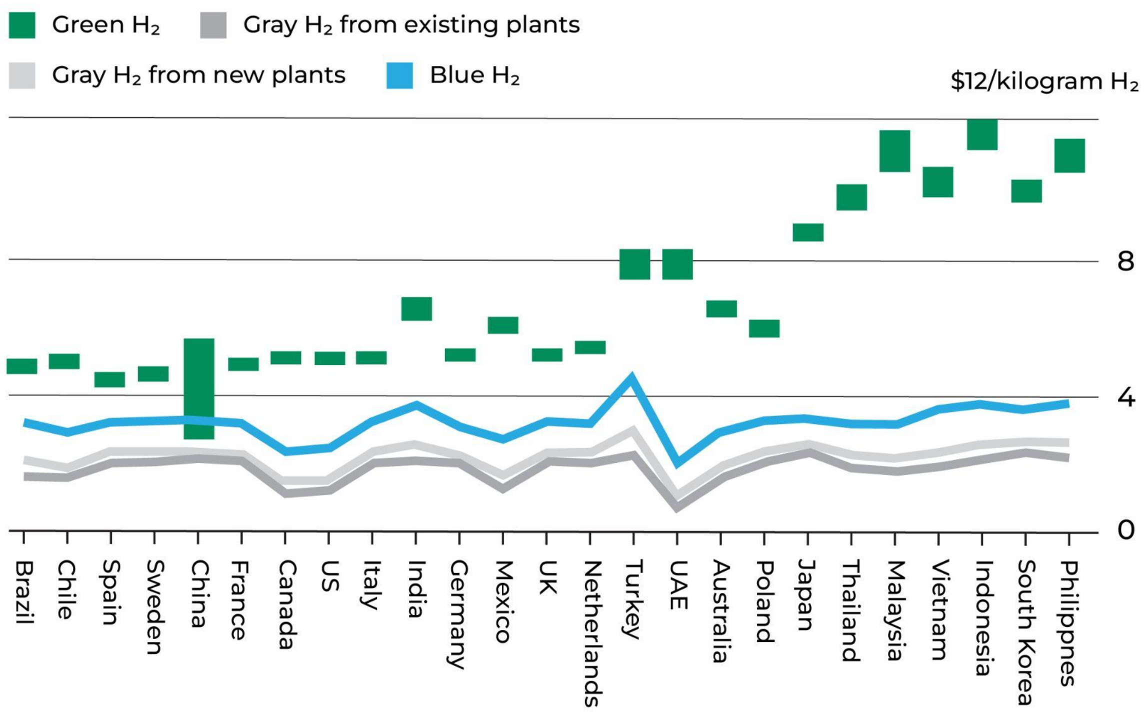


Source : *Analysis adapted from many sources*

- The hydrogen color taxonomy is determined by the energy source, raw material, process, and resulting product. it can be gray, blue, green and others.
- In 2023, about 92–98% of world hydrogen supply was generated from fossil fuels, or "gray," accounting for 3% of global CO_2 emissions (Forbes, IRENA, WoodMac).
- Hydrogen has the potential to be one of the cleanest energy sources, with a low life-cycle emissions (LCE) footprint as it can store clean electricity.
- To reach Net Zero Emissions (NZE) standards, clean hydrogen predicted will have less than 1 kilogram of CO_2 eq per kg of hydrogen by 2050.
- As a short- to long-term energy storage and feedstock, hydrogen offers practical applications similar to fossil fuels, unlike batteries.
- To minimize fossil fuel dependence, sustainable, low-emission hydrogen is aggressively advocated for energy storage and adoption across various sectors.

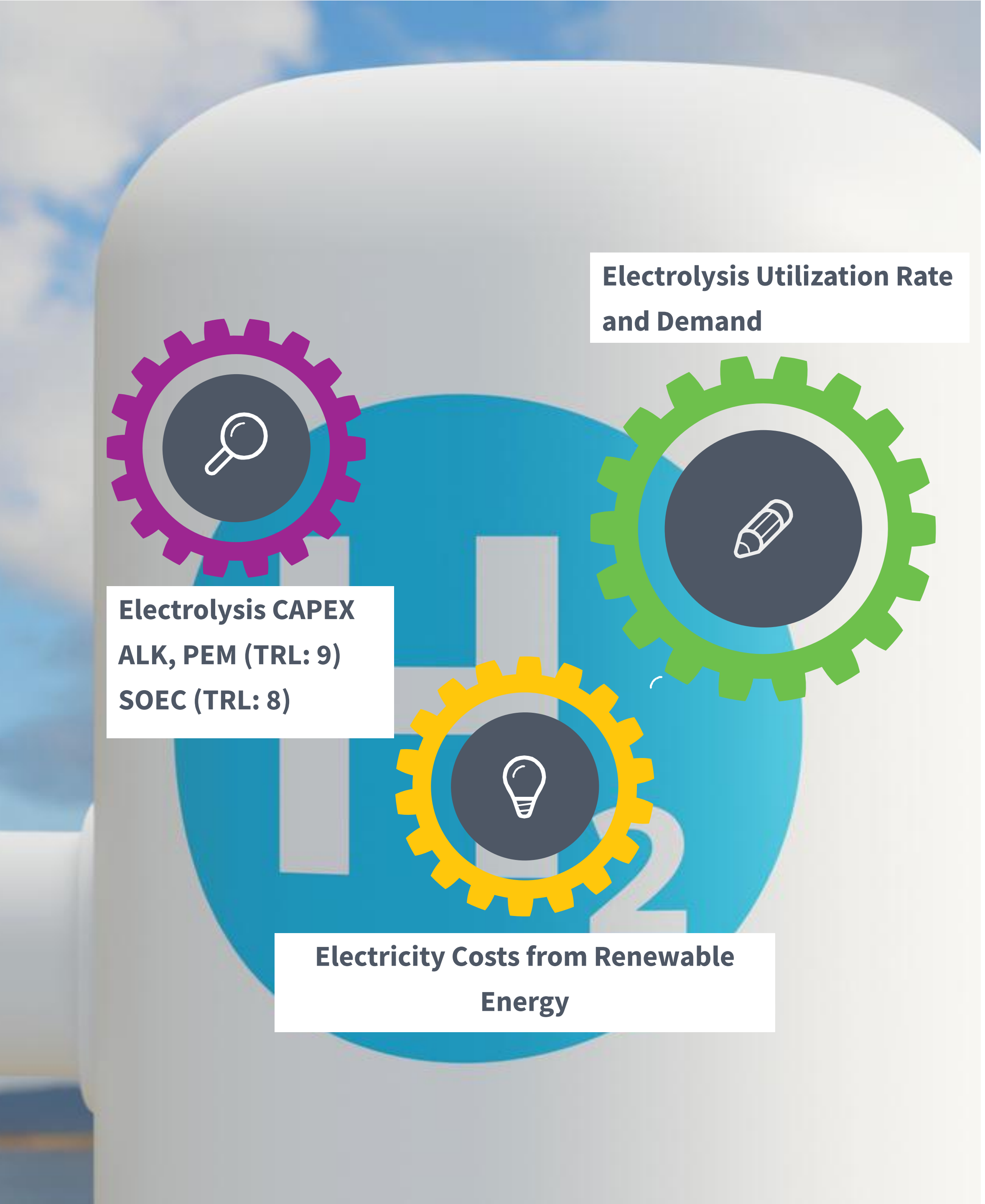
Hydrogen as energy storage is still expensive, and efforts are required to make it cheaper

Today, Green Hydrogen Is Consistently More Expensive Than Grey
levelized cost of hydrogen in 2023, by market



Source : *BNEF, 2023*

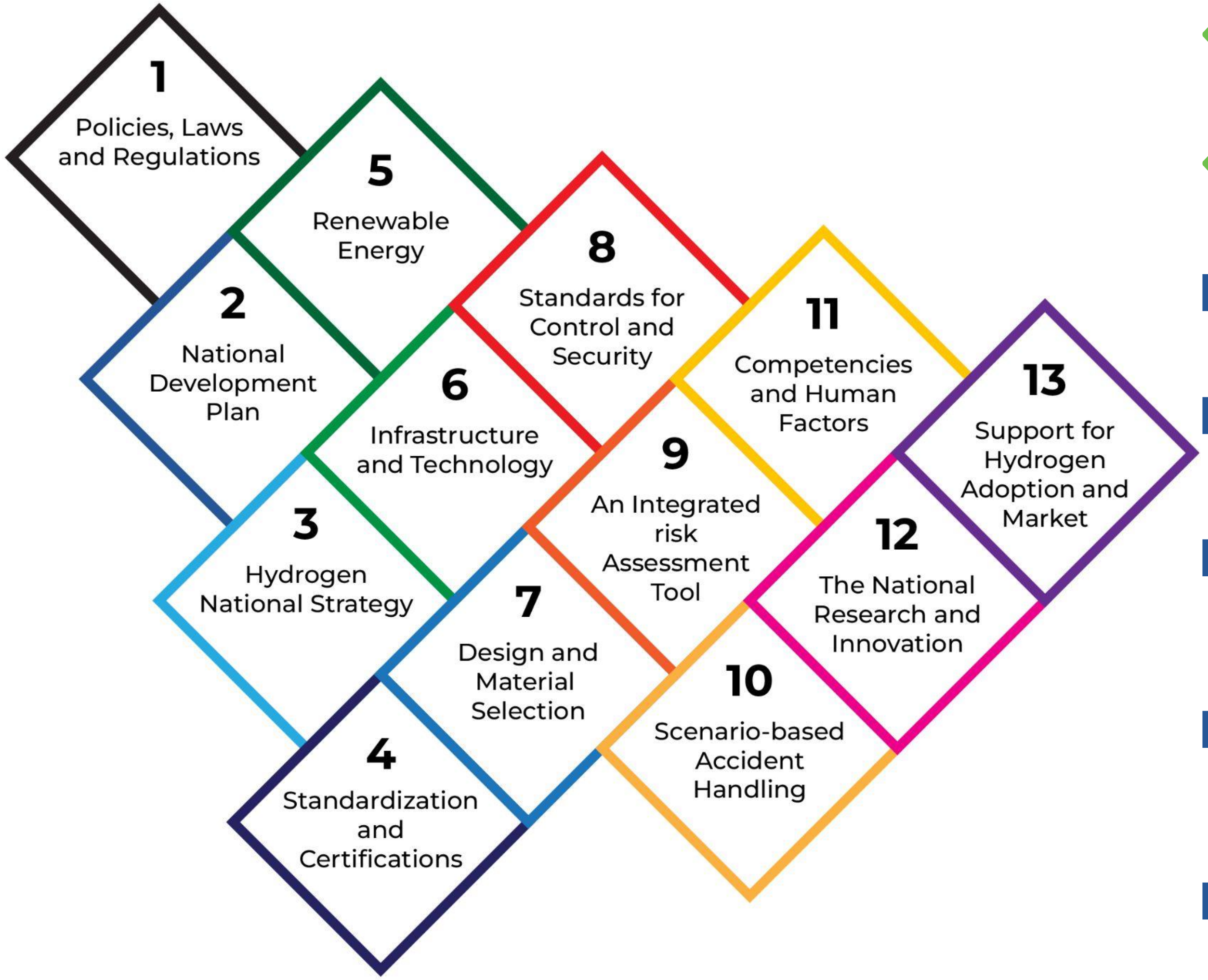
- The present global production cost of green hydrogen ranges from USD 2.7 to 12.84 per kilogram (*BNEF)*.
- Green hydrogen will be pushed closer to production cost of USD 2 per kg by 2035, and under USD 2 per kg by 2040 (*BNEF)*.
- Predicted the green hydrogen market valued at USD 6.3 billion in 2023 and will rise to USD 143–166 billion by 2033 (*GlobeNewsWire*; *Precedence Research*)
- The worldwide hydrogen market is expected to rise from USD 156 billion in 2022 to USD 292–410 billion by 2030 (*Bloomberg*; *Globe News Wire*).
- Indonesia could potentially produce green hydrogen with a competitive production cost (on-site) of USD 1.9-3.9/kg (MEMR).
- Creating opportunities for Indonesia to become a world's major hydrogen production hub in satisfying local and global demands.
- Large investments and efforts are needed to build a supporting ecosystem for the adoption and market of hydrogen domestically.



Factors influencing the reduction in green hydrogen production costs

- The production cost of green hydrogen is dictated by the costs of water electrolysis powered with renewable energy.
- Hydrogen producers worldwide employ ALK electrolyzers, with 45% market share and 15% PEM, and 40% unknown (Hydrogen Councils).
- ALK electrolyzers are favorable with a longer history, need less maintenance, and use alkaline electrolytes. PEM requires a costly, short-lived membrane, and SOEC pricing remains uncompetitive.
- Solar PV is predicted to become Southeast Asia's primary renewable energy source with PEM and ALK for green hydrogen generation, reaching USD 2.67 to 4.33 per kg by 2050 (ERIA).
- The cost of hydrogen production in Indonesia is still more competitive and needs to be maximized by intervention, including:
  1. Building value chain technology ecosystem,
  2. Mass production of RE electricity and green hydrogen,
  3. Developing technology ecosystem.

Achieving 185 GWh of green hydrogen generation potential by 2060 via optimizing renewable energy potential and developing technology ecosystem



- Indonesia has outlined the map potential of 185 GWh of renewable energy for green hydrogen production by 2060 (MEMR).
- This represents just less than 5% of Indonesia's potential for renewable energy.
- At least USD 90.1 billion is required to use 185 GWh of renewable energy for green hydrogen generation by 2060.
- Establishing an ideal hydrogen ecosystem is necessary to support this large investment and hasten Indonesia's adoption of hydrogen.
- If the Government of Indonesia (GoI) does not act to create a positive investment environment for green hydrogen, this amount may be unreachable.
- Addressing at least 13 crucial elements is part of policy strategies meant to overcome obstacles, create a hydrogen market, and unleash Indonesia's hydrogen potential.
- To expedite the development of an ideal hydrogen environment in Indonesia, it is essential to carefully examine the expedited preparation of these 13 elements.

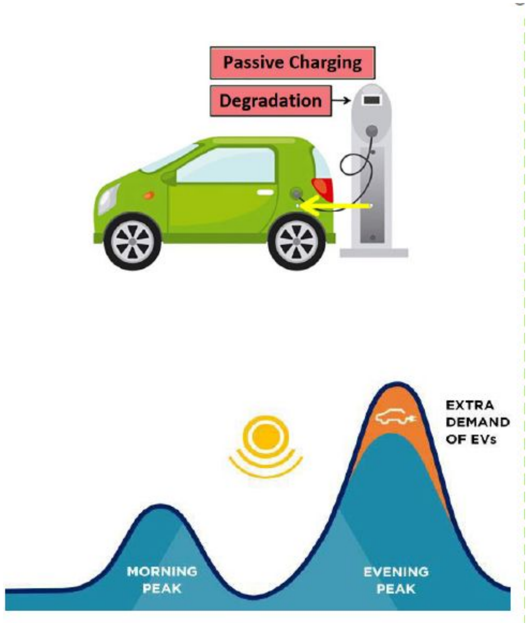
Source : *Analysis adapted from many sources*

- Power and transportation sector coupling
- Domestic battery supply chain
- Recommendations

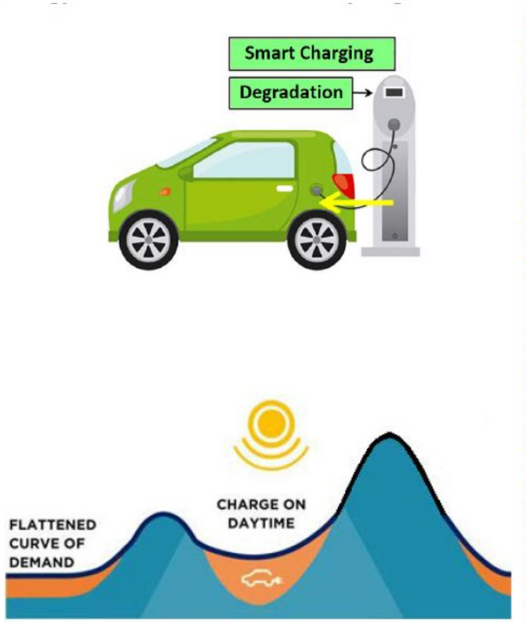
Further challenges and opportunities, along with the steps Indonesia needs to take

Charging Behaviour Type

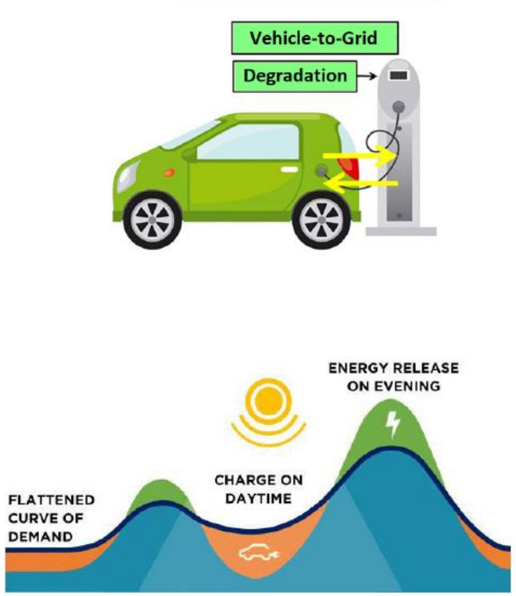
Unmanaged Charging



Managed Charging



V2G



Source : Chulalongkorn University, 2024

The Potential to Strengthen The Grid And Reduce GHG Emissions Lies In The Vehicle-To-Grid (V2G) Concept

- ✔ The number of EV will grown from 28.2 million in 2023 to 180 million in 2030. (IEA)
- ✔ Electricity consumption growth from 772 GWh/year in 2023 to at least 3500 GWh/year in 2030 (IEA)

- High upfront cost
- More complex system
- Interoperability among charging providers

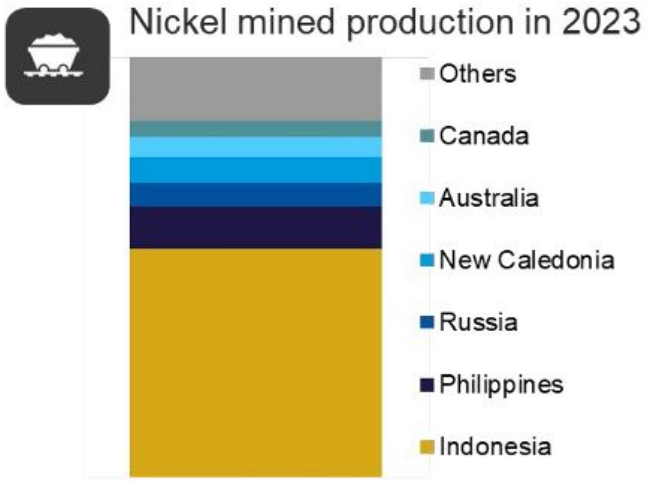
- ➜ Improve electrical grid and and prepare regulation to support power exchange between grid and EV
- ➜ Data protection and cyber security, benefits of V2G, grid overload, and other
- ➜ Managed charging is more applicable for Indonesia condition at the moment

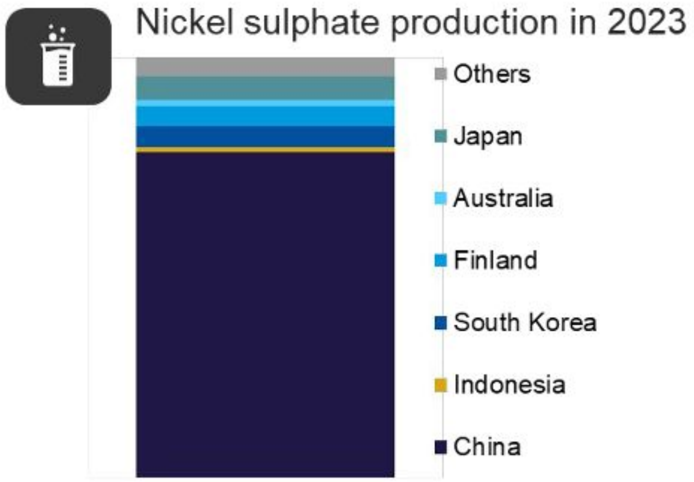
ESG issues haunt construction of ESS and EV downstreaming projects

Development of ESS project faces significant challenges in ESG issues especially in hydropower plants. Land use changes, biodiversity decline, reservoir sedimentation and social impacts are some of the ESG issues related to hydropower plants projects.

- ESS project cancelled and delayed due to severe ESG issues. Some power plants which is currently operating also faces ongoing environmental issues
- Electrochemical ESS also has ESG issues. Improper disposal can contaminate land and water sources which poses a serious health risk to humans and the environment
- Indonesia's ambition to become global EV hub also faces ESG challenges. Human right violation, deforestation, also inadequate waste management practice which create water and air pollution

EV adoption obstructs middle-stream EV battery investment

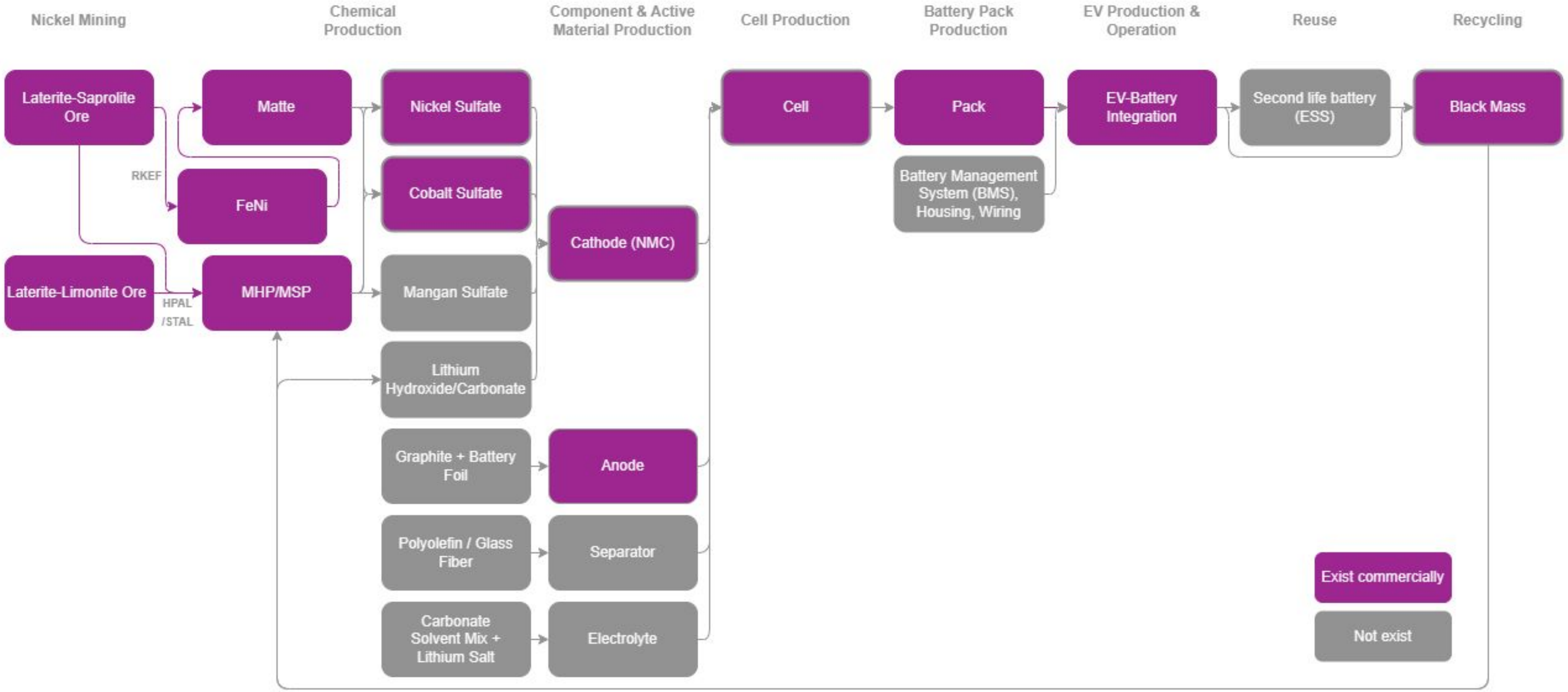




Source : Volta Foundation, 2024

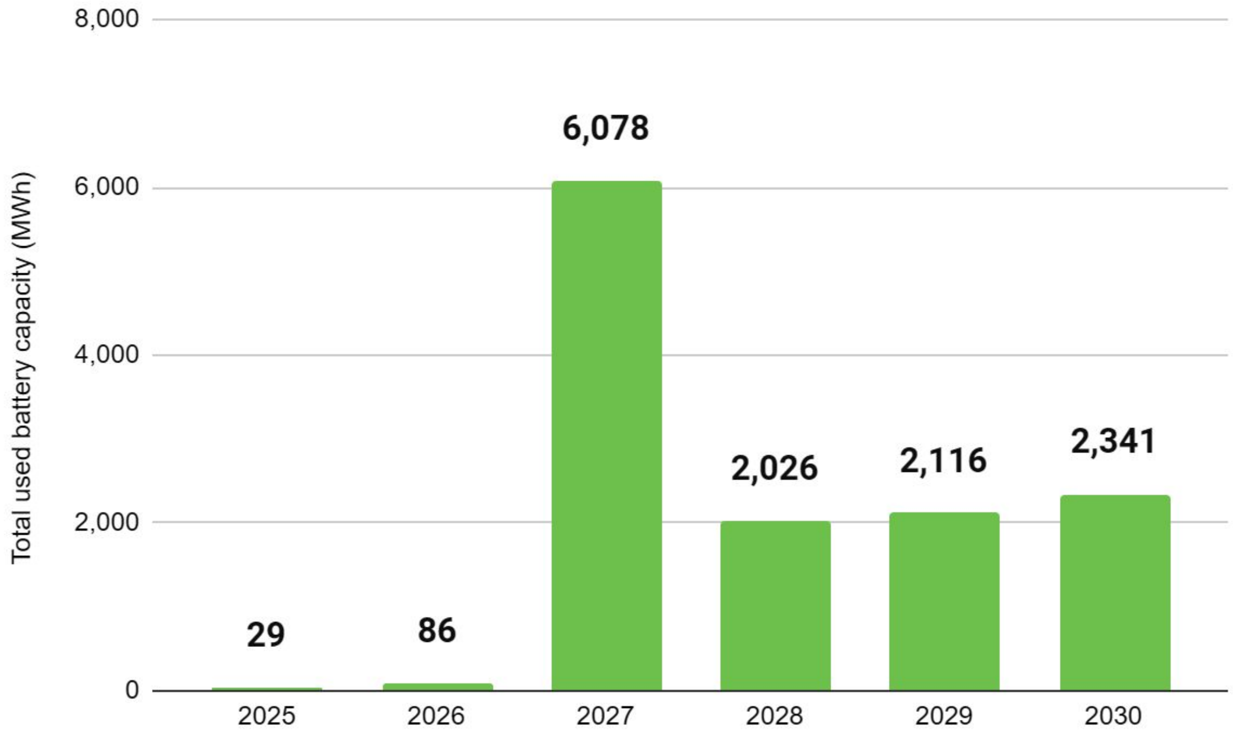
- Indonesia's abundant reserves of critical minerals for battery production, such as bauxite, tin, and cobalt, along with low-cost nickel, strategically position the country as a key player in the global battery supply chain
- Only a small portion of its mined nickel is currently processed into nickel sulfate for battery production as most of the smelters in Indonesia using RKEF (Rotary Kiln-Electric Furnace) technology, with 49 RKEF smelters compared to just 5 HPAL (High-Pressure Acid Leaching) smelters
- High carbon emissions, deforestation, and poor tailings management have led to Indonesia's nickel being labeled as "dirty mining," making it challenging to access the global market.
- Adopt responsible mining practices, such as IRMA standard, can enhance Indonesia battery attractiveness in the global market.
- Identifying substitute materials which is not currently available in Indonesia, as well as preparing for urban mining (recycling from used batteries), will be essential to ensure the longevity and sustainability of Indonesia's EV battery industry.

EV adoption obstructs middle-stream EV battery investment



- EV battery supply chain investment in recent years brings huge amount of investment and also open job opportunities. Despite that, missing link occurs in the midstream sector, as many BESS facilities focus on battery packaging.
- Preparing technological diversity outside NMC batteries is critical for Indonesia to align with global trends and ensure the sustainability of local battery industry
- Small production capacity hinder local industry to compete with global battery producers.

Huge potential within used EV batteries in near term, but battery waste collection, transport, and pricing issues remain challenging



- Repurposing EV battery into residential BESS to support VRE or as backup power unit could significantly lower overall expense. Recycling EV battery is also important for sustainability of critical mineral and profitability of recycling business.
- Business models and scheme to manage used EV batteries as the profitability of recycling EV battery is still uncertain. Collecting and recycling EV battery which are spread across Indonesia might be a challenge in maximizing EV battery second life
- Recycling is very important for Indonesia's ambition to become global EV hub and also transitioning from conventional mining which has ESG issues to urban mining, recycling from used EV batteries and also keeping critical mineral to stay in Indonesia.

Recommendation

Recommendation

Energy storage is a critical component to decarbonize power systems. Energy storage enables high level integration of variable renewable energy and could make the system more flexible, green, and efficient. Indonesia is currently in the early stages of adopting energy storage. To accelerate energy storage deployment in the Indonesian power system, key actions are needed to address existing opportunities and challenges, including:

Tapping into the limited but existing opportunities for deploying energy storage systems (ESS) is vital for expanding their role in Indonesia's power sector. At present, the greatest potential for ESS deployment lies in smaller and/or isolated systems, as well as in industrial or large scale commercial solar rooftop PV with BESS. Alongside these initial efforts, improving access to affordable ESS technologies, particularly batteries, and building the expertise of power sector stakeholders will be essential in laying the foundation for broader, large-scale implementation in the future.

Improving the regulatory framework and establishing legal certainty to adequately compensate ESS for the value it can provide, reducing development risks, and boosting investor confidence in ESS initiatives are imperative. Planning for energy storage systems should be well integrated with power transmission, distribution, and generation planning in Indonesia, aligning with the increasing installation of VRE. Besides setting capacity targets, planning documents should outline the full range of potential ESS roles. Currently, they primarily focus on smoothing and capacity firming without fully exploring technologies beyond BESS (Battery Energy Storage Systems) and PHS (Pumped Hydro Storage). Once these planning documents are updated, additional regulations will be necessary, including revisions to the grid code to reflect the latest technical capability. Additionally, policy support for long-duration energy storage should be explored further.

Taking the best practices from other countries. Nations such as the US, China, UK, and Australia, and which have significant ESS deployments, follow similar strategies: supportive policies that focus on three key areas—strong market signals, innovative revenue mechanisms, and enabling regulations that include industry support and R&D investment. These countries have set specific capacity targets for ESS and variable renewable energy (VRE) and have introduced carbon pricing, tender schedules, and procurement frameworks. Additionally, various ESS roles have been developed into value-stacking schemes, enhancing the economic feasibility of ESS ownership.

Recommendation

Enhancing the economics of energy storage projects can be achieved by adjusting electricity tariffs for ESS assets, providing incentives to installers, and clearly outlining the roles of energy storage in the power system to enable value-stacking. Furthermore, removing fossil fuel subsidies for utilities would create a more level playing field for VRE and storage, enabling their combination to deliver economically competitive, dispatchable power and serve as a viable alternative to gas and coal power plants.

Conducting pilot projects to test various ESS technology options. Experience in developing ESS projects in Indonesia is still very limited, and local expertise needs to be strengthened. Through planning, the government should encourage utilities to test various emerging energy storage technologies to better understand their characteristics, performance, and interoperability within the power system. Financial support or grants should be made available for these pilot projects, with funding extended not only to utilities but also to research institutions and universities.

Enabling innovative sector coupling approaches. The Vehicle-to-Grid (V2G) scheme, for instance, exemplifies how decarbonization efforts in the transport sector can benefit the power sector by reducing the need for costly investments in new batteries. However, technical improvements to the grid network are necessary to support V2G. Moreover, clear policies and business models must be established to make V2G both feasible and attractive. Beyond V2G, the power-to-x concept, particularly using hydrogen as a versatile energy feedstock, should also be further developed.

Establishing a storage technology ecosystem and R&D roadmap. Variations in ESS installation costs across countries are driven by factors such as project size, labour costs, and the availability of a strong technology supply chain. China currently leads in this area due to relatively low soft costs and advanced hardware manufacturing, particularly in lithium iron phosphate (LFP)-based LIB cells. As Indonesia begins to develop its battery ecosystem, it must anticipate market shifts, such as the rise of sodium-ion battery (SIB) technology, which is expected to capture a share of the LFP-based LIB market. To remain competitive, Indonesia's domestic industry development strategy must align with R&D efforts that keep pace with global technological advancements.

To ensure responsible mining practices for mineral extraction and prepare for battery recycling and reuse, Indonesia must enforce robust ESG standards, particularly in upstream activities, to secure international market access and support its ambition of becoming a regional battery hub. National regulations should adopt frameworks such as the Initiative for Responsible Mining Assurance (IRMA). Moreover, urban mining, which involves recovering materials from old batteries, needs to be developed, especially as nickel reserves are expected to be depleted within 6 to 34 years. This will help Indonesia maintain its strategic position as a regional hub. In the interim, while awaiting sufficient battery waste and advancements in recycling technology, repurposing waste EV batteries into BESS offers a promising business model for the country.

THANK YOU

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