January 7, 2026　IEEJ webinar for the world

IEEJ Outlook 2026
-Evaluating the Integration Costs and Deployment Potential of Variable Renewable Energy-

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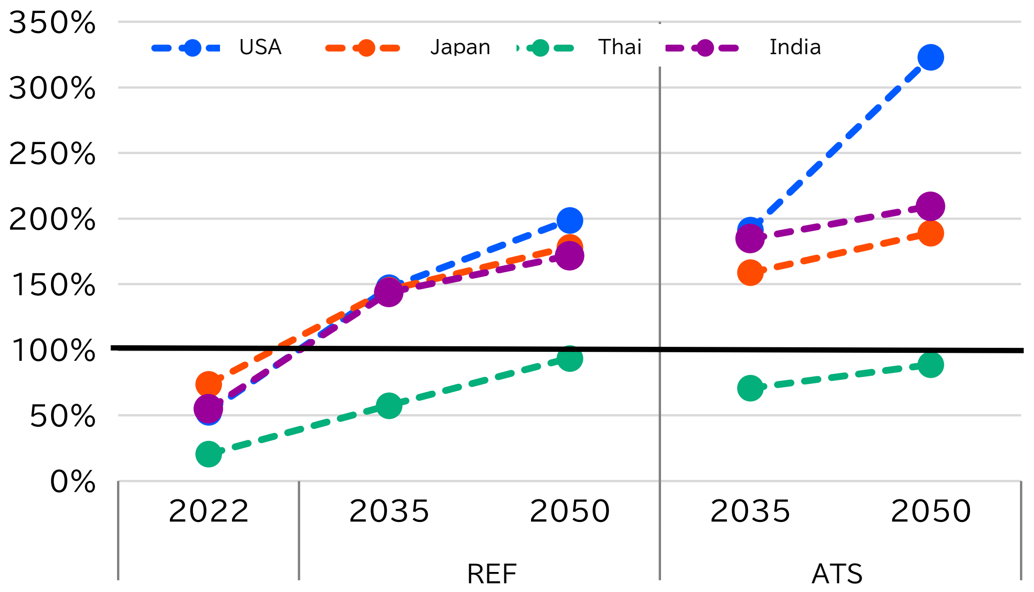
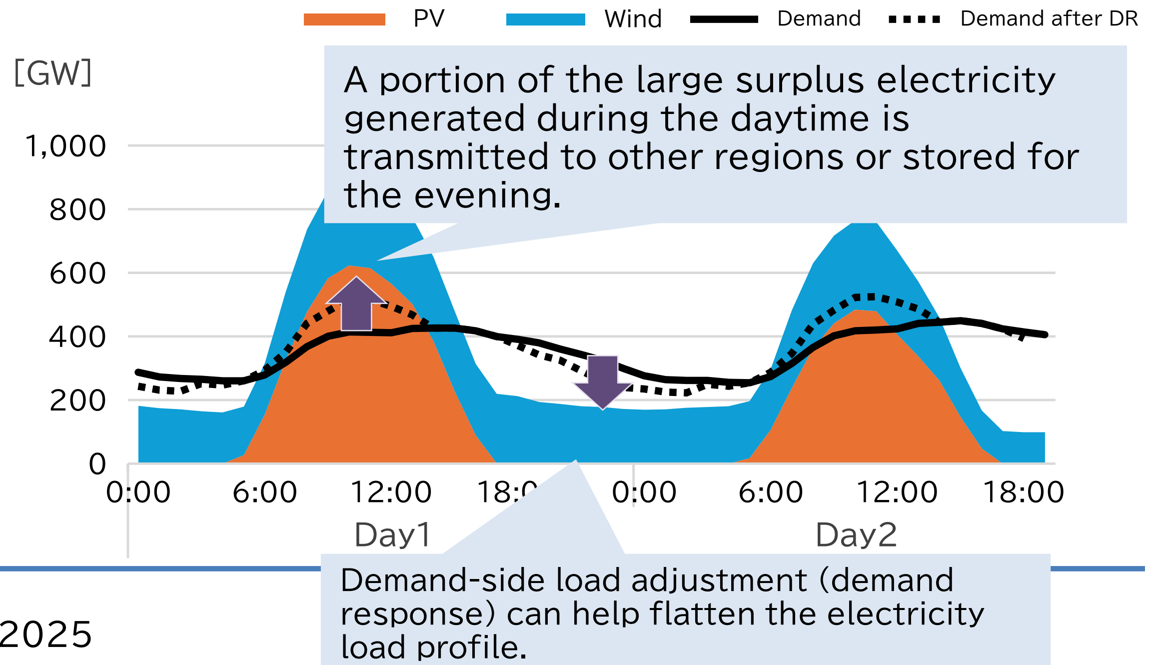
Rising VRE Penetration and the Changing Supply–Demand Balance in the Power System

- The IEEJ Outlook 2026 projects that under the Reference Scenario(REF), VRE power generation will increase approximately fivefold from current levels to 2050, rising to approximately sevenfold under the Advanced Technologies Scenario(ATS).
- As VRE scales toward decarbonization, the electricity supply–demand balance will shift significantly — as already seen in regions with high solar penetration, where daytime and nighttime conditions diverge sharply.
- Power systems must therefore be designed to manage VRE fluctuations through accurate forecasting, flexible operation of power generation, storage deployment, and grid reinforcement.

Ratio of Installed VRE Capacity to Average Annual Electric Load [GW]



Gap Between Solar/Wind Output and Power Demand (Illustrative)
ATS– India, 2050 (August)

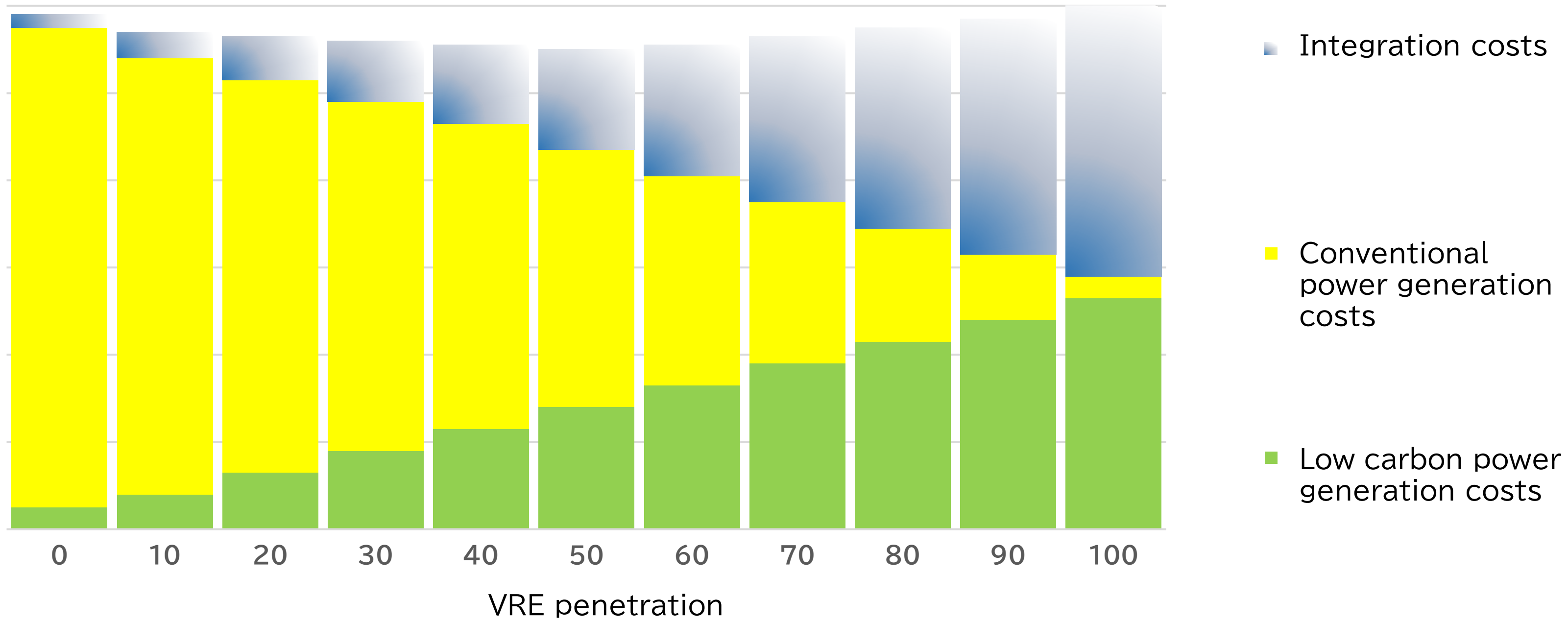


Source:IEEJ Outlook 2025

VRE Deployment and the Evolution of Integration Costs

- When integrating a power source, additional system costs beyond its generation cost — known as integration costs — are incurred. These include expenses for grid reinforcement and storage.
- As VRE penetration rises, it is crucial to account for these growing integration costs and assess the total system cost to achieve an optimal balance.

Illustrative image: Growth in VRE deployment vs. system cost trajectory

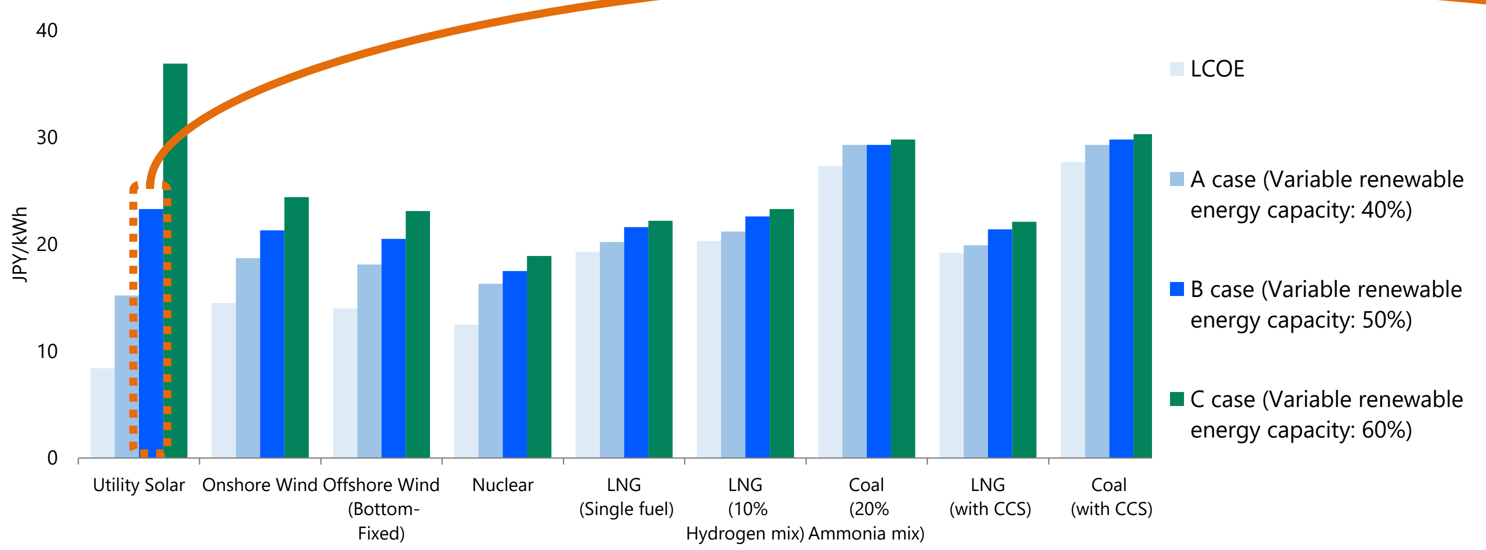


Source：Author, based on Matsuo (2021) and The Working Group on Power Generation Cost Verification (2025)

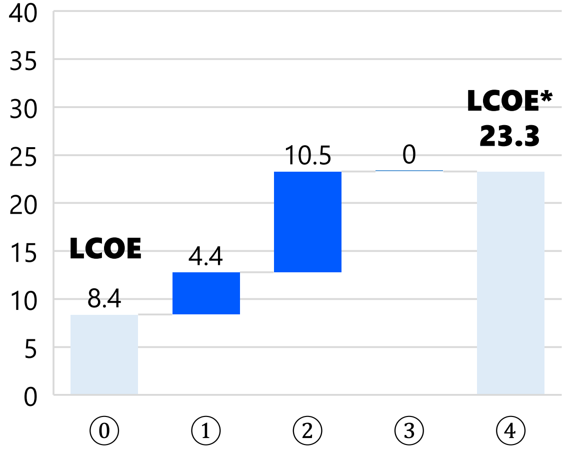
Example of the Study on Integration Cost:
The Working Group on Power Generation Cost Verification (2025)

- As VRE penetration increases, curtailment and storage losses grow, while the capacity factor of balancing plants declines — resulting in a much steeper rise in LCOE* for VRE compared with nuclear and thermal power.
- The right-hand side figure decomposes the gap between generation cost (LCOE: Levelized Cost of Energy) and adjusted LCOE (LCOE*), which incorporates part of the integration costs, showing that charging/discharging losses and curtailment have the largest impact.

Comparison of Generation Cost vs. Adjusted Generation Cost (including part of the integration costs)



Breakdown of Utility-Scale Solar PV Cost

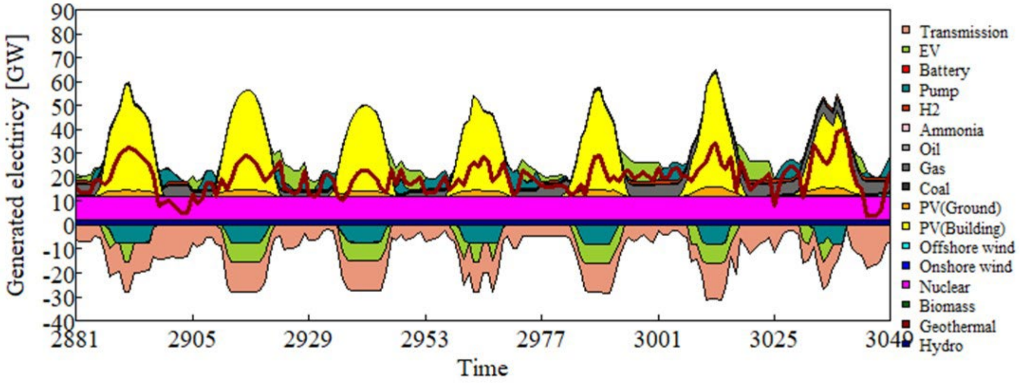


Source：Author, based on The Working Group on Power Generation Cost Verification (2025)

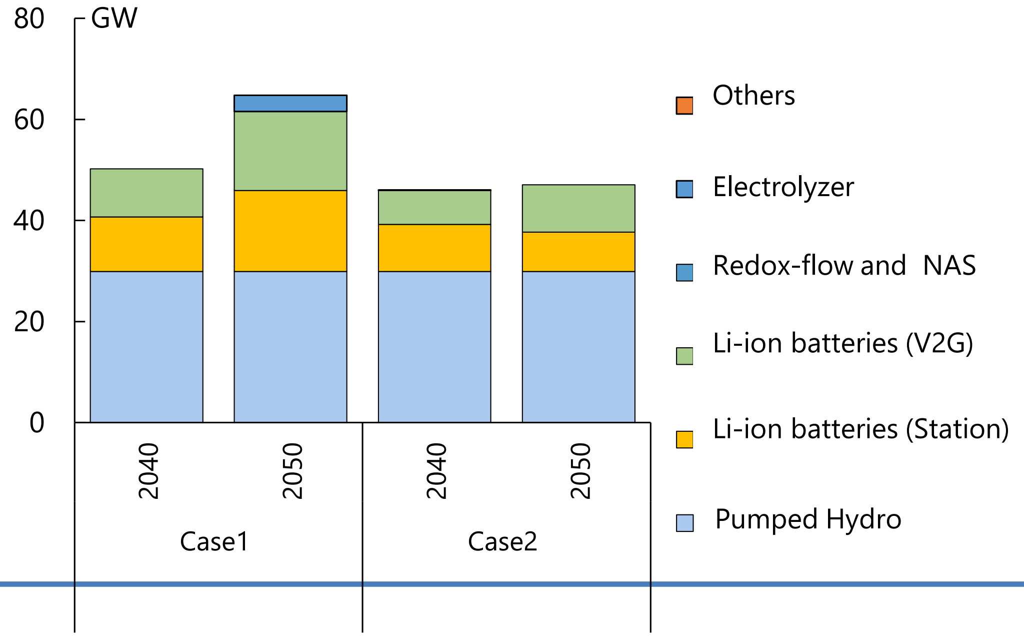
Overview of the IEEJ Technology Selection Model (IEEJ-NE Model)

- Using the IEEJ-NE model, we analyze the least-cost technology mix for ASEAN under varying levels of VRE deployment.
- The analysis assumes each country follows its NDC targets and evaluates VRE deployment and integration costs through 2060.
- IEEJ-NE Model Framework
  - ✓ Simulates annual power and hydrogen supply–demand on a time-step basis
  - ✓ Calculates required capacity for power generation and storage
  - ✓ Considers grid reinforcement and energy storage for power system balancing

Example of Power Supply–Demand (hourly)



Required storage capacity estimated by area



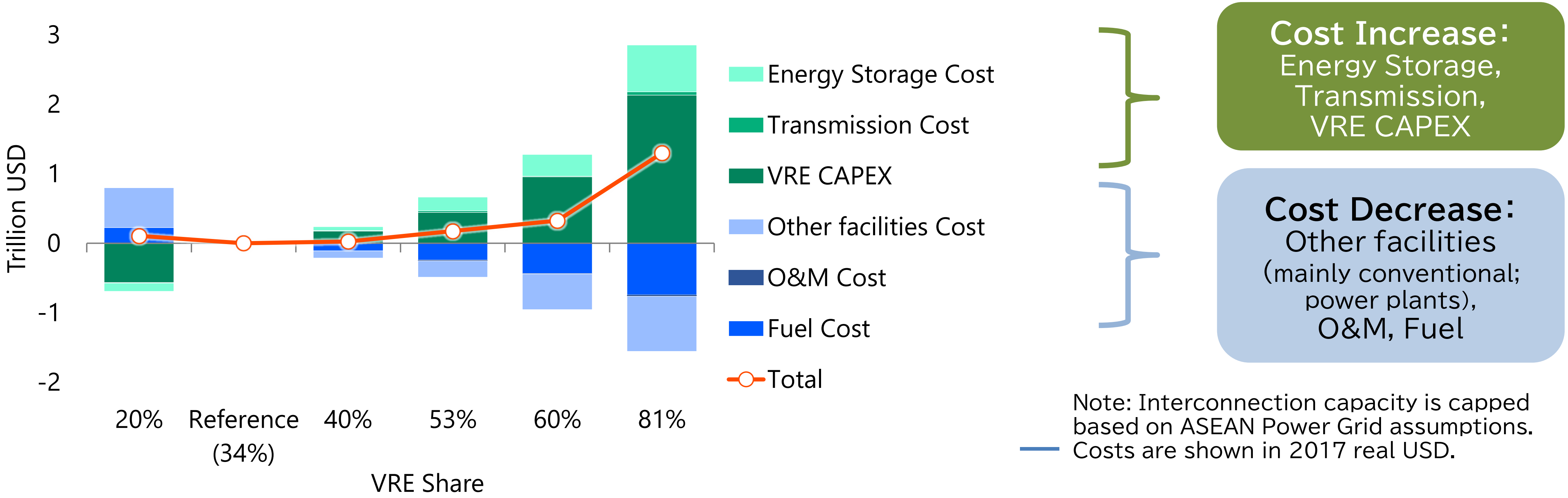
Technology list

Energy Storage	Pumped hydro, Li-ion batteries (grid-side and demand-side), NaS batteries, redox-flow batteries, hydrogen storage
(Demand Response)	Demand-side flexibility: EV charging, passenger EV V2G, and heat pump water heater load shifting

VRE Deployment and Changes in System Cost

- In ASEAN, the least-cost VRE share in 2060 is estimated to be around 30% — used here as the reference.
- Increasing VRE beyond this reference reduces conventional generation capital and fuel costs, but raises VRE installation costs and integration costs such as storage.
- At 81% VRE, cumulative system cost rises by approximately USD 1.3 trillion over 2030–2060 compared with the reference.

Cumulative System Cost Change in ASEAN (2030–2060, vs. baseline)

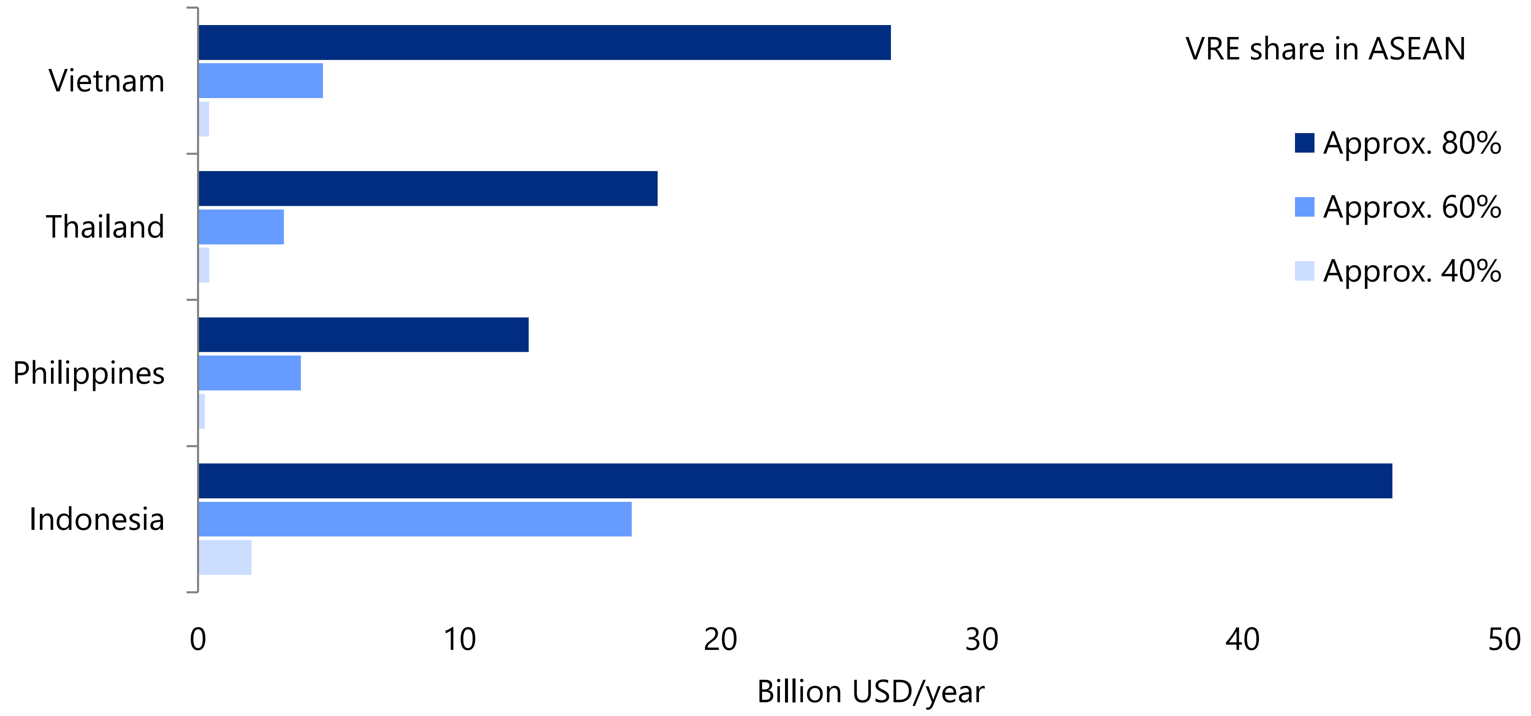


Note: Interconnection capacity is capped based on ASEAN Power Grid assumptions. Costs are shown in 2017 real USD.

VRE Deployment and Country-Level System Cost Impacts

- The change in system cost from higher VRE deployment varies significantly by country.
- Indonesia, Vietnam, and Thailand — with large populations and economies — see the largest cost increases, including VRE capital costs.

Change in System Cost by Country in 2060 (vs. baseline)



Summary

- As variable renewable energy (VRE) expands toward decarbonization, the future supply–demand balance of electricity will change significantly.

- In the decarbonization era, integration costs are increasingly seen as a key metric for evaluating energy costs, and a growing number of studies and analyses are focusing on them.

- This report analyzes VRE deployment and integration costs in ASEAN through 2060.

- When VRE is increased beyond the reference level, capital and fuel costs for conventional power are reduced — but VRE installation and integration costs rise, resulting in a net increase in total system cost.

- The cost and additional deployment potential of VRE vary by country, making it essential to pursue diverse and country-specific pathways to decarbonization.

Appendix: Key Components of Integration Costs (Typical Classification)

Category	Item	Detailed item	Description	Considered in various analyses
Cost of managing forecast errors	Balancing costs		Short-term balancing costs from dispatchable plants responding to intra-day VRE fluctuations (seconds–minutes reserve).	
Grid reinforcement costs	Grid-related costs		Investment in transmission infrastructure and congestion management (e.g., redispatch) due to geographical mismatch between VRE generation and demand.	<u>This study</u>
Cost of supply–demand mismatch / adequacy	Profile costs/utilization costs	Cost of supply–demand mismatch / adequacy	Backup capacity required due to the low capacity value of VRE, especially during peak demand (e.g., thermal, flexible renewables, storage).	<u>This study</u> The Working Group on Power Generation Cost Verification
		Curtailment costs	Higher unit cost of electricity when VRE output exceeds demand and curtailment is needed.	<u>This study</u>、 The Working Group on Power Generation Cost Verification
		Reduced capacity factor of dispatchable plants	Increase in unit generation cost as baseload and mid-merit thermal plants operate fewer hours due to VRE.	The Working Group on Power Generation Cost Verification
		Increased cycling and start-up/shutdown costs	Additional costs from more frequent and unplanned ramping or cycling of dispatchable power plants.	The Working Group on Power Generation Cost Verification

Source：Author, based on Ueckerdt et al. (2013) and Matsuo (2021)

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Various pathways for decarbonizing the road transport sector in the Global South

～Efforts and challenges toward BEV and biofuels deployment～

The Institute of Energy Economics, Japan

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Introduction

IEEJ Outlook 2025 :

- LCA of GHG emissions for different powertrains (ICV, HEV, PHEV and BEV) and different regions (advanced Europe, Brazil, ASEAN and India)
- Various pathways for decarbonizing the road transport sector and different optimal powertrains depending on the circumstances of countries and regions

IEEJ Outlook 2026 :

- More comprehensive analysis beyond powertrains
- Three case studies on various pathways of the Global South leaders: Indonesia (BEV), Brazil (bioethanol) and India (biogas)
- Analysis on their efforts and challenges toward BEV and biofuels deployment

Indonesia: BEV policies

- Ambitious BEV industrial policies aiming at a global hub of BEV production
  - Existing industrial base: the second largest car-production and the largest car-sales in ASEAN
  - Critical mineral for battery: 51% share of global nickel production (2023)

- Targets of BEV domestic production

Year	2024	Target for 2025	Target for 2030	Target for 2035
BEV production	**42K**	**400K**	**600K**	**1,000K**

Source: 2022 regulation of Ministry of Industry of Indonesia and GAIKINDO

- Target of BEV domestic stock

Year	2024	Target for 2030
BEV stock	**76K**	**2,000K**

Source: press release from Ministry of Energy and Mineral Resources of Indonesia (May 2024) and IEEJ's estimate based on GAIKINDO

Indonesia: Nickel refining by Chinese companies

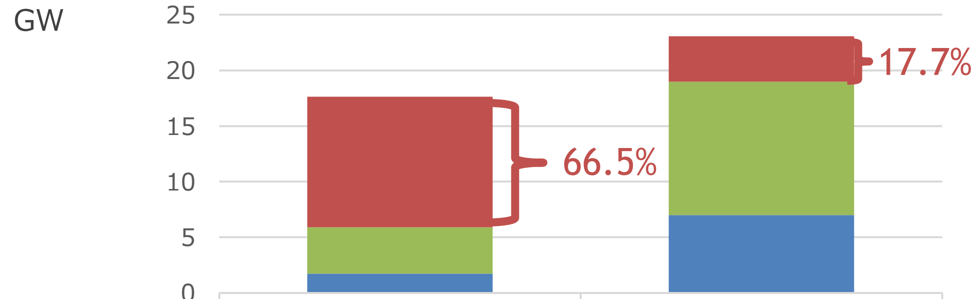
- GOI’s ban on Ni ore exports since 2014: Chinese smelters account for three-quarters of Ni refining in Indonesia, building on remote islands smelters and small, low-efficiency coal-fired power plants (CFPP).

- Exception plus exception
  - Captive CFPP serving Ni smelting and industrial parks is exempt from GOI’s ban on CFPP construction after 2023.
  - Captive CFPP in industrial parks related to the Belt and Road Initiative is exempt from GOC’s policy of halting support of new CFPP abroad.

- In addition to CO_2 emissions increase by captive CFPP,
  - Deforestation and degraded ocean eco-system
  - Risk of SO_2 emissions

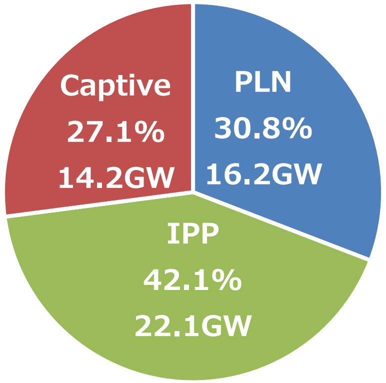
Overall environment impacts including supply chain?

CFPP by Supplier and Status (Planned & UC / Cancelled)



	Planned / Under Construction	Cancelled (2021-)
Captive	11.71	4.09
IPP	4.16	11.98
PLN (State-owned)	1.74	7.00

Operating CFPP by Supplier

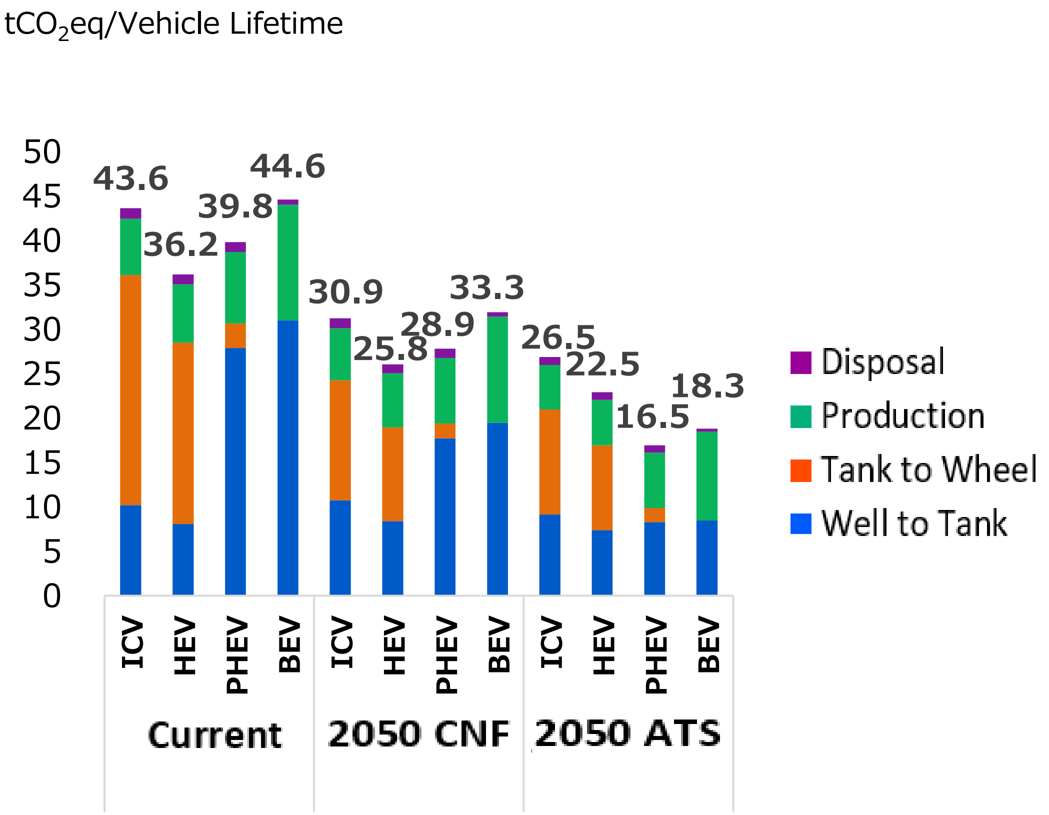


Source: Global Coal Plant Tracker; compiled by IEEJ. As of July 2025.

Indonesia: Is BEV low carbon?

- Two thirds of power generation are from CFPP: its emissions factor, 829gCO_2/kW, is 1.4 times higher than global average, 575gCO_2/kWh.
  - Current: BEV's LCA GHG emissions are higher than ICV
  - Future: the same without sufficient decarbonization of power sector (2050 CN Fuel case)
- The above is based on all-day/all-source emissions factor, but:
  - Current: excessive CFPP could be used for charging BEV, leading to more CO_2 emissions.
  - Future: if BEV charging concentrates in the evening, cheaper CFPP could be used as marginal power source.

BEV's Well to Tank emissions could increase by 1.3 times currently and 1.6～3.8 times in 2050.



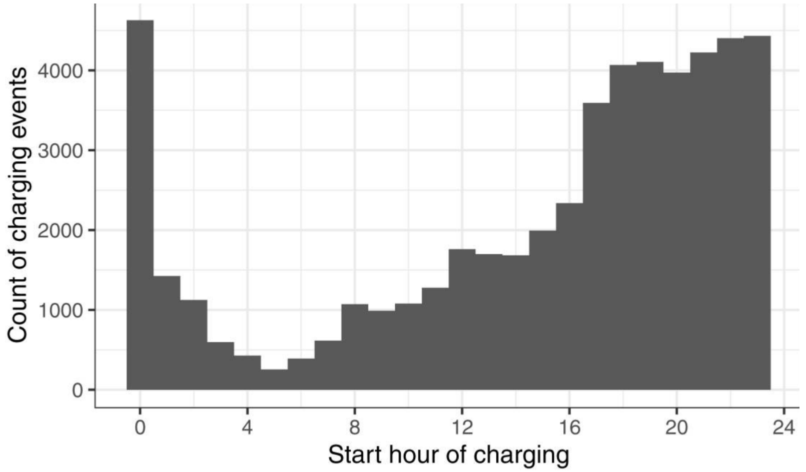
Decarbonization of electricity and peak-shift are essential.

Indonesia: Infrastructure for BEV deployment

- Power supply and grid expansion
  - 15GW or more additional power demand in 2040 if BEV deployment is accelerated as targeted and if half of BEV charging concentrate in the evening as in California.
  - GOI plans to increase power capacity from 106GW in 2025 to 242GW in 2040; 15GW is significant.

BEVs play a pivotal role in demand-supply adjustment if peak can be shifted, avoiding infrastructure costs.

Start hour of BEV charging in California

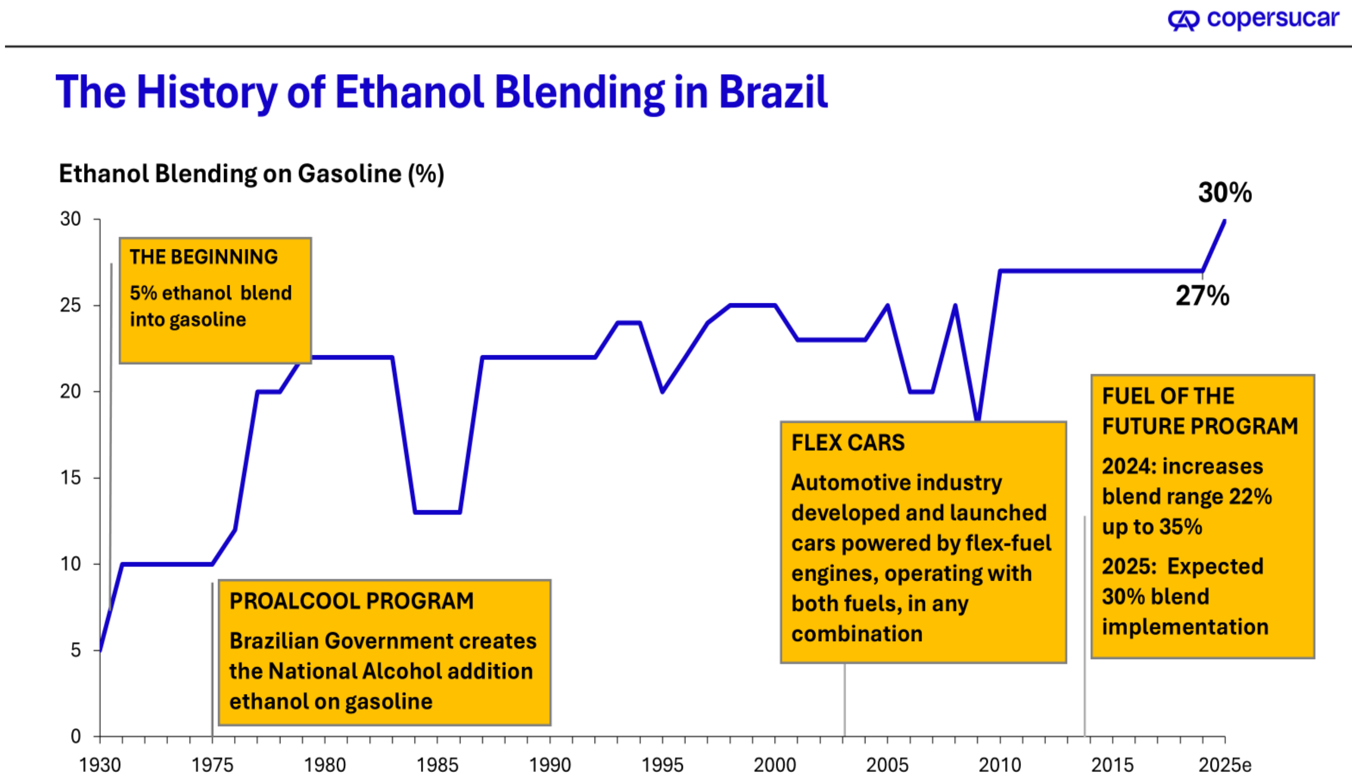


Charging speed	2024	Target for 2030
Middle High Ultra-high	3,202 units	30,796 units 19,538 units 12,584 units
Total	3,202 units	62,918 units

- Charging infrastructure
  - The targets require 23 trillion IDR for the next 6 years.
- Support measures for BEV
  - 5 to 6 trillion IDR are needed annually for purchase incentives (VAT and luxury tax reduction) and discount of electricity tariff for BEV night-charging.
- Decrease of local tax revenues (5～10% of gasoline price)

Brazil: Bioethanol policies

- 100-year history of blending
  - Both regulation (e-30) and actual use (45%) are the highest in the world.
- Industrial promotion and job creation
  - Started in 1931 as support for sugarcane industry, doubling the percentage of sugarcane employees in agriculture from 4% to 8% in the 2000s.
  - High domestic production ratio of automotives: 80% of new car-sales are FFV



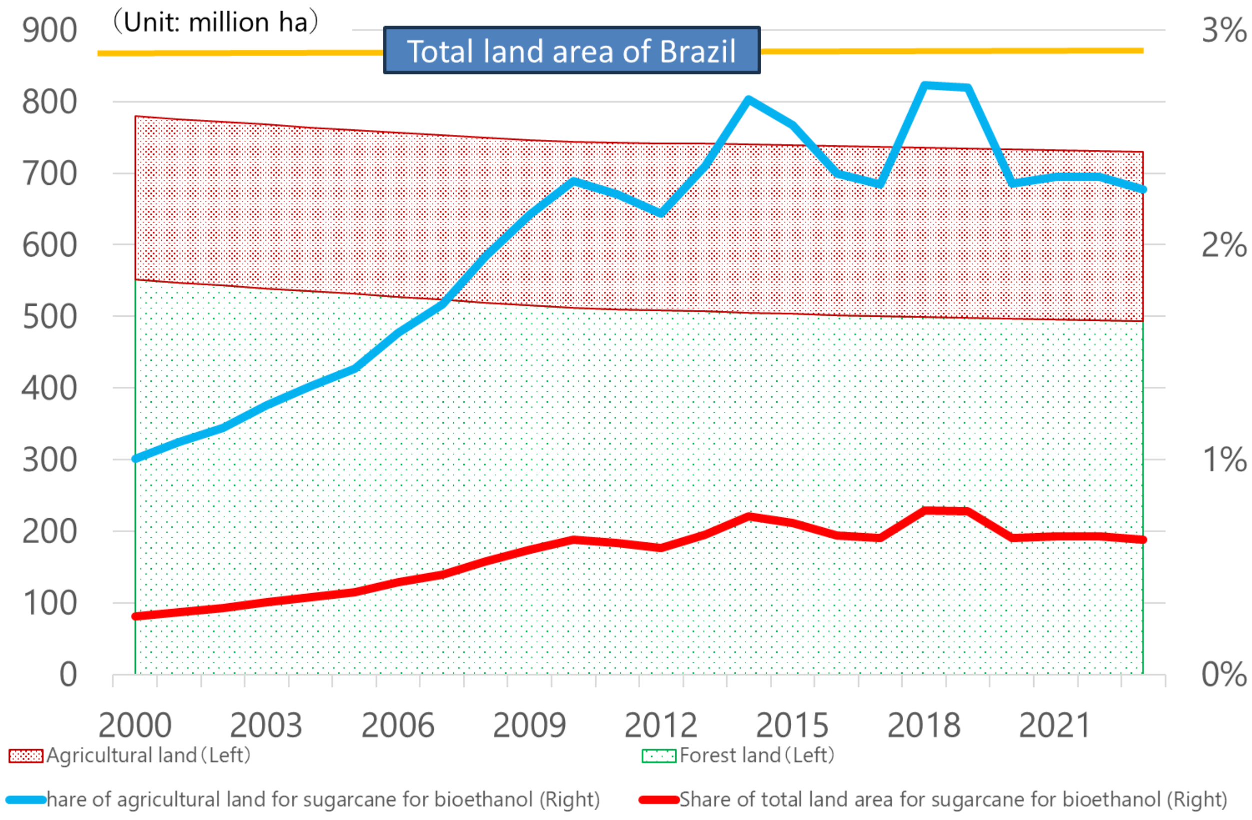
Source：Copersucar

- Energy security
  - Blending ratio was raised in WW2 and Oil Shock to conserve oil; energy self-sufficiency reached 116% in 2023, with biofuels contributing 33% of primary energy supply.
  - Crude oil exports quadrupled in this decade; in 2023, 70% of increase of domestic energy demand was covered by biofuels, leading to more crude oil exports and foreign currency earnings.

Brazil: Challenges for bioethanol

- Deforestation due to land-use change is the biggest concern in Brazil.
- Ratio of sugarcane fields for bioethanol to total national land remains stable historically.
- Efforts to reduce CFP of bioethanol:
  - Utilization of byproducts for truck fuels as biogas and fertilizer
  - two-term cultivation with corn
  - Utilization of bagasse, sugarcane residues, for power generation and second-generation bioethanol
  - Possible introduction of BECCS

Higher accountability and further R&D are needed.

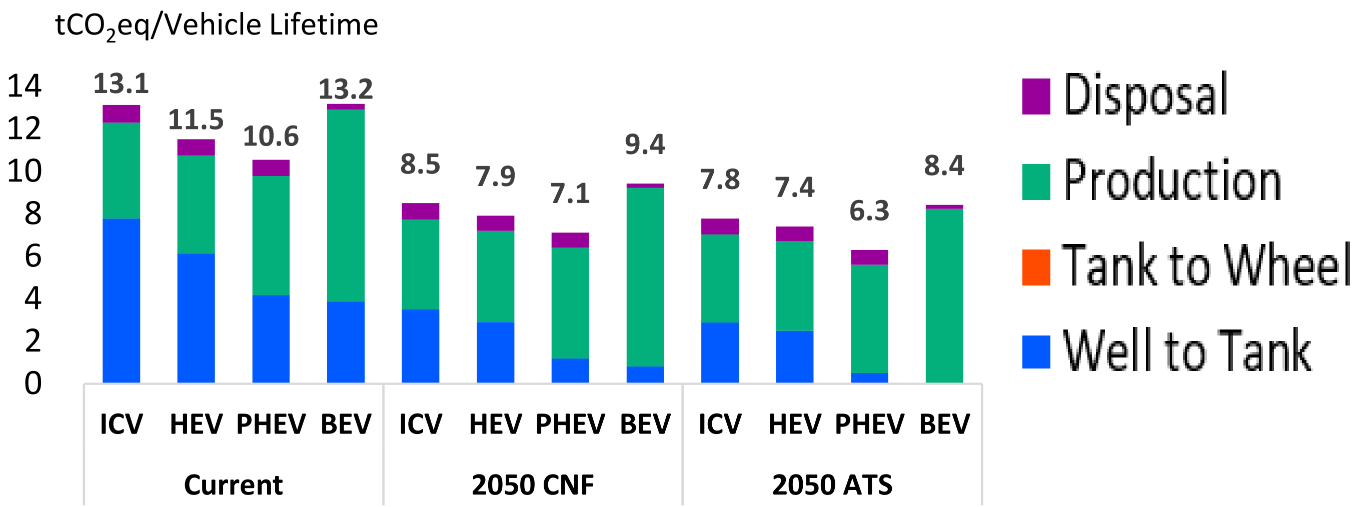


Source: IEEJ, based on World Bank Database

Brazil: Bioethanol's potential

- LCA of GHG emissions for different powertrains in Brazil
  - With e-100, BEV's CFP is the highest currently, and this remains the case in the future.

- Combination of bioethanol and HEV/PHEV well exemplifies various pathways.



- ISFM or Initiative for Sustainable Fuels and Mobility:
  - Launched in April 2024 by the two leaders of Japan and Brazil as an initiative of combining sustainable fuels such as biofuels and high-performance transport equipment such as HEV.
  - Both countries hosted the first Ministerial Meeting on Sustainable Fuels in Osaka in Sept. 2025. Expected that the bilateral cooperation would evolve to multi-lateral.

India: Biogas policies

- India is the only country in the world that mandated blending biogas into CNG (compressed natural gas) in the transport sector.
  - Wide-spread CNG vehicles due to air-pollution and cheaper fuel: as high as 28%, 19% and 7% of three-wheelers, taxis and passenger cars respectively.
  - Abundant domestic bioresources such as agricultural residues, livestock manure and wastes: as rich as Brazil for biogas potential.
  - Contribution to agriculture and livestock promotion, lower LNG import with conserved foreign currencies, and circular economy.

Sustainable Alternative toward Affordable Transportation（SATAT）scheme

	Bioethanol	Biodiesel	Biogas					SAF
Blending ratio	20%	5%	Optinal	1%	3%	4%	5%	2%
Target year / period	2025	2030	Until 2024	From 2025	From 2026	From 2027	From 2028	2028

- In India, only 5% of its huge biogas potential has been utilized; significant future production growth is expected (16 times increase by 2030 relative to 2024)

India: Challenges for biogas

- Challenges include:
  - Seasonal fluctuation of agricultural residues: concentrate in harvest
  - Undeveloped logistics infrastructure to collect feedstock from rural villages
  - Difficult investment decision and financing due to unpredictable prices
  - Insufficient human resources and certification scheme

- SATAT' target: 5,000 biogas production plants by 2024
  - Just 90 plants as of Sept. 2024
  - Lacking business incentives as opposed to Indonesia's Ni refining and Brazil's bioethanol

↓

- Not only stick (blending mandate) but also carrot (support measures) are needed.
  - International cooperation for such grass-rooted various pathways
  - JCM for cooperation with Japan

Conclusions

- The Global South leaders, Indonesia, Brazil and India, are all making efforts to decarbonize the road transport sector;
  - Through taking advantage of strengths in regional resources and industries, and
  - From broader perspectives such as industrial policies and energy security beyond climate change.

- BEV's domestic production and deployment require 1) first and foremost, decarbonizing the power sector, 2) reducing environmental impacts including production stage, 3) peak-shift of electricity demand, and 4) infrastructure development.

- Biofuels could contribute to agricultural promotion. Drop-in biofuels could lower the cost for infrastructure development.

- Electrification is not a panacea. Various pathways should be pursued.