Japanese electricity market outlook

Aurora Energy Research

04 September 2024

Agenda

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I. Electricity market supply & demand - Japan

II. Deep dives:

1. Opportunities for hydrogen in Japan
2. Network congestion & the challenges for renewables deployment

Japan's power market is split into 10 regional price zones, with two non-synchronous grids separating East from West

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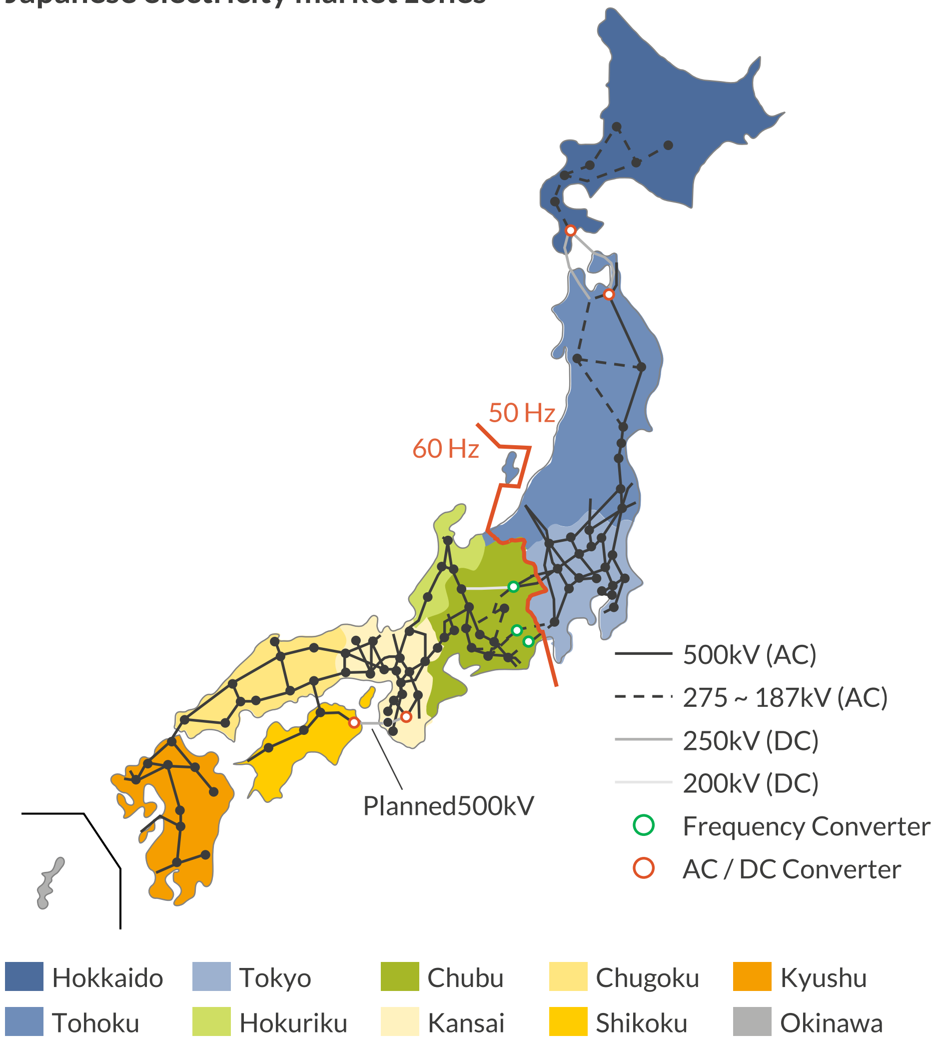
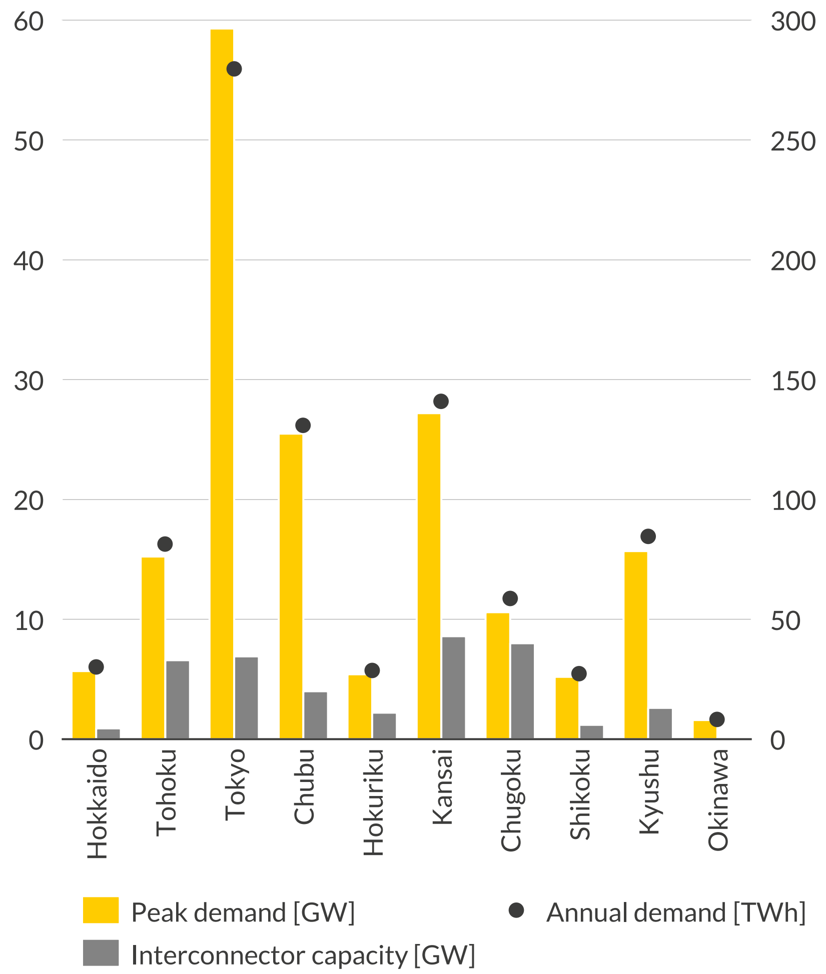
Japanese electricity market zones



Peak/annual demand & interconnector capacity (FY 2022)

GW (left axis) & TWh (right axis)



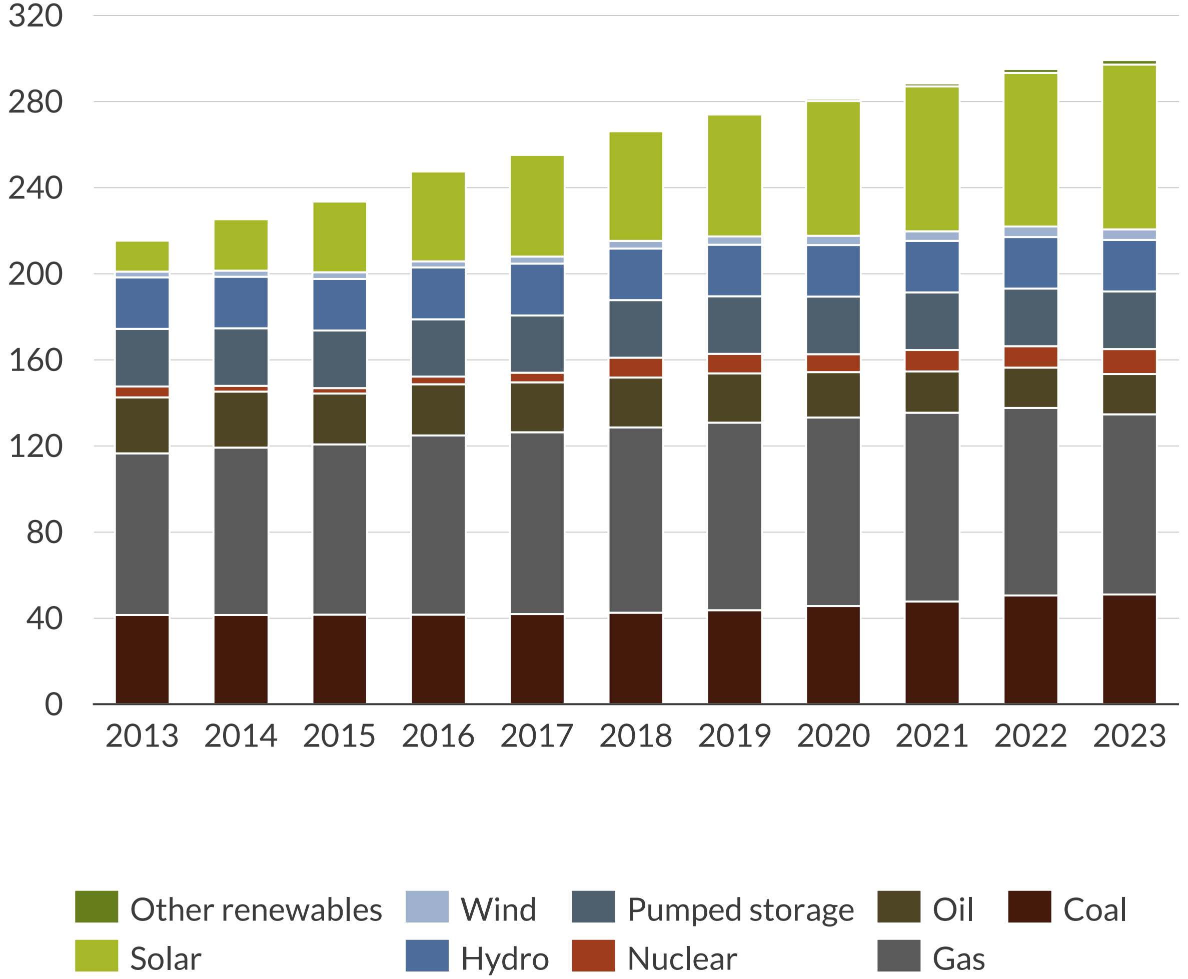
- Japan has been divided up into two non-synchronous areas since country started electrifying in the 1890s. From Tokyo in the East (50 Hz) and Osaka in the West (60 Hz)
- Japan is divided up into ten vertically integrated regional utilities
- After legal unbundling[1] of transmission & distribution from regional utilities' generation and retail came into force in 2020, General Transmission & Distribution Businesses (GTDBs) have inherited TSO-like functions in the original 9 mainland[2] zones

1) This is distinct from ownership unbundling, which Japanese has not implemented yet. The Tokyo and Chubu utilities chose a holding company structure for their various previous functions, whereas all others opted for a parent-subsidiary relationship. 2) The Okinawa utility continues to exist in a fully vertically integrated state.

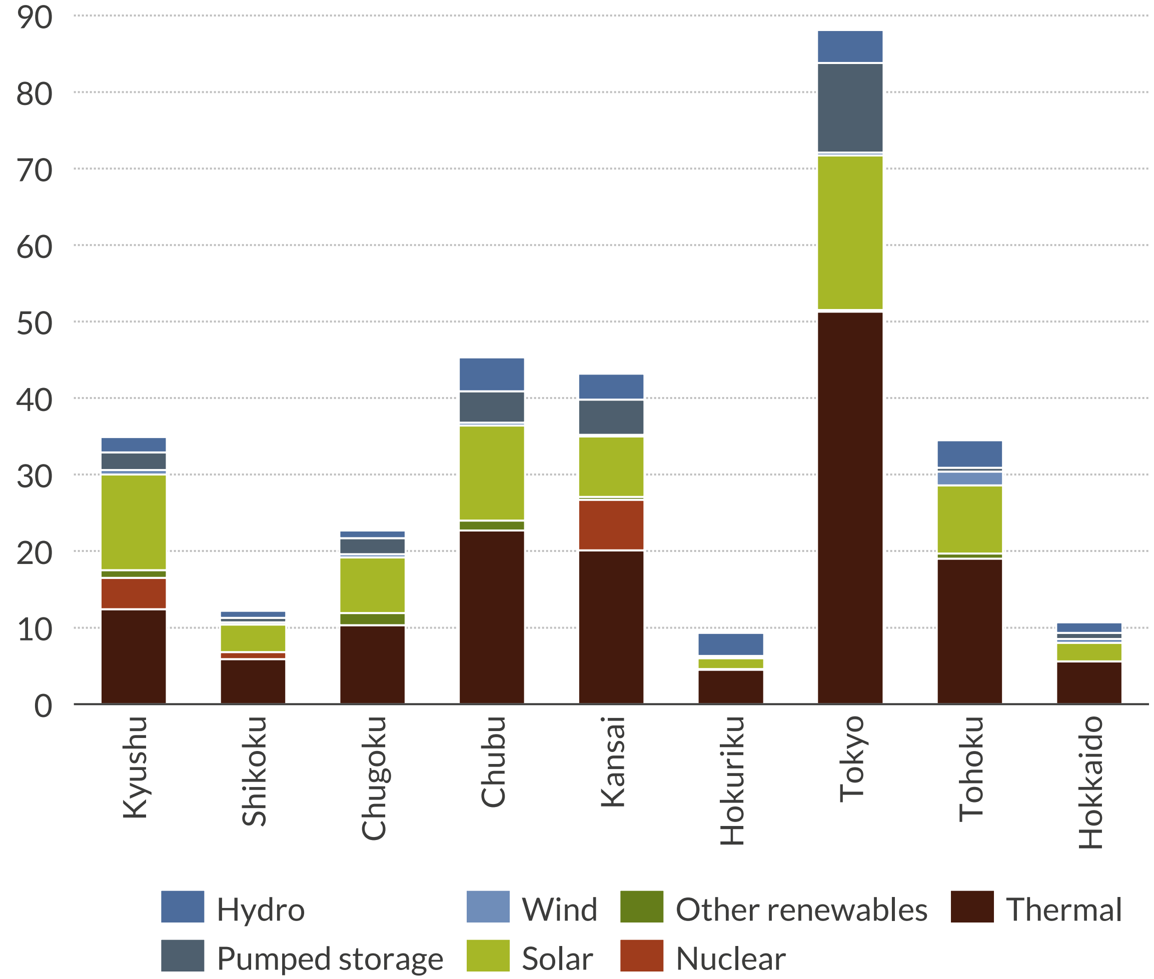
Sources: OCCTO

Japan is still dominated by thermal power, providing 50% of total capacity, while feed-in tariffs raised solar to 25% of nameplate capacity

Nameplate capacity – nationwide[1]
GW



Nameplate capacity – regional[2]
GW



1) METI data and Aurora estimates. 2) Estimated capacity by region for 2023.

Sources: METI/OCCTO, Aurora Energy Research

There are a number of major energy policies and regulatory changes ongoing in Japan which are shaping the investment landscape

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2017 – In accordance with the Electricity Business Act, OCCTO became in 2017 responsible for developing the **Grid Master Plan,** and published its first version.

2018 – Quarterly auctions providing **Non-Fossil Certificates (NFC)** issued to eligible generators to retailers started in 2018.

2020 – 1st **T-4 capacity market auction** is held in 2020 w/ delivery in 2024.

2021 – The 6th **Strategic Energy Plan** (SEP) is released in October 2021. 1st plan released in 2003 and updated roughly every 3 years; SEP is the national energy policy outlining objectives and policy measures to achieve them.

2021 – **New balancing market[1]** introduced in stages, w/ Tertiary-2 in 2021, Tertiary-1 in 2022 and Primary/Secondary 1-2 rolled out in 2024.

2022 – **Feed-in-Premium (FiP)** auctions, a successor to the Feed-in-Tariff (FiT) program in place since 2012, launched in April 2022.

2023 – 1st phase of the **Emission Trading System** ("ETS") is launched in 2023. Trading of carbon credits rather than allowances; voluntary participation by emitters.

2023 – In March 2023, OCCTO updated its **grid expansion plan** out to 2050.

2024 – **Auction for the long-term support of decarbonised generators ("20-year Support Mechanism")** will be held from 2024 onwards and initially for a total procurement target of 10GW[2]. The mechanism is aimed for retrofitting of thermal plants, battery storage and renewables.

2026 – 2nd phase of the **ETS**, featuring mandatory participation for further large emitters and free allocation of carbon allowances to all participants, is expected to start in 2026.

2028 – **Carbon levy** applied to upstream emissions embedded into imported fossil fuels will be introduced in 2028. It is likely to replace the current Tax for Climate Change Mitigation[3].

2030 – **2030 Emission/Energy Targets:**

- GHG emissions to be reduced by 46-50% relative to 2013 levels
- Renewables to make up 36-38% of the power mix
- Supply to reach 3 Mt of hydrogen equivalent for hydrogen and ammonia

2033 – 3rd phase of the **ETS**, requiring progressively increasing role for auctions for the power sector, is planned to begin in 2033.

2040 – Government aims the supply of **hydrogen** to reach12 Mt by 2040

2050 – **2050 Emission/Energy Targets:**

- Economy-wide emissions to reach net-zero by 2050
- Renewables to make up 50-60% of the power mix
- Supply of hydrogen and ammonia to reach 20 Mt of hydrogen equivalent

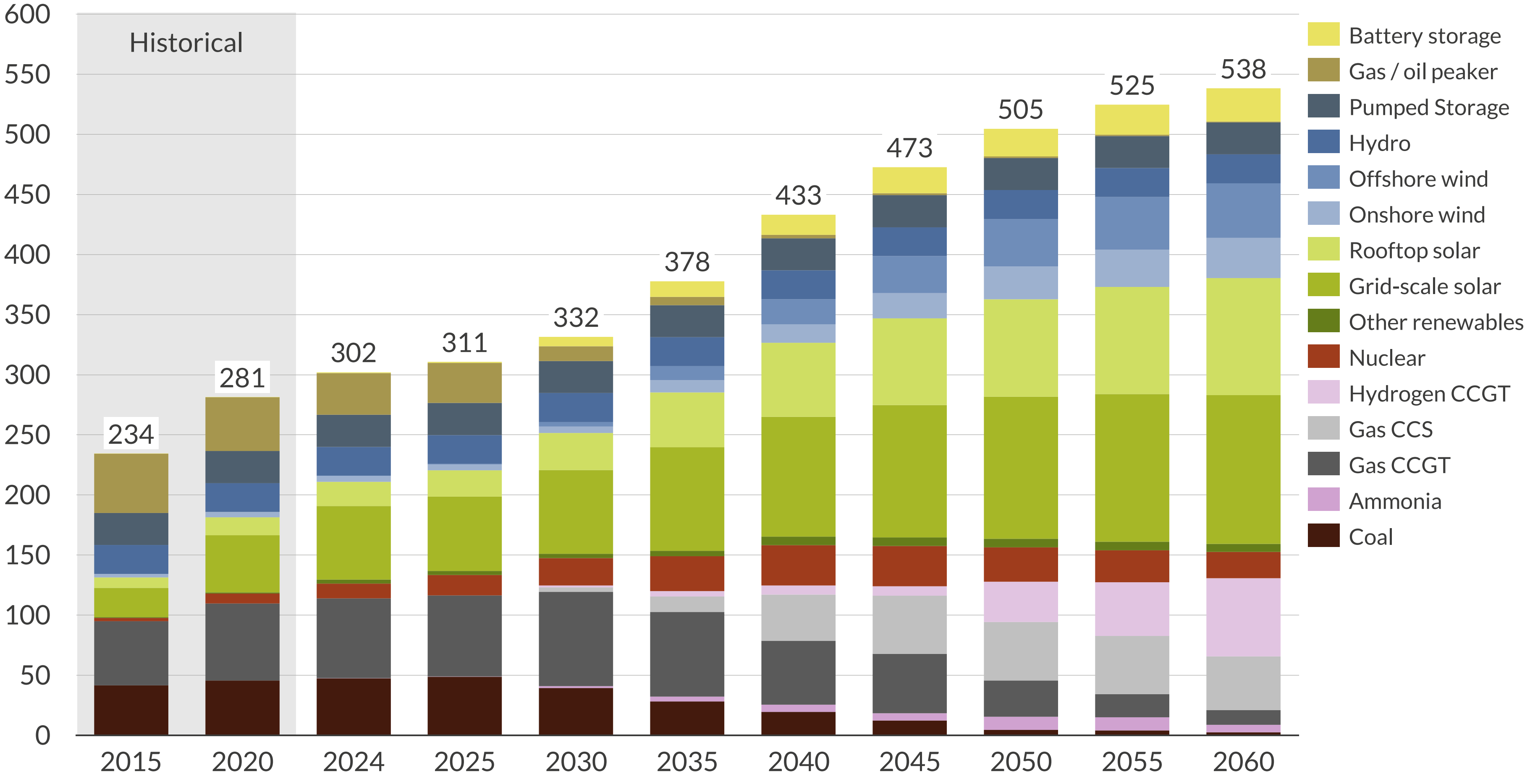
1) The balancing market is being reformed to replace the existing 3 services with 5 new services which allow faster response to frequency deviations etc. and address within-day system imbalance. 2) Procurement target of 4GW/year for retrofitting and new-build of thermal plants, battery storage and renewables and a total of 6GW for the first 3 years for emergency capacity to be provided by LNG thermal plants. 3) Currently levied at a rate of 289 yen/tCO2, unchanged since 2016.

Sources: OCCTO, METI, Aurora Energy Research.

Japan's electricity mix is expected to become increasingly dominated by renewable and flexible technologies as existing thermal fleet retires/refurb

Nation-wide capacity[1] – Aurora Central Scenario

Nameplate GW



- From 2023 onward, a new multi-year capacity contract will seek to bring on 4-6 GW of low-carbon capacity each year, explicitly for existing thermal plant replacement
- Growth in renewables continues in the 2030s and 40s as current grid constraints are relieved with transmission augmentation
- Coal capacity retirements accelerate from the late 2020s as costs increase with end-of-life issues and greater ramping is required
- The build-out of grid-scale batteries accelerates in the 2030s as costs continue to fall and mid-merit coal exits, leaving spreads set more often between renewable and gas/peaking plants
- New innovative technologies such as gas with CCS, coal co-firing with ammonia, and hydrogen CCGT are gradually replacing existing coal and gas fleets delivered from the 2030s through long-term decarbonization contracts

1) Does not include self-generation except rooftops solar and does not include capacity in Okinawa.

Sources: Aurora Energy Research

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I. **Japan's electricity market supply & demand outlook**

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Japan has been a global leader in H_2 policy since 2017 and is now implementing specific mechanisms to achieve its policy goals

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Timeline of recent H_2 policy announcements in Japan

Policy & regulation | Financial support | *Deep dives on following pages*

2017

METI JAPAN

Japan's Basic Hydrogen Strategy was published in December 2017. It established an H_2 consumption goal of 300,000tpa by 2030, as well as a goal to reduce supply cost to ¥334/kg-H_2[1] (US$2.74/kg-$H_2$[2])by 2030.

METI JAPAN

5th Strategic Energy Plan was released in April 2018, which reinforced measures for the realisation of a "hydrogen society". It set an aim to cut the unit H_2 power generation cost to ¥17/kWh (US$0.12/kWh) by 2030.

2020

METI JAPAN

Green Growth Strategy was announced in 2021. It identified H_2 as one of 14 priority technology areas and emphasises Japan's need to strengthen H_2 supply, including transportation and storage.

METI JAPAN

Green Innovation Fund (GI Fund) was established by METI[3] in March 2021. It is a ¥2tn (US$16bn) fund to support R&D projects over 10 years, around ¥800bn (US$6.5bn) of which is allocated to the development of H_2-related technologies.

METI JAPAN

6th Strategic Energy Plan was released in October 2021, planning to accelerate the social implementation of H_2 as a new resource. It proposed the achievement of a hydrogen/ammonia power generation mix of 1% by 2030.

2023

1

METI JAPAN

Updated Basic Hydrogen Strategy was published in June 2023. It confirmed the 2040 midway consumption target as 12Mt. It also introduced Japan's goal to build 15GW of water electrolysers domestically and internationally, as well as an annual CO_2 storage capacity of 12Mt by 2030.

2

METI JAPAN

GX Promotion Act was enacted in May 2023. It authorised the issuance of GX Economy Transition Bonds. At the subsequent GX conference, the government announced that more than ¥7 tn will be invested in hydrogen and ammonia. This is a critical law to secure financial resources for hydrogen investment.

2024

3

METI JAPAN

Hydrogen Society Promotion Act was passed by the Diet in May 2024. The law establishes specific measures to use GX Economy Transition Bond. 2024 will be the year to implement the key measures, **the price gap support** and **the establishment of hydrogen/ammonia clusters**.

METI JAPAN

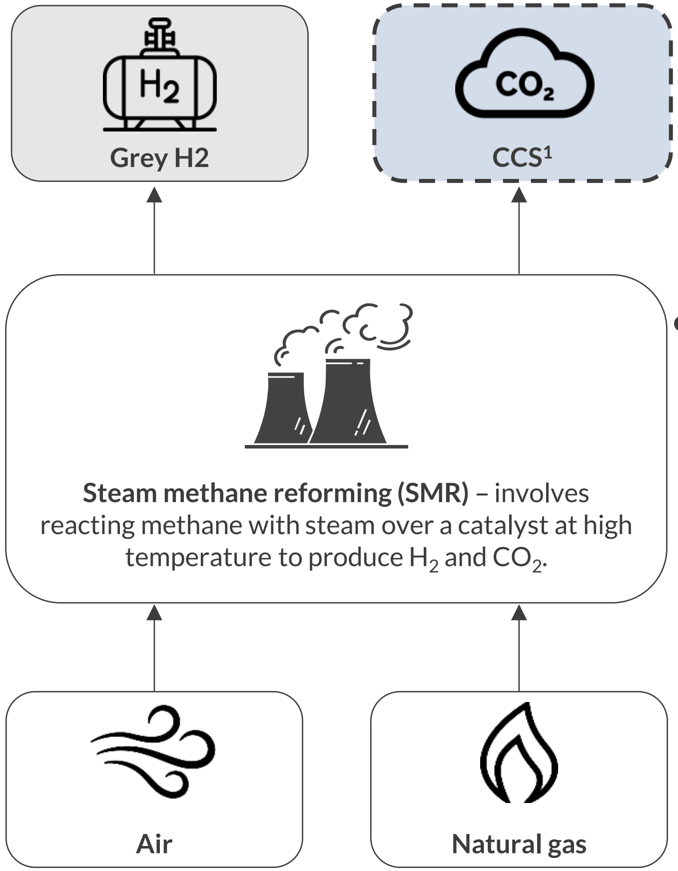
The first LTDA[4] result came out in April 2024. 55MW of H_2 and 770MW of NH_3 co-firing power plants (retrofitting) were awarded subsidy payments[5]. For the second round, an increase in the cap prices, considering the additional fixed costs of upstream facilities, is being discussed under METI. Integrated efforts with the price gap support and cluster support are desired.

1) The cost is based on plant delivery costs and includes transport costs.; The official cost target is ¥30/Nm^3, and ¥334/kg-H_2 is calculated using a conversion of 0.08988kg-H_2/Nm_3; 2)The Exchange rate: ¥121.7 /US$; 3) METI - Ministry of Economy, Trade and Industry; 4) LTDA – Long-term Decarbonisation Auction. ; 5) 68 MW hydrogen co-firing (replacing) were offered but not awarded.

Sources: Aurora Energy Research, METI, various news outlets

Blue H_2 (with carbon capture) may offer a cost-effective alternative in the short term, but its carbon intensity might not align with Japan's standards

Production process for grey and blue H_2



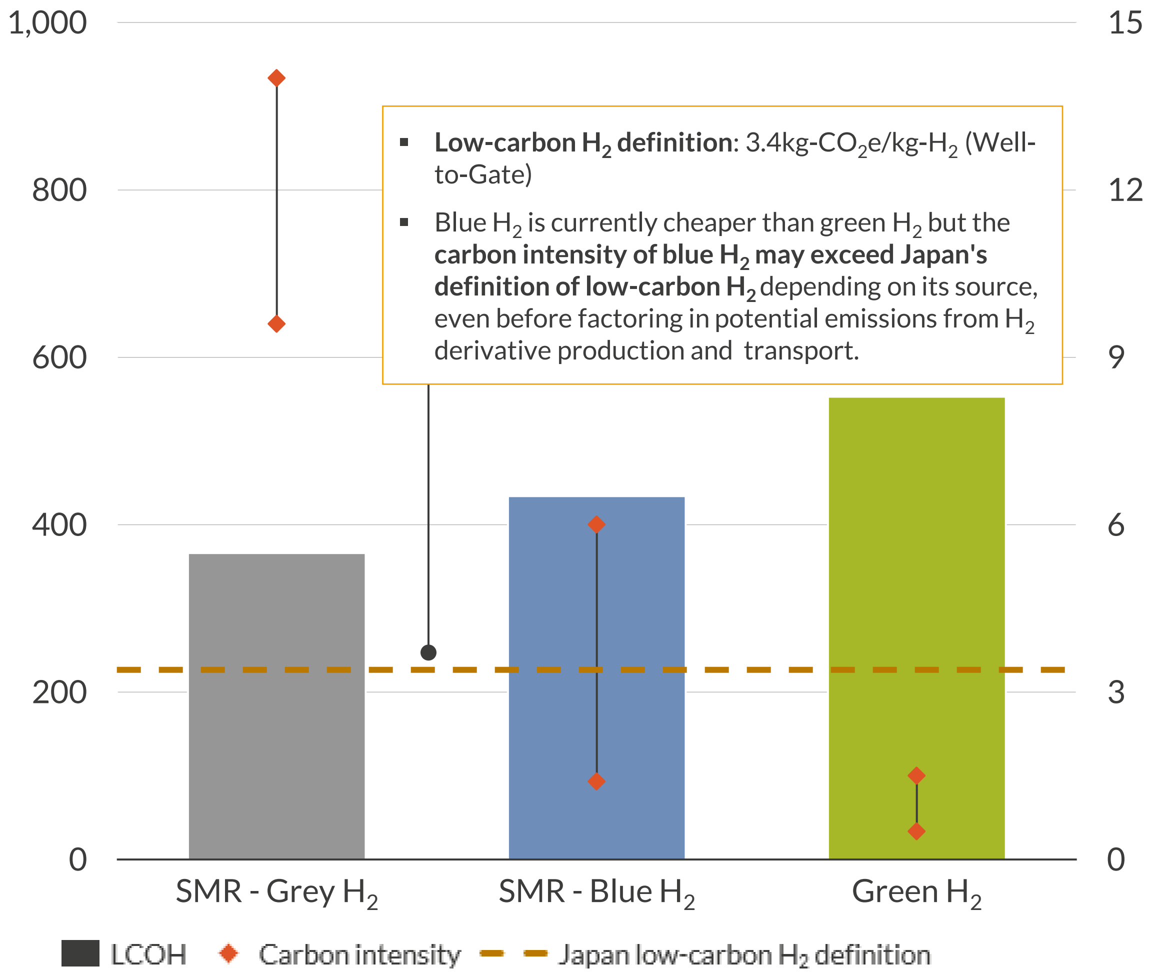
- Grey H_2 accounts for the majority of the current H_2 consumption
- Blue H_2 uses the same SMR process but captures and stores the CO_2 to reduce emissions
- However, CCS requires the presence of appropriate geological formations capable of securely storing captured CO_2
- CCS has also received criticism that the carbon capture equipment was ~55% efficient[2], compared to a designed capture efficiency of 90%. Even if the efficiency is as designed, its upstream emissions and operational cost make it less efficient than renewables

Levelised cost of H_2 production in Australia, entry year in 2030

¥/kg-H_2, real 2023

Carbon intensity[3,4,5]

kgCO_2eq/kg-H_2



1) Carbon capture and storage; 2) As reported by Jacobson 2019; 3) Carbon intensity includes lifecycle emissions upstream and midstream emissions and emission intensity varies across natural gas sites due to differences in technology, practices, and regulations; 4) Blue H_2 assumes median upstream emissions with 93% CCS efficiency, while green H_2 assumes on-site renewable generation; 5) Carbon intensity excludes emissions from transportation post-production.

Source: Aurora Energy Research, Jacobson 2019, IEA, Institute for Energy Economics and Financial Analysis

APAC sees a significant number of large-scale advanced hydrogen projects, with Japanese companies' overseas projects mostly located in Australia

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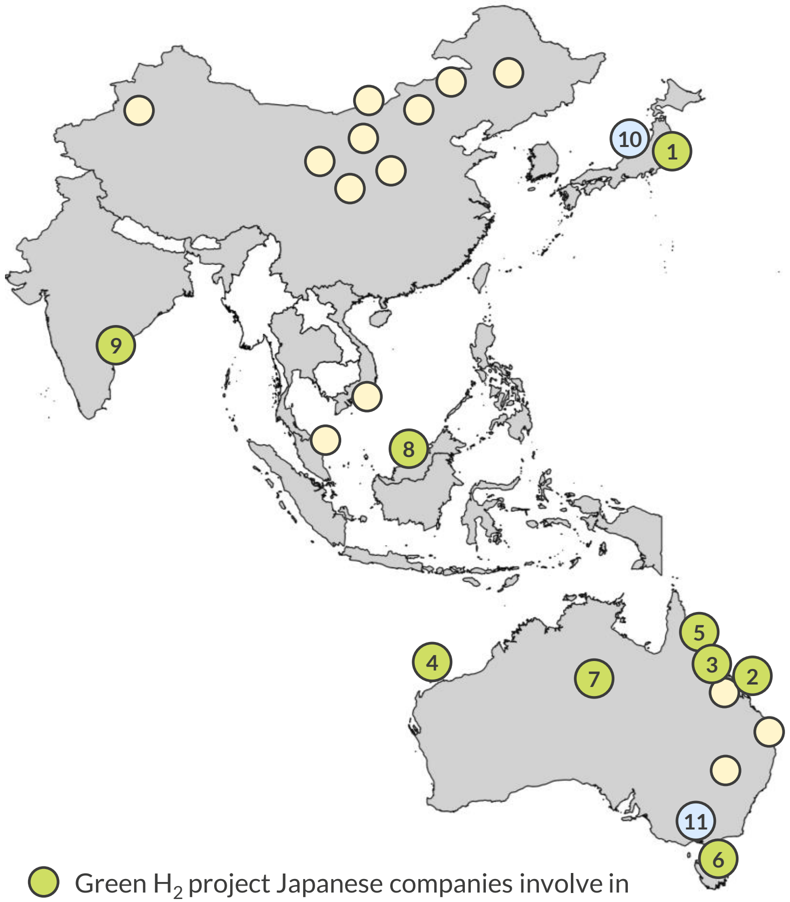
Examples of advanced hydrogen projects in APAC



- Green H_2 project Japanese companies involve in
- Blue H_2 project Japanese companies involve in
- Other large H_2 project

Examples of projects with Japanese companies involved

		Country	Project name[1]	Key partners	Product	Amount tpa(H_2)[3]	End use	Status
Green hydrogen	1		FH2R[2]	Toshiba, Tohoku Electric, Iwatani, NEDO	Green H_2	200	Transport, Power	Operational
	2		CQ-H2	Iwatani, Marubeni, KEPCO	Green H_2	36,500	Industry, Power	Construction
	3		HyNQ	Idemitsu, Energy Estate CS Energy	Green NH_3	80,000	Transport	Construction
	4		Yuri	Mitsui Co., Engie	Green H_2/NH_3	640	Ammonia	Construction
	5		Townsville	Kawasaki Heavy Industry, Origin Energy, Port of Townsville	Green H_2	36,500	Industry, Transport	Construction
	6		H2TAS	Marubeni, IHI, Woodside	Green NH_3	30,000	Industry	Construction
	7		Desert Bloom Hydrogen	Osaka Gas, Aqua Aerem	Green H_2	400	Industry, Transport	Construction
	8		Sawaraku	ENEOS, Sumitomo Co.	Green H_2	90,000	Industry	Planning
	9		Odisha	Kyushu Electric, Sojitz, Sembcorp	Green NH_3	30,000	Industry	Planning
Blue hydrogen	10		Niigata	INPEX, JGC	Blue H_2	700	Power, Ammonia	Construction
	11		HESC	Kawasaki Heavy Industry, J-Power, Iwatani, Marubeni	Blue H_2	250	Aluminium	Construction

1) If there is no specific project name yet, we list site name instead. 2) Fukushima Hydrogen Energy Research Field. 3) Convert to hydrogen basis unit when ammonia is produced

Sources: Aurora Energy Research, various news sources

Only ~17% of electrolyser projects in APAC have indicated potential offtakers and a few advanced projects are primarily focused on self-consumption

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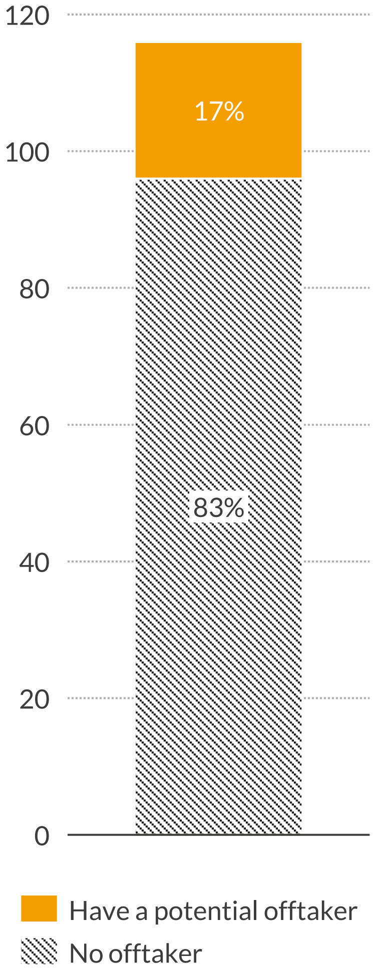
APAC electrolyser projects with potential offtakers[1]
# of projects



Key H_2 offtake agreements in APAC

Country	Buyer	Seller	Quantity (ktpa-H_2)	Offtake start date	End use	Notes
Japan	Ishikawajima-Harima Heavy Industries (IHI)[2]	ACME	~71[3]	2028	Power, Industry	▪ Ammonia will be used as the carrier; IHI will then distribute the ammonia locally in Japan.
Japan	JERA	Exxon Mobil	80	2028	Power generation	▪ Ammonia will be transported into Japan and used in coal fired power plant.
Japan	Haneda Airport	ENEOS	10	2030	Power generation	▪ ENEOS plans to procure H_2 from Malaysia and Australia.
Japan	Cosmo Oil	ADNOC	~0.002	2022	Industry	▪ Cosmo Oil will transport Blue ammonia into Japan and use for their business.
Australia	Yara Pilbara Fertilisers[2]	Engie, Mitsui	0.64	2024	Fertilisers	▪ H_2 from Project Yuri will provide feedstock into the Yara operations in Western Australia.
Australia	Orica[2]	Origin	~4.4[3]	2026	Ammonia	▪ H_2 from the Hunter Valley hub will be consumed at Orica's Kooragang Island plants.

Self-supplying H_2 offtake – the same entity producing and consuming the H_2

Country	Producer/User	Usage facility	Quantity (ktpa-H_2)	Offtake start date	End use	Notes
Oman	J-Power	Hydrom	166.67	2030	Ammonia	▪ Produce Green H_2 using Solar, Wind and Battery and supply to ammonia manufacturing plant.
China	Sinopec	Yanshan Petrochemical	100	2027	Oil refinery	▪ H_2 from project Ulanqab (Inner Mongolia) is to be transported to Beijing via a 400km pipeline.
China	Sinopec	Tahe Refining and Chemical	~4–10	2023	Oil refinery, Chemicals	▪ The Kuqa plant (260MW) is only operating at ~20–50% of its capacity due to safety concerns.
India	HPCL[3]	Visakhapatnam Refinery	0.37	2024	Oil refinery	▪ The project has missed two announced operation dates (June 2023 & September 2023).

1) Excluding early-stage projects and projects with commissioning dates after 2030; Some of these agreements are MoUs which are not legally binding contracts; 2) Buyer is also the partner of the electrolyser project; 3) Estimated hydrogen offtake quantity from announcements; 3) HPCL – Hindustan Petroleum Corporation Ltd.
Source: Aurora Energy Research, various news sources

Australia is one of the most cost-competitive exporters of Green H_2 to Japan, although the USA and Middle East are very competitive for Blue H_2

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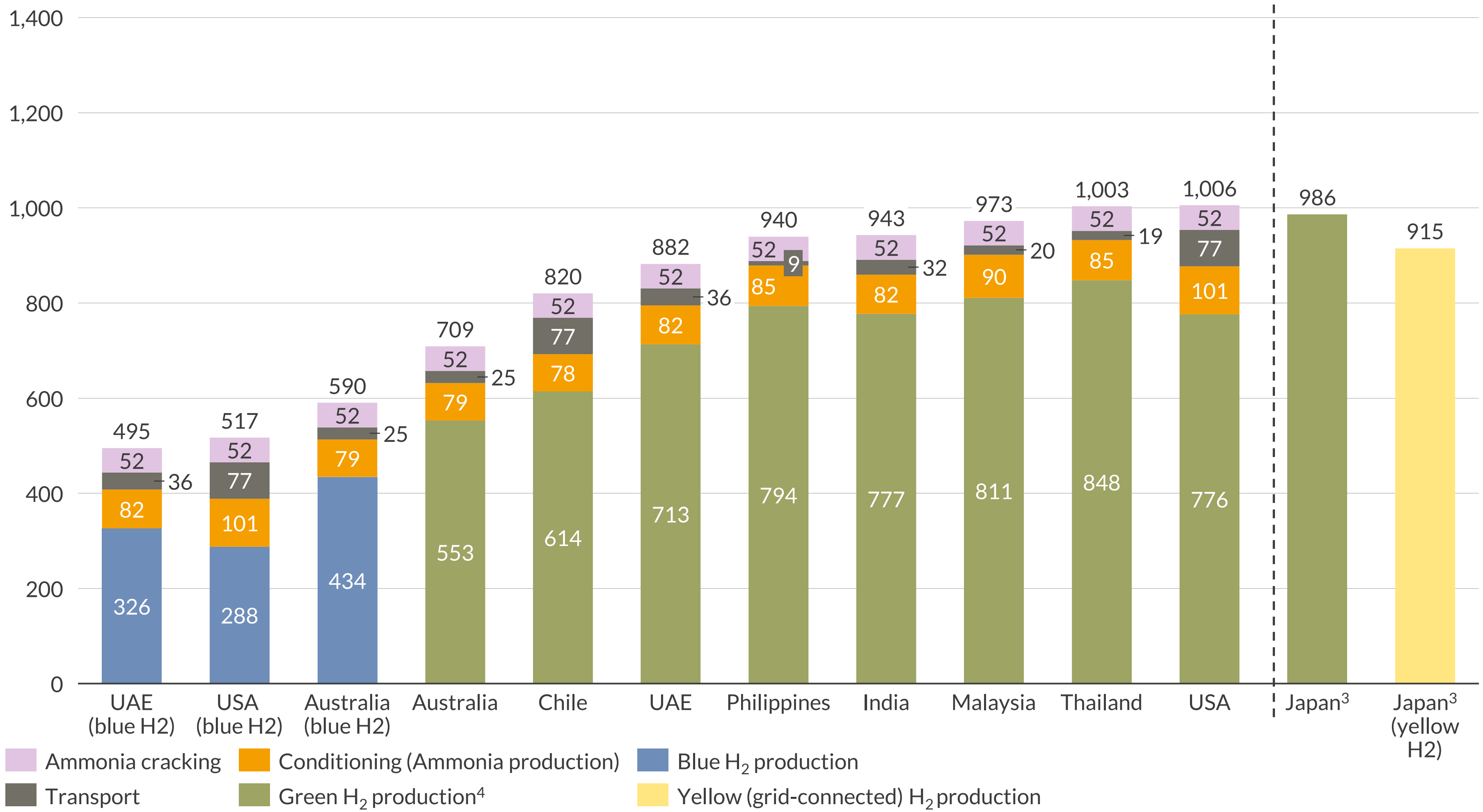
Levelised cost of H_2 (via ammonia imports) to Kobe, Japan in 2030[1,2] – Aurora Central Scenario

¥/kg-H_2 (H_2 contained in ammonia), real 2023



1) Region in the country with the best solar and wind resources was considered, unless stated otherwise; 2) The levelised cost of ammonia excludes domestic transport costs; 3) Hokkaido production cost in Japan; 4) Using the co-located islanded electrolyser business model optimised for the ratio of solar and on-shore wind capacity.

Sources: Aurora Energy Research

- The levelised cost of green H_2 from Australia to Japan totals ¥709/kg-H_2 in 2030, which is 39% cheaper than the cost to producing H_2 locally in Japan.
- It is more cost effective to import H_2 as ammonia from most exporting countries than producing it domestically in Japan.
- Blue H_2 from the UAE, US and Australia with carbon capture could offer a cost-effective alternative in the short term in Japan, but its carbon intensity must meet Japan's government standards. Blue H_2 production is also subject to presence of appropriate geological formations capable of securely storing captured CO_2.
- Transport accounts for only 2-10% of the total delivery cost, depending on the exporting country's proximity to Japan. Geographical distance between exporting and importing countries is therefore less important in identifying suitable trade partners.

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Renewable targets are exceeding the currently available and planned network capacity – this is creating challenges with renewables being curtailed…

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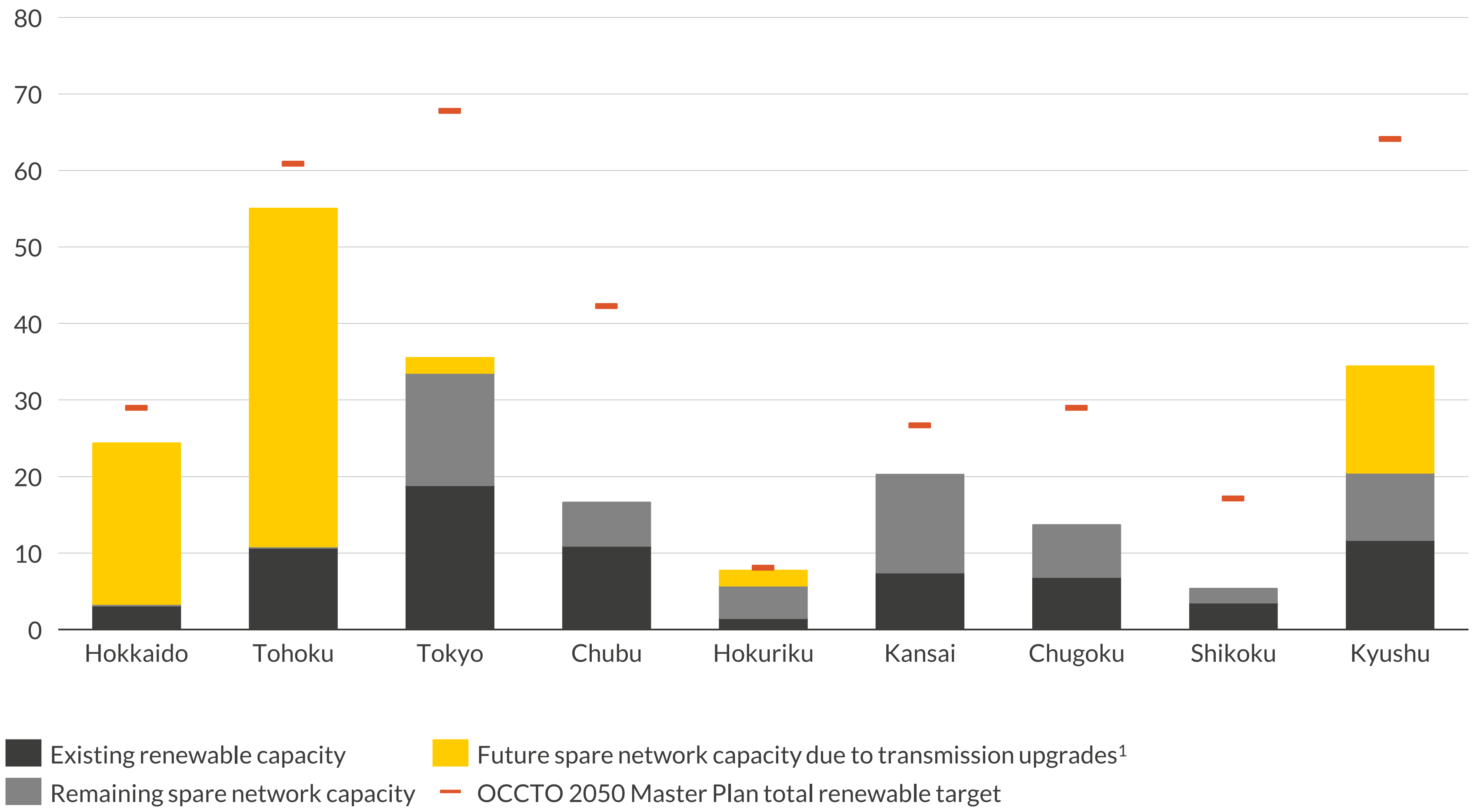
Renewable and network capacity

Nameplate, GW



- Remaining spare network capacity is calculated based on spare capacity of substations published by each transmission operators
- The announced interconnection upgrades are transferred into spare network capacity for all regions based on the expected flow direction and load factors of expected renewable resources
- Further regional enhancement and thermal plant retirements are expected to create additional spare capacity for renewable buildouts across Japan

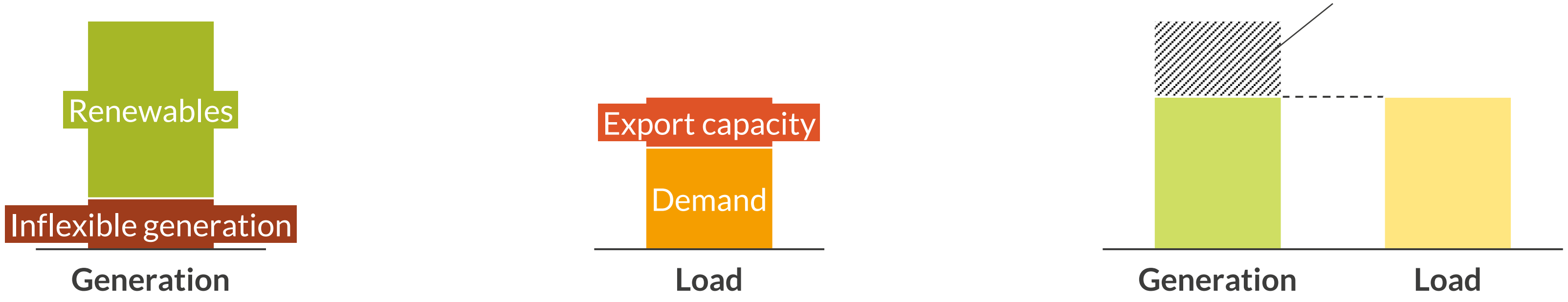
1) The unlocked renewable capacity from transmission upgrades is calculated based on interconnection size and relative renewable load factor in the region based on the expected flow direction. For example, 1 GW increase in transmission capacity from region A to region B is assumed to increase spare network capacity in A by 1/0.3 = 3.3GW based on average renewable load factor of 0.3.

Sources: OCCTO, Aurora Energy Research

What is curtailment? *Economic curtailment* is driven by region-wide oversupply, while *grid curtailment* is caused by individual transmission line limits

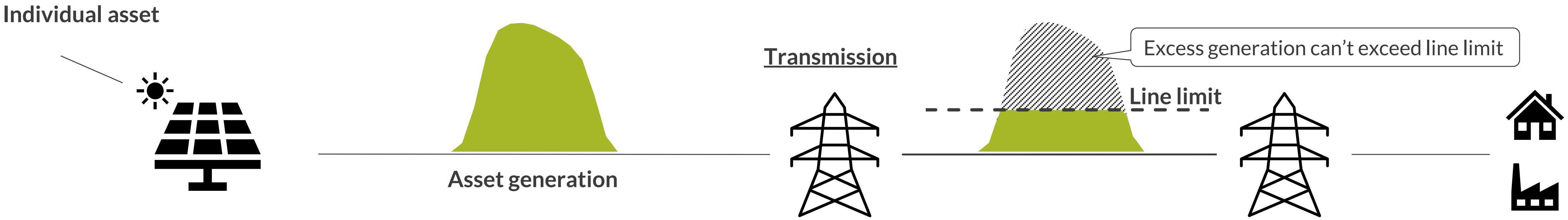
Economic curtailment

When region-wide generation is greater than region-wide load (+export), the result is economic curtailment



Grid curtailment

When asset-specific generation causes transmission line limits to be exceeded, the result is grid curtailment



Source: Aurora Energy Research

Aurora approach | Aurora's network model utilizes detailed market and transmission data combined with OCCTO/METI curtailment logic

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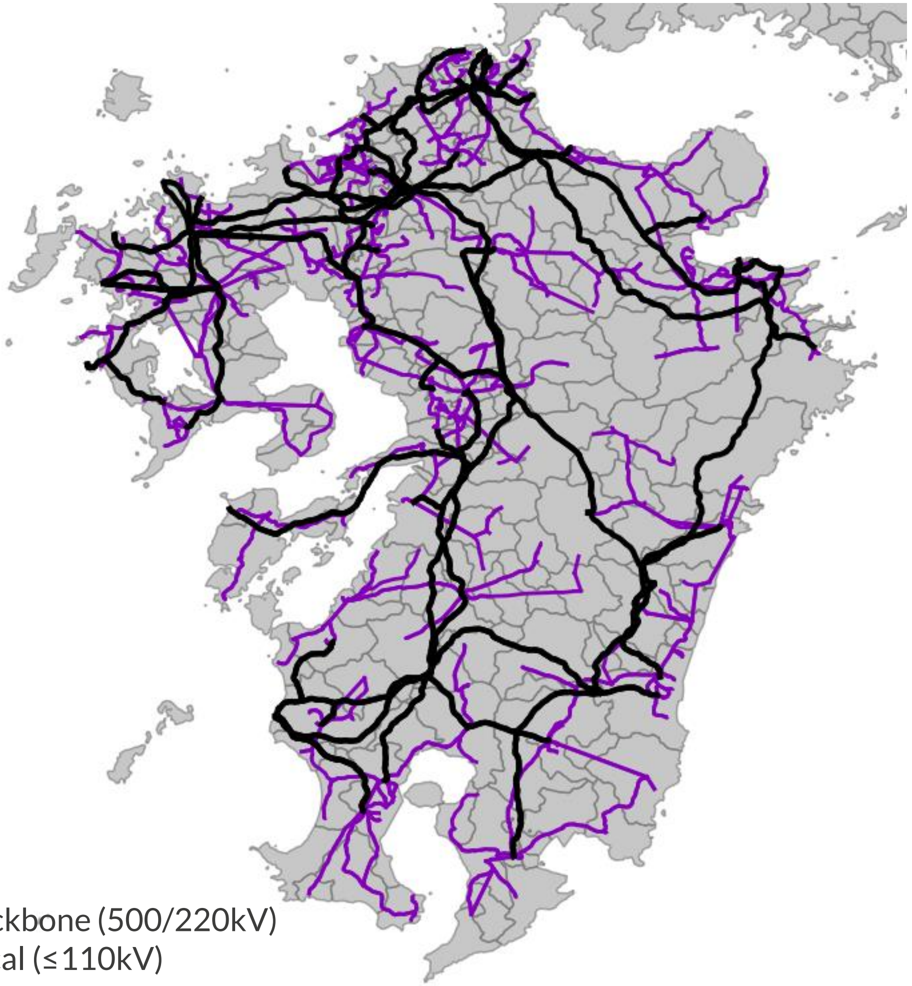
Kyushu network – major topology



Key:
Backbone (500/220kV)
Local (≤110kV)

Key inputs for power flow simulation:

Aurora network model load flow

I Load

- Proximity to load – residential, commercial, or industrial
- Load growth and major changes in load patterns

II Generation

- Proximity to existing generation
- Changes in local generation mix (thermal retirement, renewable buildout etc.)
- Imports/exports

III Network

- Network topology, transmission asset parameters and connectivity
- Network outlook: transmission upgrades to support changing load and generation patterns

IV Curtailment Logic

- Generator tech type/connection type (firm vs non-firm)
- Curtailment type: backbone vs local
- Curtailment methodology
  - Backbone lines - repowering method
  - Local lines - schedule change method & repowering method

Sources: Aurora Energy Research, OCCTO, Kyushu Electric Power Transmission and Distribution

Renewable investment cases in Japan are increasingly undertaking mapping of individual line utilizations to identify congested areas

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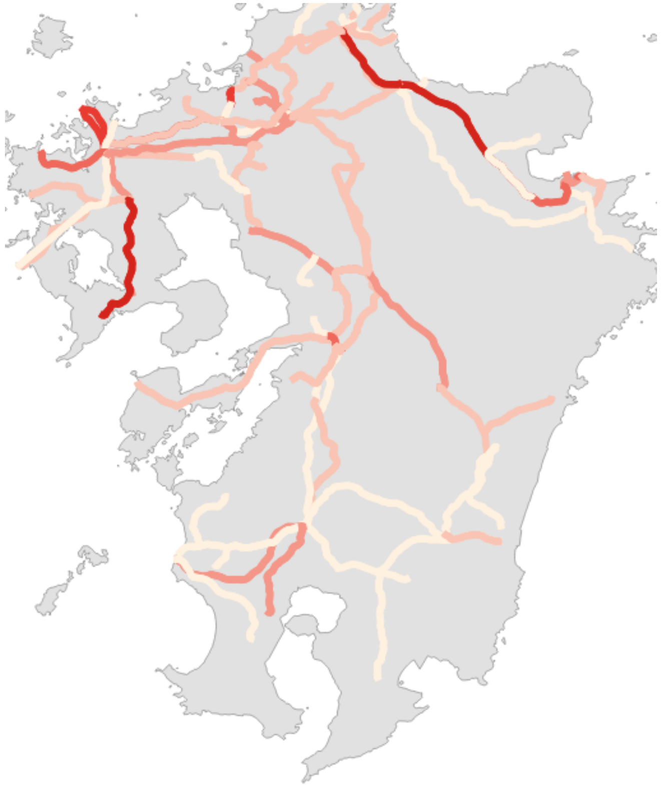
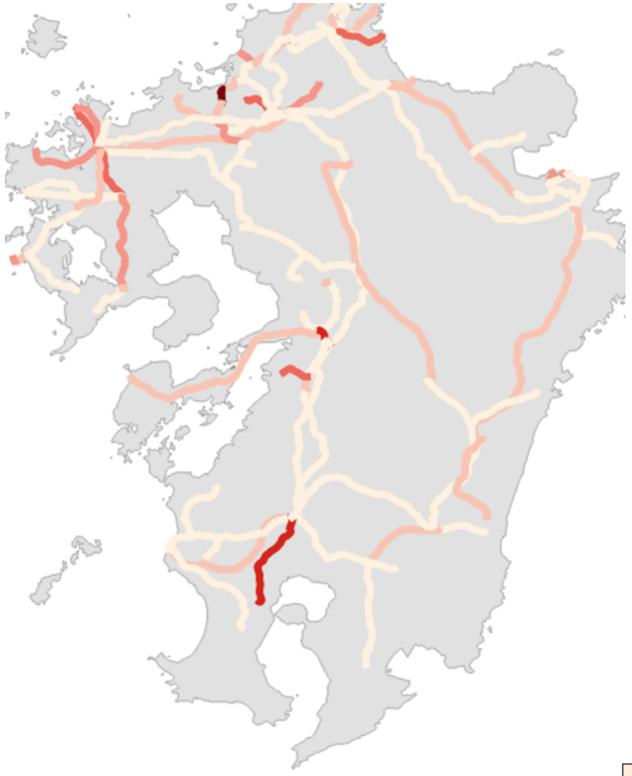
2021

History (published by Kyushu EPCO T&D[1])
Utilization %, 75th percentile



2030

Forecast – Aurora Central Scenario
Utilization %, 75th percentile



Short-term line congestion is concentrated in the North & West of the region. This dynamic shifts over time as thermal plants retire and generation is further sourced from renewables located further from metropolitan load centers

Backbone line utilization[2], %

1) Historic data is not published for certain backbone lines however are modelled by Aurora; 2) Line utilization is defined as the percentage loading of a particular transmission asset, relative to its capacity

Sources: Aurora Energy Research, Kyushu Electric Power Transmission and Distribution

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