Strategic Report

The New Role of Coal-Fired Power Plant in the Era of Energy Transition

August 2021

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Foreword

We are pleased to present the Strategic Report on the New Role of Coal-Fired Power Plant in the Era of Energy Transition which was developed by the Japan Coal Frontier Organization (JCOAL) Team and the ASEAN Centre for Energy (ACE) in close cooperation with the ASEAN Forum on Coal (AFOC).

From the result of the 6th ASEAN Energy Outlook, it was found that coal has been and will continue to play a crucial role in ensuring the steady growth of many ASEAN Member states. However, with the need for the ASEAN region to transition into low-carbon power generation, ACE deemed that now is the time to reidentify the role of coal in the coming era of the energy transition. This strategic report aims to serve as a reference for the ASEAN Member States in identifying available and emerging clean coal technologies, and policies that could promote its wider adoption, in order to support the global action towards low carbon transition while maintaining energy security and energy resilience in the region.

This report includes a review of the existing coal and renewable energy policies in the ASEAN Member States (AMS) and introduced the use of the Grid Fluctuation Index (GFI), a tool developed by JCOAL, to determine when and to what extent a grid would possibly experience fluctuation given the current and projected capacity additions. It also discussed solutions that allow flexible operations – techniques that have worked effectively in Japan and countries with similar market systems; and highlights the importance of enhanced pollution and emission regulation on the continuous utilisation of the existing coal fleet. To maintain the sustainable use of coal in the ASEAN region, this report also recommends policy developments on increased HELE utilisation, enhanced pollution and emission regulation, and carbon capture, utilisation, and storage (CCUS) deployment.

I highly appreciate the authors, contributors, and reviewers who have worked hard in developing this report. Appreciation to Mr. Osamu Tsukamoto, the President of JCOAL, with his leadership, we had initiated this joint strategic report as part of our result discussion on the future of energy in ASEAN.

We hope that this report will be a valuable resource to advance the adoption of clean coal technologies (CCT) in the region in parallel with the use of renewable energy and energy-efficient technologies.

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Acknowledgments

The Strategic Report on the New Role of Coal-Fired Power Plant in the Era of Energy Transition was prepared by the Japan Coal Frontier Organization (JCOAL) Team and the ASEAN Centre for Energy (ACE) in close cooperation with the ASEAN Forum on Coal (AFOC).

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Abbreviations

ACE	ASEAN Centre for Energy
AEDS	ASEAN Energy Database System
AIMS	ASEAN Interconnection Masterplan Study
AMS	ASEAN Member States
APAEC	ASEAN Plan of Action for Energy Cooperation
APG	ASEAN Power Grid
APS	APAEC Target Scenario
AQCS	Air Quality Control System
ATS	AMS Target Scenario
CCT	Clean Coal Technology
CCUS	Carbon Capture, Utilisation, and Storage
CO_2	Carbon dioxide
CR	Carbon Recycling
COVID-19	Coronavirus 2019
DR	Demand-on-response
EE	Energy Efficiency
EP	Electrostatic Precipitator
EE&C	Energy Efficiency and Conservation
EIA	US Energy Information Administration
FGD	Flue Gas Desulfurization System
GDP	Gross Domestic Product
GFI	Grid Fluctuation Index
GHG	Greenhouse gas
HELE	High Efficiency and Low Emission
JCOAL	Japan Coal Frontier Organization
MEEP	Moving Electrode type Electrostatic Precipitator
$MTCO_2$-eq	Metric Ton of carbon dioxide - equivalent
OAP	Over Firing Air Port
OCCTO	Organization of Cross-regional Coordination of Transmission Operators
PLS	Partial Least Squares
RE	Renewable Energy
SCR	Selective Catalytic NOx Reduction device

SDG	Sustainable Development Goals
UN	United Nations
VRE	Variable Renewable Energy

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Executive Summary

For the past decades, coal has been playing a crucial role in the ASEAN energy sector by supplying the steady growth in power demand of the developing region. But now that Southeast Asia embarks into energy transition following the global shift into a low-carbon economy to address climate change, reidentifying the role of coal in the energy sector is deemed essential to ensure the security, accessibility, affordability, and sustainability of energy in the region.

The ASEAN has been one of the fastest-growing regions in the world. This growth increases energy demand and an anticipated release of bulk emissions from power generation. The region is facing the pressure of maintaining its energy supply while aiming to resolve the existing energy issues, alongside the impacts of climate change.

The primary energy demand for the region is projected to increase up to 2.5 times higher in 2040 from the 2017 level. This would need up to 179 GW of cumulative capacity installation for the same period. The AMS has been working towards the decarbonisation of its power grid which is demonstrated by the presence of regional and national policies that are aimed to promote the increased penetration of renewables. The region under the ASEAN Plan of Action for Energy Cooperation (APAEC), intends to achieve an RE share of 23% by 2025 in the energy mix and to increase the RE share to 35% in terms of installed capacity. These existing policies have driven large uptake of renewables in the past years even with the COVID-19 pandemic in 2020 and are expected to push more RE deployments in the long run.

However, the regional forecast determined that existing national RE policies and targets are insufficient to achieve the regional target by 2025. Grid reliability due to intermittency of Variable Renewable Energy (VRE) technologies such as solar and wind power remains to be a major challenge. in its wider deployment. Until the advanced grid integration technologies – such as storage, smart grids intelligence, and digital technology for demand management – reach technology saturation such that their price falls due to the economies-of-scale, coal and natural gas power will remain the main source to back up and maintain grid stability to ensure energy security.

The region employs High-Efficiency Low Emission (HELE) technologies such as Super Critical (SC) and Ultra-Super Critical (USC) Pulverise Coal Technologies for new coal-fired power installations. ASEAN also explores the feasibility of adopting technologies that can reduce emissions and improve existing coal-fired power plants such as coal upgrading, cofiring systems with biomass, Carbon Capture Utilisation and Storage (CCUS), and flexible operation for more sustainable coal use.

GFI (Grid Fluctuation Index) is a convenient analytical tool that does not require a complicated analytical process, expert software, etc. We would be able to know when and to what extent a country would possibly experience grid fluctuation, and how the energy transition path would be, by calculating GFI and plotting it with timelines, baseload generation capacity, or mid-merit generation capacity with the standard energy and electricity data, which would be conducive to the national policies and measures to prevent or minimise the negative impact of RE integration. Accordingly, GFI is suitable for policymakers and the national utilities to foresee how the energy transition will proceed according to the present national scenario without any specific measures, further discussing and considering any desired measures to be taken.

To address the issues proactively by controlling grid fluctuation, a comprehensive set of measures in terms of market system formulation/transformation, digitalisation, and regulatory reforms are required aside from providing flexible operation of the existing power plants and introduction of new technology for generation, transmission, and storage. In this context, the ongoing flexible market system formulation and relevant policy reforms in Japan and comparable market systems in a few other countries are introduced as a useful reference for relevant ASEAN stakeholders to provide a comprehensive view of what needs to be developed and sustained during and beyond the energy transition.

To maintain the sustainable use of coal in the ASEAN region, this report recommends policy developments and updates on increased HELE utilisation, enhanced pollution, and emission regulation, and Carbon capture, utilisation, and storage (CCUS) deployment. Increased HELE utilisation calls for a solid regulatory framework on the application of HELE technologies on newly built plants and will also require consistent support when it comes to the financial, construction, and operation aspects. It was projected that ASEAN will need 60 GW additional capacity of supercritical and ultrasupercrital coal-fired power plants in 20 years which requires around US$77 billion investment.

Likewise, enhancement of pollution and emission regulations needs a presence of a more stringent emission standard, strengthened research on emerging pollution control technologies, and support to its adoption in terms of legal and financial aspects. Reduction of dust, SOx, and NOx is particularly important as a regional environmental measure, and many reduction measures are being implemented worldwide. Advanced technologies on pollutants removal were explored in this report, and comprehensive evaluation and adoption of these technologies are seen as means of achieving stringent emission standards for power plants.

Lastly, CCUS deployment in the region would still require numerous discussions on several topics such as legal and regulatory frameworks, storage, liability, pricing mechanisms, on top of ensuring public awareness and acceptance of the technology. The Tomakomai CCS Project in Japan demonstrates that the understanding and support of the local community and project partners can make a full chain CCS system from capture to storage feasible and effective means of preventing a bulk release of CO_2 to the atmosphere.

Chapter 1: Global Energy Transition and the ASEAN

It has been a goal to limit the increase of global average temperature to 1.5°C above pre-industrial levels to slow down, if not prevent, the irreversible effects of climate change on humanity and the environment. This colossal challenge demands the effort of every country and region to transition into a low-carbon economy by shifting into clean and renewable technologies and by improving energy efficiency across all sectors. The energy transition requires commitment from governments, followed by the establishment of necessary legal and regulatory frameworks that would provide an environment conducive to implementing the strategies needed to achieve the climate targets.

Southeast Asia homes countries that are most vulnerable to climate change. Member states - the Philippines (2nd), Vietnam (16th), Lao PDR (22nd), Cambodia (38th), and Myanmar (48th) were among the countries that are most susceptible to extreme weather events such as typhoon and flooding, which results in fatalities and loss of livelihood yet have a minimal capability in mitigating these risks[1]. It has been estimated that climate change could reduce Southeast Asia's GDP by 11% as it damages critical sectors such as agriculture, tourism, and fisheries, on top of health implications to its citizens[2].

If the above is not enough of a challenge, the region also consists of developing countries with a steadily increasing energy demand for the growing population and economy. Because of this, the ASEAN member states (AMS) need to address the complex issue of energy security, accessibility, affordability, and sustainability along with climate change. This has been a reason why the energy transition pathway of Southeast Asian nations could be different from the rest of the world, or at the very least to more developed regions.

This strategic report on the new role of coal aims to serve as a reference for the ASEAN Member States in identifying available and emerging clean coal technologies, and policies that promote its wider adoption, in order to support the global action towards low carbon transition while maintaining energy security and energy resilience in the region. Chapter 1 of the report outlines the current energy situation in the ASEAN region and the energy futures that were explored in the 6th ASEAN Energy Outlook. Chapter 2 and Chapter 3 discuss the existing renewable energy and coal

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[1] Global Climate Risk Index 2020. (2019). Available at https://germanwatch.org/en/17307.

[2] Southeast Asia and the Economics of Global Climate Stabilization. (2016) Available at https://www.adb.org/publications/southeast-asia-economics-global-climate-stabilization

policies in each ASEAN member states and tackle the challenges and barriers that hinder the wider integration to the grid in the case of VREs, and the need for more stringent emission standards in the case of utilising the existing coal-fired power plants for energy security.

Using the existing capacities and energy policies presented in the previous chapters, the ASEAN grid was assessed for reliability using the tool, Grid Fluctuation Index (GFI). GFI, a tool developed by JCOAL, can determine when and to what extent a grid would possibly experience fluctuation. The result of the assessment was presented in Chapter 4 of the report. Chapter 5 presents solutions that allow flexible operation in the case of high fluctuation in a grid. It also introduces relevant policy reforms in Japan and comparable market systems in a few other countries that may serve as useful references for its adoption in ASEAN.

Chapter 6 highlights the importance of enhanced pollution and emission regulation and explored advanced technologies on pollutants removal. Government-driven initiatives such as carbon recycling are also introduced, as well as updates and lessons learned from the Tomakomai CCS demonstration project.

The strategic report was concluded with Chapter 7 which recommends policy developments on increased HELE utilization, enhanced pollution, and emission regulation, and CCUS deployment that allows sustainable coal use, in parallel of renewable energy use and energy efficiency, to ensure energy security and grid resilience in the region.

1.1 Regional Energy Targets and Strategies

Since the Conference of the Parties (COP) 21, the ASEAN has taken the Paris Agreement as a direction for cooperation to address climate change. In the region, the energy transition transpires through the combined efforts of the AMS under the guidance of the ASEAN Plan of Action for Energy Cooperation (APAEC). The APAEC is a series of policy documents supporting multilateral energy cooperation to advance regional integration and connectivity goals in ASEAN.

APAEC serves as a blueprint for better cooperation towards enhanced energy security, accessibility, affordability, and sustainability. It accelerates the energy transition in the region by developing and implementing outcome-based strategies that are established to 1) expand regional multilateral electricity trading, strengthen grid resilience and modernisation, 2) pursue the development of a common gas market for ASEAN by enhancing gas and LNG connectivity and accessibility, 3) optimise the role of clean coal technology towards sustainable and lower-emission development, 4) reduce the energy intensity of consuming sector, 5) to increase renewable energy integration in the grid, 6) advance energy policy and planning, and 7) build human resource capabilities on nuclear science and technology for power generation.

The APAEC Phase II: 2021-2025, building on the success of APAEC Phase I: 2016- 2020, sets out more ambitious targets and initiatives for the region and supports the realisation of the United Nations Sustainable Development Goal 7, Affordable and Clean Energy. Under the current phase, ASEAN aims to reduce their energy intensity by 32% in 2025 based on the 2005 levels and encourage further energy efficiency and conservation efforts, especially in the transport and industry sectors. In terms of renewable energy deployment, the region seeks to achieve a RE share of 23% by 2025 in the ASEAN energy mix and to increase the RE share in installed power capacity to 35% in the same period.[3]

1.2 ASEAN Energy Outlook

The APAEC through ASEAN Centre for Energy (ACE) develops the ASEAN Energy Outlook (AEO), highlighting the key trends in the energy landscape and policy direction to enhance energy security, transition, and resilience in the region. The recent release, 6th ASEAN Energy Outlook (AEO6) explores demand and future developments under four energy scenarios: Baseline, AMS Targets Scenarios (ATS), APAEC Target Scenarios (APS), and Sustainable Development Scenarios (SDG) for the period of 2017 - 2040.[4]

The baseline projects the ASEAN energy system considering the historical trends in each country with the modest implementation of the policies and strategies to meet their national and regional targets. The AMS Targets Scenarios (ATS) and APAEC Target Scenarios (APS) project the future development of the ASEAN energy system considering the attainment of their country-specific targets and the ASEAN regional target, respectively. The SDG is an additional scenario from the previous edition (5th ASEAN Energy Outlook), which aims to explore the pathways required by the ASEAN to significantly contribute to the attainment of the United Nations SDG 7 targets on 1) ensuring universal access to affordable, reliable, and modern energy service, 2) increase the share of renewables in the global energy mix, and 3) double the global rate of improvement of energy efficiency (from 2015 levels).[5]

[3] ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 Phase II: 2021-2025. (2020). Available at https://aseanenergy.org/asean-plan-of-action-and-energy-cooperation-apaec-phase-ii-2021-2025/

[4] The 6th ASEAN Energy Outlook 2017 - 2040. (2020). Available at https://aseanenergy.org/the-6th-asean-energy-outlook/

[5] See https://sdgs.un.org/goals

According to the AEO6 projection, the region's population and economy are expected to grow significantly in the long term, despite the slowing down in the recent year due to the COVID-19 pandemic. In the baseline scenario, the total primary energy supply (TPES) is projected to increase by 2.5 times in 2040 at 1,589 Mtoe from the 2017 level at 625 Mtoe, as shown in Figure 1. Renewable energy is expected to grow at an annual rate of 4.2%. However, coal and oil still dominate the energy mix, increasing at an annual rate of 4.8% and 4.0% from 2017 to 2040. Coal is mainly used as a fuel for electricity generation, while oil is for transport. In 2040, RE share in TPES following the historical trends in the AMS accounts for 14% while the combined share from coal, oil, and natural gas accounts for 83.8%. With the modest implementation of AMS national and regional RE policies, the region is at risk of resource depletion, relying on fossil fuel imports. Aside from vulnerability to global market price volatility, the increase in fossil fuel consumption at this rate would results in energy-related GHG emission for the region to be six times higher in 2040 at 4,171 $MTCO_2$-eq from the 2017 level of 1,686 $MTCO_2$-eq taking a toll on public health and labour productivity.

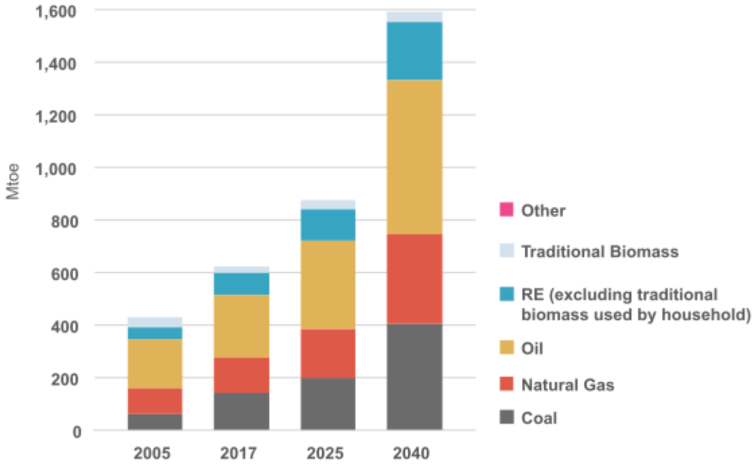


Figure 1. Total Primary Energy Supply (TPES) for Baseline Scenario (Source: AEO6)

Although renewable share grows steadily in the baseline, and with the efforts made to reach the national energy targets, it remains insufficient to achieve the regional target of 23% share by 2025, as shown in Figure 2. It would require the collective commitment and efforts of the AMS to close this gap. Few policy recommendations from the AEO6 are to raise the current AMS national targets by accelerating the biofuel mandates through increased blending ratio and investing more in renewable power installations.

In the APS scenario, 138 GW of renewable capacity is required to be built from 2018 through 2040 out of the 179 GW total capacity additions. The total investment needed for this capacity expansion is USD 508 Billion, driven by capital needed for cleaner technologies installations. However, the cost of capacity expansion can be balanced by the socio-economic benefits such as job creation and emission reduction. Investment in renewables, especially solar and wind power, can create new jobs (e.g., installers, fabricators, and engineers). The projected job created by solar and wind power investment is 223,000 by 2025, which is 2.7 times more than the baseline. Cumulative employment may reach 303,000 jobs in 2040 – 220,000 of which is from solar deployments and the remainder from wind deployments.

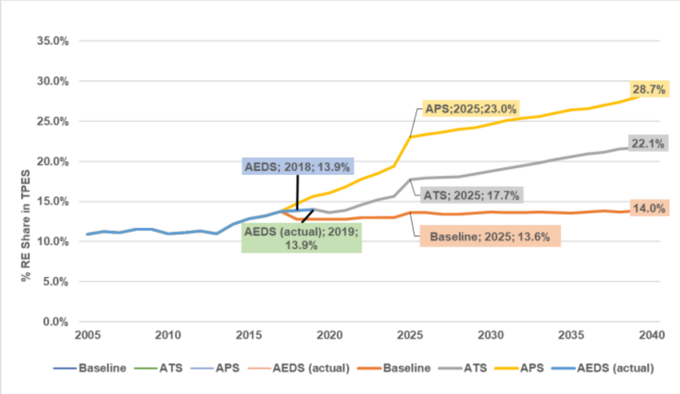


Figure 2. Projected RE Shares for the Baseline, ATS, and APS Scenarios (Source: ASEAN Energy Database System, AEDS)

The GHG emission of the region sharply lowers to 2,264 MTCO$_2$-eq in the APS scenario, which is almost as half much as the baseline emission. However, like the baseline scenario, the electricity sector remains the most significant greenhouse gas and pollution emitter, followed by the transport and the industry. On a positive note, this presents an opportunity for the power industry – which can easily be regulated – to create a huge emission reduction by shifting into clean and climate-neutral technologies for electricity generation.

The critical approach for attaining the regional RE target is the increased penetration of variable renewable energy. Solar and wind capacity must reach an average annual growth of 15% and 12%, respectively. By 2025, solar capacity is expected to jump to 83 GW from 32 GW in 2020. Meanwhile, the capacity of hydropower (the major renewable energy resource in the region) is expected to jump to 77 GW from 59 GW during the same period.

A reduction of coal power capacity of about 15% from major coal-consuming countries, Indonesia, Malaysia, the Philippines, and Vietnam, has been observed with this transition from conventional to VREs deployment. However, as shown in Figure 3, fossil fuel (coal and natural gas) remains a significant part of the ASEAN power mix even in the next 20 years.

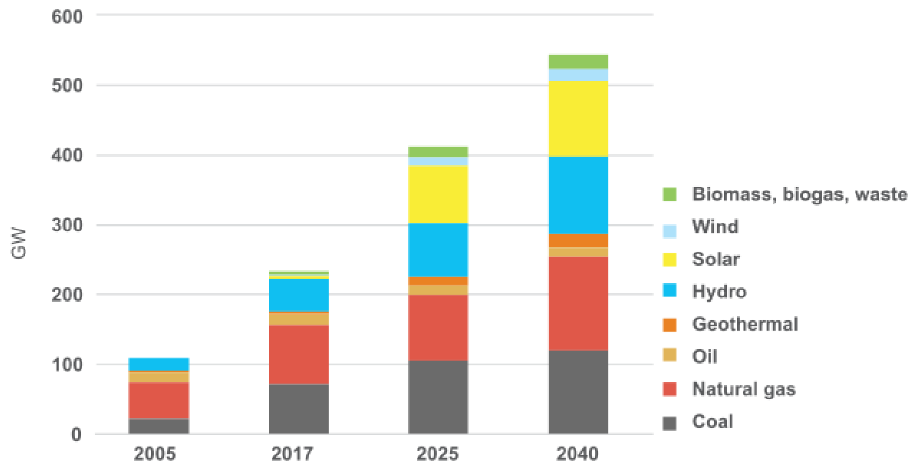


Figure 3. ASEAN Installed Capacity Mix for APS Scenario (Source: AEO6)

The SDG 7 – affordable and clean energy, links access to clean energy and energy efficiency measures as key climate change strategies to reduce greenhouse gas emissions.[6] The attainment of APAEC target on renewable energy and energy efficiency has provided the region a good direction to the attainment of SDG targets 2 and 3. But to meet the energy intensity reduction target stated in SDG 7.3, it was projected that ASEAN would need to reduce the energy intensity at an annual average of 2.6% from 2015 to 2030. The current national and regional energy efficiency target would only achieve 1.7% and 2.2% annual reductions, respectively. Therefore, raising the energy efficiency target of the ASEAN is deemed important to meet the global energy intensity reduction target.

Meanwhile, the achievement of national and regional RE targets would increase the RE share to 18.8% and 24.6%, respectively, by 2030. These figures seem to be adequate given that the SDG has not specified a target percentage of renewables in the global power mix. IRENA even determined that Southeast Asia must meet 53% of its power generation from modern renewable energy to align itself to meeting the upper-temperature limit of 2°C Paris Agreement target. If ASEAN intends to support the global goal of keeping the temperature away from the tipping point, it must improve its renewable targets for the region.[7]

ASEAN as a region also needs more effort to attain SDG 7.1, particularly on getting a significant portion of the population access to clean fuel and technology for cooking. AMS has already made significant progress to ensure 100% electrification by 2030 through combined conventional and renewable generation both on grid-connected and off-grid areas. However, the pace at which

[6] Connections between the Paris Agreement and the 2030 Agenda. (2019). Available at https://www.sei.org/publications/connections-between-the-paris-agreement-and-the-2030-agenda/
[7] Global Renewables Outlook. (2020). Available at https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Apr/IRENA_Global_Renewables_Outlook_2020.pdf

clean energy cooking is pushed in the region still lags the global target. About 60 million households or 240 million people in ASEAN still cook with traditional biomass such as wood, crop wastes, charcoal, or kerosene stove. Rural households with low-income are least likely to adopt the use of modern stoves and fuels. Meeting SDG 7.3 would require policies and financial instruments that would encourage the population to shift into liquefied petroleum gas (LPG), biogas, and natural gas for the near term, then eventually to electric stoves.

Summing up this chapter, ASEAN through APAEC initiatives has been continuously pursuing efforts to transition into a cleaner energy sector by encouraging the increase in uptake of renewable and energy-efficient technologies, aligning its future developments to the global goal of mitigating the impact of climate change. The energy transition in ASEAN will require a high upfront cost in the short term, but in the long run produces substantial socio-economic benefits such as job creation, public wellness, and most importantly, emission reduction. Achieving the APAEC targets ensures good alignment with the UN SDG 7 goals, but despite the attainment of both national and regional targets, coal and other fossil-based fuel remain to be a significant source of energy to supply the region’s increasing energy demand.

Chapter 2: Renewable Energy Policies in ASEAN

To achieve the ASEAN's aspirational target of 23% RE share in TPES by 2025, the APAEC establishes the outcomes-based strategies (OBS) for the region namely, 1) advance renewable energy policy and decarbonisation pathways, 2) conduct high-level policy dialogue on renewable energy, 3) enhance renewable energy research and development (R&D), 4) promote renewable energy financing schemes and mechanisms, 5) support biofuel and bioenergy development and lastly 6) enhance renewable energy information and training centre.

Under these strategies, the region intends in the following year to develop a long-term renewable energy roadmap for the ASEAN, conduct an impact assessment of RE financing implemented in the past five years, initiate discussion on biofuel and bioenergy guideline standards for the ASEAN, and establish a nodal network with research institutions and academe for joint studies and information sharing on RE policy support and instruments.

The long-term energy roadmap shall guide the AMS on the technical and economically viable renewable uptake, taking on the findings and recommendations of the ASEAN Interconnection Masterplan Study (AIMS) III, ASEAN renewable energy outlook, and the review on the readiness of the RE supporting industries. The AIMS III is an ongoing study with the Heads of ASEAN Power Utilities/Authorities (HAPUA) that seeks to explore the feasibility of a more ambitious renewable energy target and its implication on ASEAN Power Grid (APG). The APG is another strategic programme under APAEC that aims to facilitate electricity trading among the Member States through strategic interconnections and enhance the integration of their power systems, built to accommodate higher VRE penetration cost-effectively and reliably.

The ten (10) ASEAN Member States – Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam, given that the roadmap is yet to be developed, has been working on their national targets to encourage an increase in renewables in their country's energy mix.

2.1 AMS National Renewable Energy Targets, Policies, and Mechanisms

Table 1 summarises the official energy targets of each of the ASEAN member states. ASEAN is rich in hydropower resources which supply around 18% of the power requirement of the region but is working towards diversification by improving the capacity uptake of variable renewable energy resources. Cambodia, a country that is rich in hydropower resources, stated in the 2019 Cambodia

Basic Energy Plan to source 10% of its power mix from biomass, wind, and solar by 2030 and to source 3% of its residential electricity demand from rooftop solar by 2025. Meanwhile, Malaysia implemented a solar PV net energy metering (NEM) scheme in 2017, setting a target of 500 MW of distributed solar capacity in 2020. Complementing this mechanism in the commercial sector are the Solar Leasing Policy that allows private companies to install rooftop solar panels at no up-front cost, Green Investment Tax Allowance (GITA), and Green Income Tax Exemption (GITE). Malaysia also pioneered peer-to-peer (P2P) trading using blockchain technology in the region that allows NEM "prosumers" to sell excess power on an energy trading platform to other consumers. In addition, the Malaysia Green Attribute Tracking System (MGATS) supports the issuance and trade of renewable energy certificates (RECs).

Myanmar, which also sources its electricity from hydropower, sets a target of increasing solar and wind power share to 1.2% in their energy mix, supporting a target of 12% non-hydro renewables by 2030. Despite the land area, Singapore aspires to achieve 350 MWp of solar capacity by 2020 and at least 2 GWp by 2030.

Thailand has always been leading the region in terms of renewable deployment. Thailand is the first ASEAN country that has introduced a feed-in-tariff scheme for small-scale power producers. In the current RE Map, the country aims to increase solar capacity from 6 GW to 17 GW by 2036 and is looking to expand solar opportunities through the development of floating solar PV farms at their dams. Vietnam saw a massive leap in solar power deployment in 2019 due to generous solar feed-in-tariff and tax reduction for developers. The country targets to reach 32.3% renewable share in TPES by 2030 and 43% by 2050 according to the Vietnam Renewable Energy Development Strategy for 2030 with an outlook to 2050.

Table 1. Existing National Renewable Energy Targets in the AMS

AMS	Official Targets
Brunei Darussalam	10% renewable energy share in installed power generation capacity by 2035
Cambodia	55% of Hydropower share, 10% of other renewable energy in power generation mix by 2030 (other renewable Energy: 6.5% from biomass and 3.5% from solar) 3% of residential electricity demand met by rooftop solar PV by 2035
Indonesia	23% RE in primary energy supply by 2025
	Biodiesel blending ratio target 30% by 2020 and maintain that level through 2025 and to 2050
	20% bioethanol blending ratio target by 2025; 50% by 2050

Lao PDR	30% RE share of total energy consumption by 2025, including 20% of electricity from RE that is not large-scale hydro, and 10% biofuel share (blending ratio 5–10%)
Malaysia	20% RE in the power capacity mix by 2025 (excluding large-scale hydro)
Myanmar	12% share of RE in national power generation mix by 2030 (excluding large-scale hydro)
Philippines	35% RE share in the generation mix by 2030 with 1% minimum annual increment from the previous year
	Biofuel blending ratio around 2% for biodiesel and 10% of bioethanol
Singapore	350 MWp of solar capacity by 2020 and at least 2 GWp by 2030
Thailand	30% RE share in total final energy consumption (TFEC) by 2036, including15–20% renewable electricity in the total generation; 30–35% of consumed heat from renewables; and a 20–25% biofuel share in TFEC
Vietnam	32.3% RE share in TPES by 2030, 44% by 2050
	32% RE share in power generation by 2030 and 43% by 2050

Biofuel blending is considered as an integral means of reducing the emission in the transport sector. It is also crucial in reducing the import reliance of several ASEAN member states. Indonesia, Lao PDR, Malaysia, the Philippines, Singapore, and Thailand are a few of the AMS with a clear biofuel mandate policy that targets a typical blending ratio of 5-10%. Indonesia even aspires to achieve a 50% blending ratio by 2050.

Despite the existing targets, policies, and mechanisms that AMS implements to promote the RE deployment on the national level, it remains insufficient to meet the regional target—achieving the national targets yields an RE share of 17.7% by 2025, which is 5.3%-pts below the regional target. The APAEC Phase II initiative has been to align the AMS national policies and plans with the APAEC regional strategies.

2.2 Barriers and Policy Gaps to Wider Deployment

The increased integration of more renewables in the grid is one of the most desirable pathways to decarbonise the power sector. However, it still faces tech-economic and legal barriers which hinder its larger implementation in the ASEAN region.

Despite policies that promote renewable uptake, particularly solar and wind, the state of grid infrastructure remains a limiting factor to higher VRE integration. Power fluctuation and interruption in the power grid exhibit the difficulty in maintaining the stability of the electricity transmission system due to the intermittent nature of variable renewable energy. This challenge in balancing power supply to the demand also makes VRE deployment less attractive to its application to heavy industry and other end-users that require consistent and reliable electrification. ASEAN being archipelagic makes the integration of VRE even more difficult since variability in the generation is considerably impacting smaller systems compared to larger ones.

Battery storage, which has exhibited significant cost reductions in the past years, could play a major role in allowing an increased share of VREs in the grid. However, comparing the cost of VRE and battery storage technologies from other regions globally, ASEAN prices are still way higher.[8]

The cost of VRE, although it is becoming more competitive with conventional technologies, remains capital intensive. It would require legislative and fiscal instruments to ensure renewable projects are bankable to attract investors. With this, implementing regulations needs to keep up with the national and regional policies that are put in place.

[8] Regional Energy Trends Report 2020. (2020). Available at https://www.unescap.org/publications/regional-energy-trends-report-2020-tracking-sdg-7-asean-region

Chapter 3: Clean Coal Utilization Policy in ASEAN

In the ASEAN power sector, a significant transition to low carbon sources is expected to take place under the ATS and the APS, yet coal and gas will remain important. The ATS reflects the country's power development plan with energy efficiency measures while the APS implies the acceleration of RE considering each country's RE potential. The projection of ASEAN installed capacity in both APS and ATS are illustrated in Figure 4 and Figure 5, respectively. In 2017, the ASEAN installed capacity was 234 GW, with a 26.1% share coming from RE.

Under the ATS, coal-fired power plant contributes 37% of total capacity, followed by RE (33%) and gas (27%) in 2025. While, when ASEAN upscales RE penetration under the APS, Figure 5 depicts the most significant share are from RE (23% of solar and wind, 19% of hydro, 10% of other RE), followed by coal (26%), and gas (23%) in 2025. With this high penetration of solar and wind, the role of fossil fuel power plants or other flexible generation will be essential to maintain grid stability. On top of this, coal will likely remain the second primary fossil fuel due to its availability and affordability.

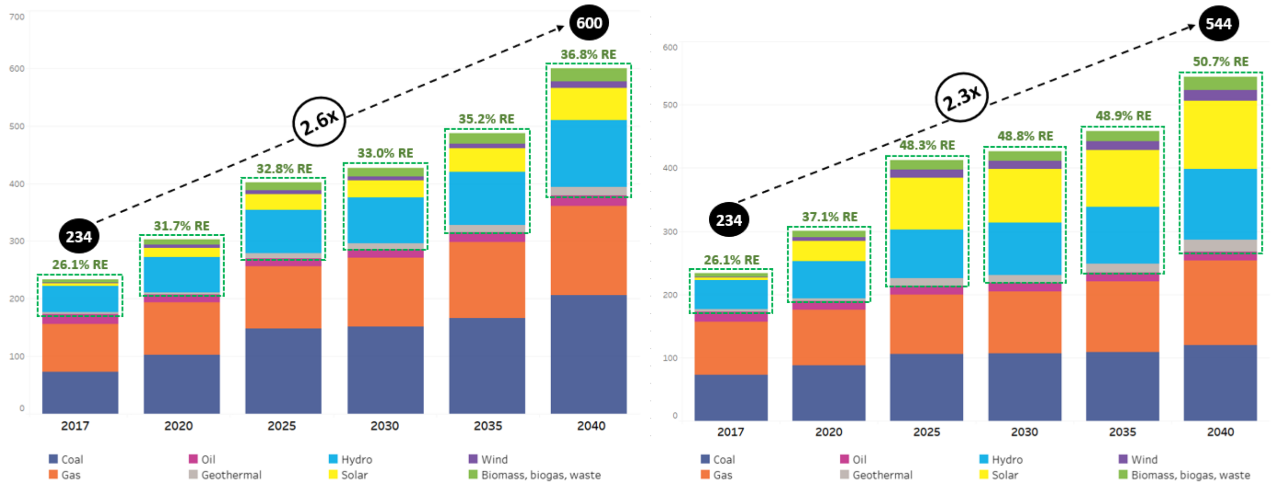


Figure 4. ASEAN Total Installed Capacity under ATS (left) and APS (right) (Source: AEO6)

Coal has been crucial for economic development within the region by providing reliable, affordable, and flexible energy. Moving towards low carbon transition pathways, worldwide best available technologies are proven for the region to adopt. Those technologies include coal upgrading, High-Efficiency Low Emissions (HELE) technologies, cofiring systems with biomass, and most importantly, Carbon Capture Utilisation and Storage (CCUS) or Carbon Capture and Storage (CCS).

ASEAN is actively promoting the utilisation of clean coal technologies (CCT) by establishing the ASEAN Forum on Coal (AFOC). Most of the AMS have introduced CCT or HELE initiatives in their recent power development plan. HELE technologies, namely Super Critical (SC) and Ultra-Super Critical (USC) have a higher process efficiency than the subcritical[9].

Figure 4 presents the clean coal transition from 2017 to 2040 under the ATS. It is projected that there will be more than 60 GW additional capacity of SC and USC coal-fired power plants (CFPP) in the next 20 years with around US$77 billion investment needed. Meanwhile, it is shown in Figure 5 that Malaysia is leading the way to shift away from conventional CFPP by increasing the USC CFPP capacity from 2 GW in 2017 to 11 GW in 2040. This would be a good starting point for ASEAN further to utilise HELE technologies for new or retrofitted CFPP.

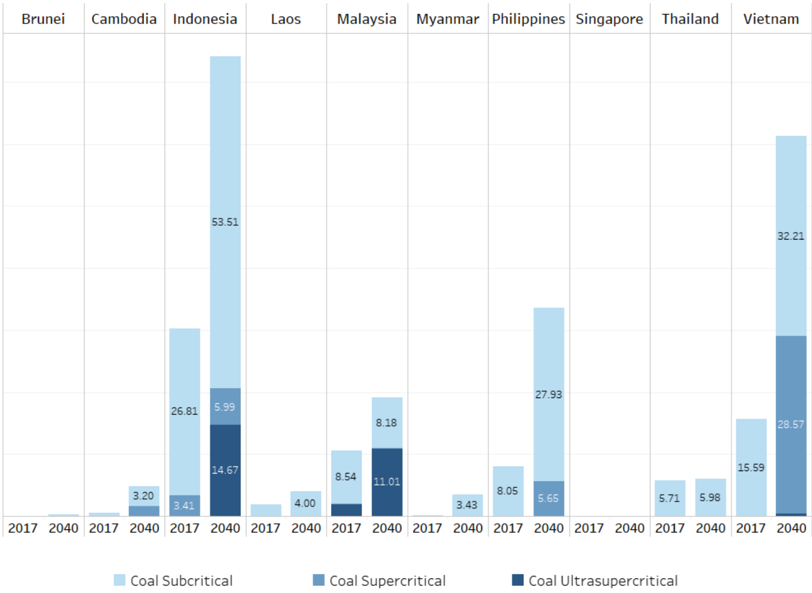


Figure 5. ASEAN Total Installed Capacity under the ATS (Source: AEO6)

Table 2 provides the updated AMS new coal policies which are usually reported in the annual ASEAN Forum on Coal. Several AMS have put in place policies to promote CCT and encourage higher domestic coal consumption to strengthen sustainable development and energy security. Being the major player on coal in the region, Indonesia has developed a CCT roadmap, conducted feasibility studies on coal gasification, and piloted cofiring systems with biomass in several CFPPs across the country.

[9] In ASEAN countries, current subcritical efficiency ranges from 20%-34%, while supercritical and ultra-supercritical are 37% and 42% respectively.

Table 2. Existing Coal Policies in AMS[10]

AMS	Coal Policy
Cambodia	Coal pricing is based on Newcastle Index
	Subsidy mechanism: No coal subsidy, only Tax and VAT is exempted
	Transport fee is based on bidding, usually every 3-4 years
Lao PDR	Based on Order No 08, dated 02 July 2018, the Lao government promotes mining company extraction coal to supply domestic consumption (i.e., cement industry), as well as the demand of domestic coal-fired power plants.
	The coal industry in Laos is in the early stage of development of its coal mining industry.
	Coal pricing is based on the international coal price.
	Lao Government takes coal royalty with a rate of 6% of sale value/ton.
Indonesia	Law No. 3 of 2020, revision on Law No. 4 of 2009 on Mineral and Coal Mining
	Government Regulation No. 77 of 2014, 3rd revision on Government Regulation No. 23 of 2010 on Implementation of Mineral and Coal Mining Business Activities.
	Regulation of the Minister of Energy and Mineral Resources No. 34 of 2009 on Preference of Domestic Minerals and Coal Supply
	Regulation of the Minister of Energy and Mineral Resources No. 50 of 2018 on Mineral and Coal Mining Business Operations
	Emission standard: Minister of Environment and Forestry Decree No. 15/2019
	Supporting Policies: • Government Regulation No. 96 of 2015 on Facilities and Incentives in Special Economic Areas • Government Regulation No. 9 of 2016 on Income Tax Facilities for Investments in Certain Business Fields and/or in Certain Regions (Tax Allowance). • Regulation of the Minister of Finance No. 188 of 2015 on The Exemption of Import Duty on the Import of Machinery and Items and Materials for Industry Development or Development in the Framework of Investment • Regulation of the Minister of Finance No. 150 of 2018 on Giving Facilities for Reducing Tax Income (Tax Holiday).
Malaysia	Emission standard: Environmental Quality (Clean Air) Regulations 2014 for Heat and Power Generation
Myanmar	Foreign direct investments are allowed in large-scale mineral exploration and production only, but not allowed in medium and small-scale production.
	To invite more local and foreign investments in coal to promote environmental-friendly and advanced coal production technologies
	To focus coal production to fulfill domestic coal demand for industrial use and electricity generation

[10]The AMS country report in the 17th AFOC Council Meeting (April 2019); Indonesia presentation (Future Policy of Coal Utilisation) in the 18th AFOC Council Meeting (July 2020)

<table>
<tr><td></td><td>To promote CCT technology for low-grade coal (lignite and sub-bituminous) and its upgrading technology</td></tr>
<tr><td rowspan="2">Philippines</td><td>The Philippine Conventional Energy Contracting Program (DC2017-09-0010):
• Transparent and competitive system for awarding service and operating contracts for the exploration, development, and production of the country's coal resources
• Nomination and publication of applied areas
• Application for Coal Operating Contracts (COC) at any given time</td></tr>
<tr><td>Coal Mine Safety and Health Rules and Regulations (DC2018-12-0028):
• Issued to make the coal mine safety and health rules and regulations more applicable to present local coal mining conditions, compatible with the provisions of the ILO C176, the Dept. of Energy has repealed the coal mines safety rules and regulations (BED DC No. 1 series of 1978)
• To ensure the safety and health of all workers involved in the coal mining operations in the Philippines</td></tr>
<tr><td rowspan="5">Thailand</td><td>Environmental and Public Acceptance is the most concern</td></tr>
<tr><td>Support the use of Clean Coal Technology in strengthening sustainable development and energy security in parallel with expanding public acceptance and improving coal image</td></tr>
<tr><td>Domestic coal is not allowed to be exported</td></tr>
<tr><td>Imported tax deduction for Clean Coal Technology</td></tr>
<tr><td>New Power Development Plan will be launched soon (likely After April to May 2019)</td></tr>
</table>

On a regional scale, Coal and Clean Coal Technology (CCT) is one of the programme areas under APAEC Phase II. Key strategies under this programme include promotion of the role of CCT and CCUS towards energy transition and low carbon economy, the conduct of outreach to advance the regional actions to enhance the public awareness of CCT, facilitate investment and partnership on CCT, and advance CCT research, development, and innovation.

In promoting the role of CCT and CCUS towards energy transition, the region seeks the advancement of CCT and low emission technologies as potential solutions to support the global action on climate change while ensuring a stable energy supply in the area.

Under this programme, the adoption of more advanced coal technologies such as cofiring technologies, integrated gasification combined cycle (IGCC), coal upgrading, coal conversion technologies, CCUS, flexible operation shall be reviewed in terms of technical and economic feasibility through engagement with the region's key stakeholders.

Chapter 4: The Present Status and Long-term Perspectives of Power Generation in ASEAN

Toward the long-term temperature goal of the Paris Agreement to hold global average temperature increase to "well below 2°C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels", it is crucial for every country to go through the energy transition toward carbon neutrality in the foreseeable future. With the massive cost reduction of RE that the world has experienced in recent years, RE is now in the center of all fuels and generation sources. It provides minimum environmental impacts and economic benefits to the respective communities and the world. However, it is also known that massive RE integration would cause grid fluctuation and associated issues if no appropriate measures are taken. Not only emerging countries but also some developed countries have yet to determine the optimum long-term actions in addressing associated issues. It is quite understandable since paradigm-shift such as RE integration is a one-time-only experience for any part of the globe. Every country has its own energy and electricity situation that would affect the respective energy transition pathways.

In summary, the global target of energy transition and carbon neutrality to cope with climate change is being shared and recognised. However, the pathways to reach the goal would be different as countries have their own social and economic conditions and energy situation. So, the initial step of prime importance in this context is to identify the currently envisaged pathway and whether, by whatever means and to what extent, mechanisms and measures would be required to sustain grid stability and sustainable electricity supply.

JCOAL has recently developed GFI (Grid Fluctuation Index) that does not require a complicated analytical process, expert software, etc[11]. The method can determine when and to what extent a grid would possibly experience fluctuation and how the energy transition path would be. By calculating as a reference and plotting it with timelines, baseload generation capacity, or mid-merit generation capacity with the standard energy and electricity data, GFI can help the establishment of national policies and measures that can prevent and/or minimise the negative impact of RE integration accordingly. GFI is suitable for policymakers and the national utilities to foresee how the energy

[11] GFI was originally developed by Dr. Kazuyuki Murakami, Senior Material Scientist and Program Manager, R&D Department, JCOAL. He is a team member of JCOAL for the ACE-JCOAL Cooperation.

transition will proceed according to the present national scenario without any specific measures, further discussing and considering any desired measures to be taken.

4.1 Grid Fluctuation Index (GFI)

To analyse the load fluctuation situation of the power system, all factors such as power generation of each power source, power transmission, substation, distribution to consumers, power demand, weather, etc. are required as shown in Figure 6. The energy flow and its bottle-neck behavior must be investigated in detail with the above parameters. Therefore, it is essential to have a total set of data for analysis, specialised tools for analysing them, and advanced expertise in research. Normally, such advanced analysis is available only to the electric power companies or related organisations that have jurisdiction over the grid. For other parties, there are little chances to know the load fluctuation situation and they have difficulties predicting future load fluctuations.

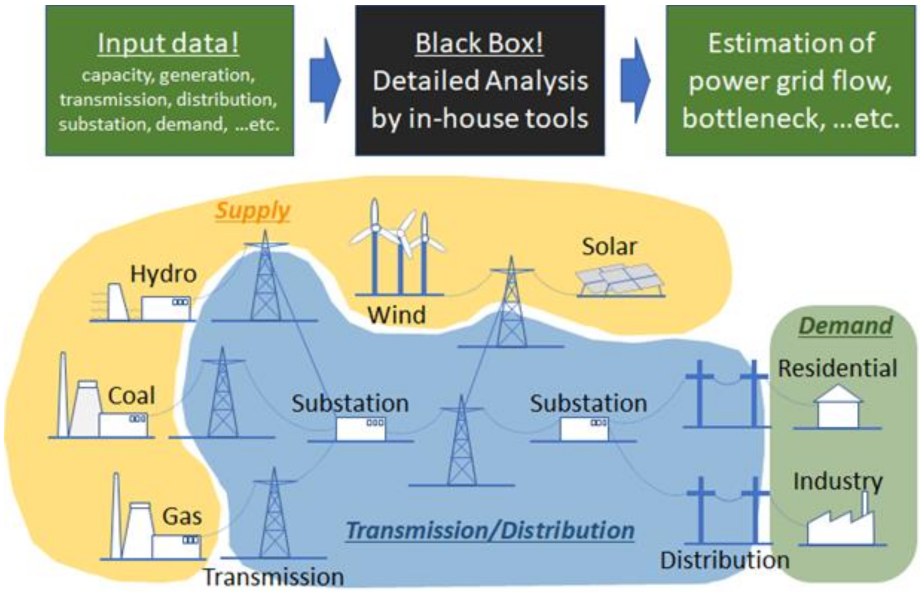


Figure 6 Grid Fluctuation analysis – conventional (Source: California ISO[12])

As the introduction of renewable energy progresses worldwide, the phenomenon that daily fluctuations increase in each country is getting attention, and discussions on the duck curve have become important.

[12] http://www.caiso.com/Pages/default.aspx, 2015

JCOAL has been recently working on developing a method for predicting and evaluating the load fluctuation situation of the power system in a straightforward process. As an index showing the load fluctuation situation, the slope of the daily load fluctuation curve is regarded as a parameter of the fluctuation, and the number divided by the total capacity of the grid is called the Grid load Fluctuation Index, GFI as shown in Figure 7.

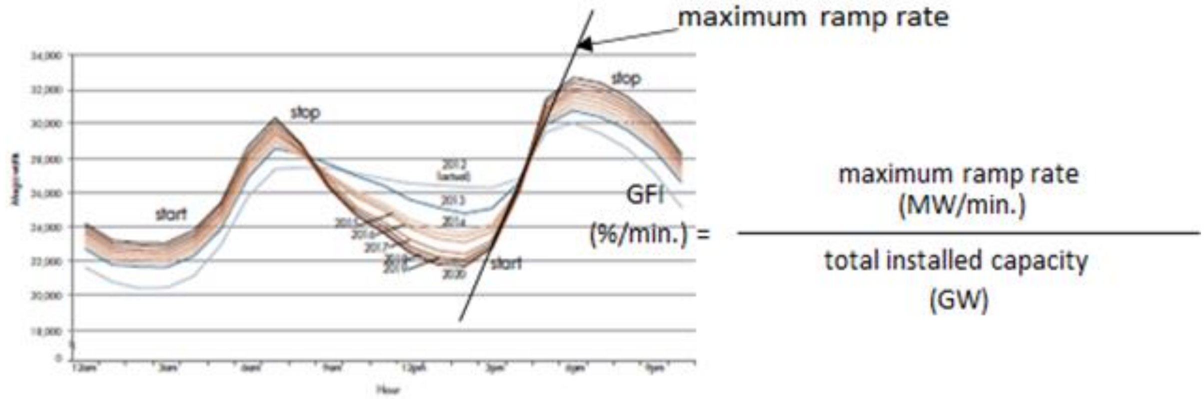


Figure 7 Grid Fluctuation Index (GFI) (Source: JCOAL)

Specifically, the coordinates of the position with the maximum slope are picked up from the country's load curve that would be available in the public domain. Figure 8 is an example of India, the maximum slope part at night is divided by the total installed capacity of the grid for obtaining its GFI.

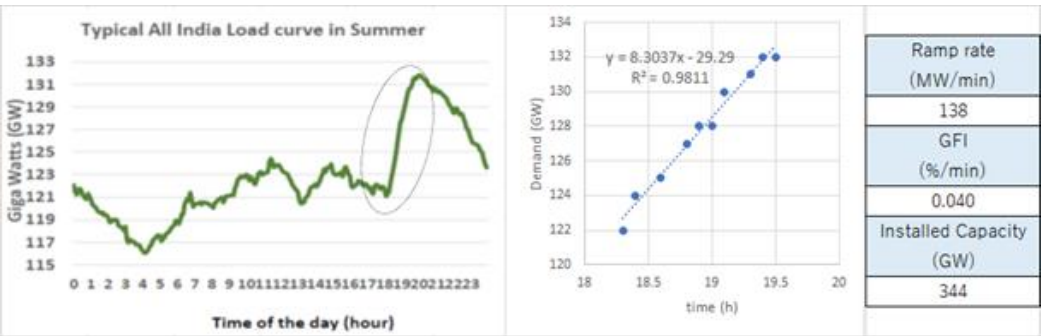


Figure 8 Example of GFI Calculation from Duck Curve (Source: CEA[13])

If a load curve is available, it is possible to calculate the GFI directly, however, there are cases where such data cannot be obtained from the public domain. In such cases, general data such as installed capacity and power generation would help us to identify the potential future grid load fluctuation. As the analytical data for the prediction herewith, "International Energy Outlook 2019" supplied on the website of the US EIA were used for multivariate regression analysis with GFI obtained from the load curve data of the country of publication. The method used is PLS, the Partial

[13] Presentation at the FY2020 CEA-JCOAL Workshop (virtual) on 25 January 2021

Least Squares method[14], which is used when the explanatory variables are collinear. As a result of the analysis, the energy availability factors of coal-fired power, nuclear power, total renewable energy, and solar power were adopted as multiple regression variables. The PLS regression equation is shown as follows.

$$GFI = E + w_1X_{coal} + w_2X_{renew} + w_3X_{nuclear} + w_4X_{solar}$$

Where, X_{coal}, X_{renew}, $X_{nuclear}$, X_{solar} are the availability factors of coal, total renewables, nuclear and solar, respectively. E and W_1 to W_4 are the residual error and each coefficient, each value is E=-0.1258, w_1=0.00147, w_2=-0.00025, w_3=-0.00014, w_4=0.00706.

The analytical results of the main countries indicated in the EIA data are shown in Figure 9. In several countries, GFI is found to increase year by year as its economic growth proceeds. By plotting the forecasted baseload generation sources share, it is expected that India would have the most severe situation in all four countries shown here from 2020 to 2050. Countries with a high share of hydro and gas generation are supposed to have no major issues of grid flexibility in the foreseeable future.

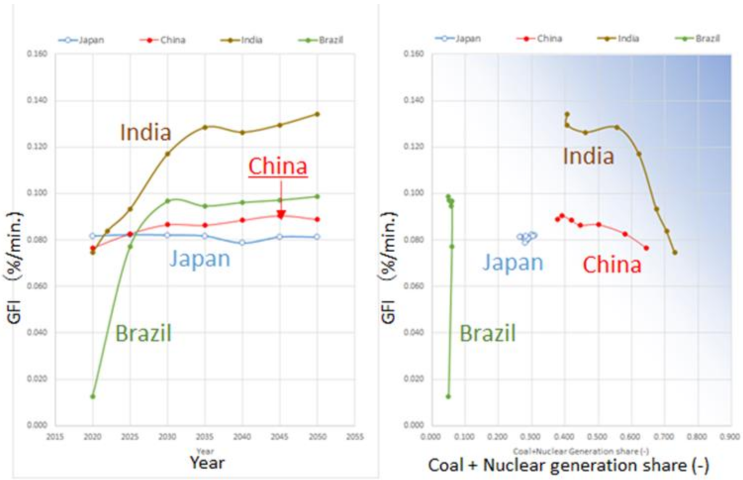


Figure 9 Analytical result of the estimated GFI for several countries (Source: JCOAL)

Japan shows a stable GFI in the next three decades. Only a slight increase of GFI in total generation will be expected despite that RE installation is continuing. The availability factor of RE is relatively low, and gas power will play a role to compensate for grid flexibilisation.

Currently, China has the largest grid in the world and keeps its position in the future. GFI of China may be in a slight upward trend with an increased total capacity of primarily RE and other

[14] For example, "Handbook of Partial Least Squares Concepts Methods and Applications" Vincenzo Esposito Vinzi et al.

generation sources. Coal is still the primary source of power generation, but its share is decreasing. India on the other hand, is an expanding power grid in which coal plays a dominant role.

The government of India pursues a policy of RE installation while decreasing the share of fossil fuels. GFI of India will increase remarkably after 2030. If any effective measures are not going to be taken, flexibilisation issues will become apparent.

GFI of Brazil will increase in 2025 then remain at around 0.1. Even GFI is approximately 0.1, the same level as China, grid fluctuation is not severe because hydropower is the main source.

A GFI analysis was conducted based on the electricity plans of ASEAN countries up to 2040 The results are shown in Figure 10. GFI is closely related to the availability of coal-fired power since coal is the primary energy source in the ASEAN region. GFI of several countries will be increasing from 2030, such countries are Indonesia, Malaysia, the Philippines, Vietnam. Meanwhile, Singapore and Thailand seem to have lesser opportunities for grid fluctuation. Brunei, Laos, Cambodia, and Myanmar despite relatively smaller grid sizes will also have fewer concerns about grid fluctuation.

As mentioned, the grid scales of Indonesia, Vietnam, the Philippines, and Malaysia are expanding without any significant change in the power supply shares. These countries would have major concerns about grid fluctuation after 2030 based on the GFI analysis.

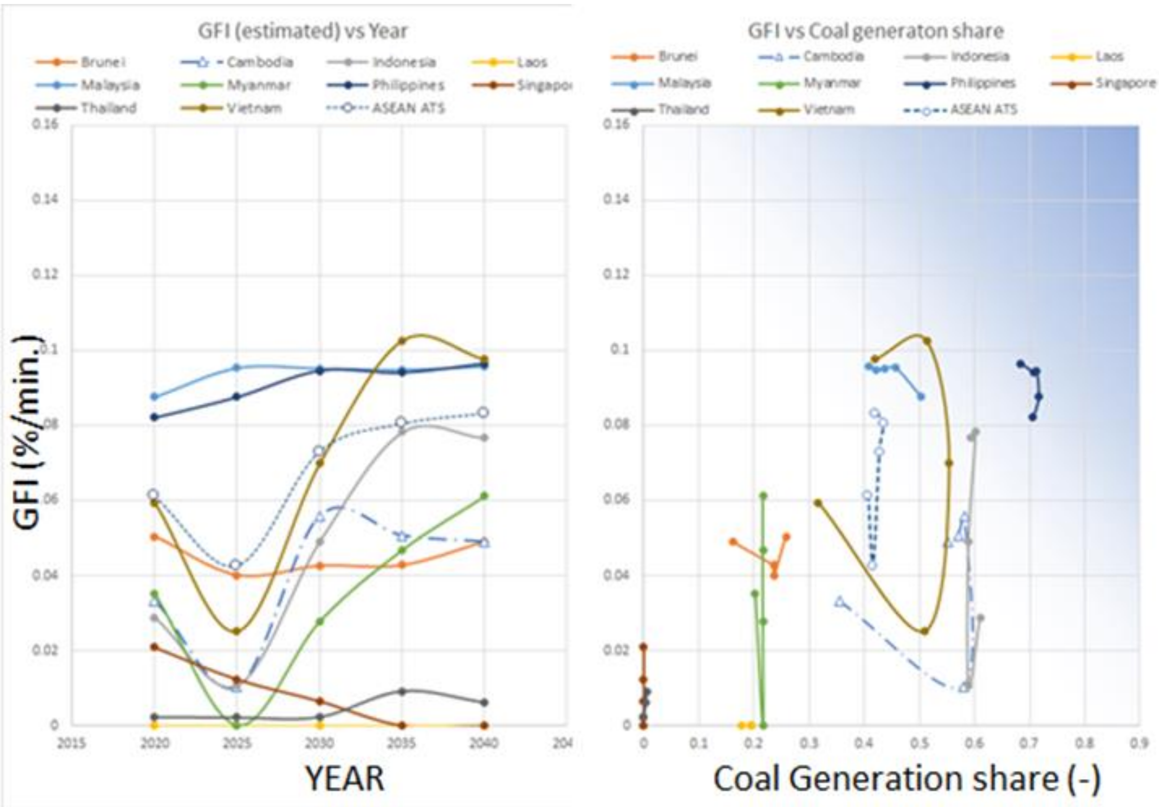


Figure 10 Analytical result of the estimated GFI for ASEAN (Source: JCOAL)

For Indonesia, GFI is projected to surge up after 2035. Flexibilisation on its coal-fired power plants would be one of the significant options to address the possible fluctuation of the national grid.

The GFI of Malaysia will stay on at a relatively high level at 0.09-0.1. Coal accounts for less than 50% of the generation mix. The GFI of the Philippines will remain at a relatively high level at approx. 0.08 to 0.1, which would require flexibilisation measures as well. High dependence on coal-fired power generation is deemed to be a significant factor that caused it. The local grid system fluctuation might occur more severely if the more flexible power supply sources such as gas and/or hydro are less available.

The GFI of Vietnam will stay at relatively low level up to 2025, following a sharp increase toward 2035 as installed capacity will continue to increase. Note that as of 2040, coal will account for less than 40% of the generation mix for Vietnam.

As described in this section, GFI analysis is a helpful tool for considering future flexibilisation measures for a country that needs to expand its energy supply with affordable and reliable costs.

Chapter 5: Flexible Operation Technology and Techniques for Coal-Fired Power Plant to Bolster Grid-connected Renewable Energy Integration

As discussed in previous chapters, a massive renewable introduction is imperative in the context of globally shared actions to address climate change. Yet, without appropriate measures, it would cause grid fluctuation that may work even against sustainable and efficient electricity supply.

To address the issues proactively to control grid fluctuation to the minimum extent possible, a comprehensive set of measures in terms of market system formulation/transformation digitalisation will be required in addition to the flexible operation of the existing power plants and introduction of new technology for the generation, transmission, and storage.

This chapter mainly outlines the ongoing flexible market system formulation and relevant policy reforms in Japan and comparable market systems in a few other countries. It will be a valuable reference for ASEAN stakeholders to obtain a comprehensive view of materialisation during the energy transition.

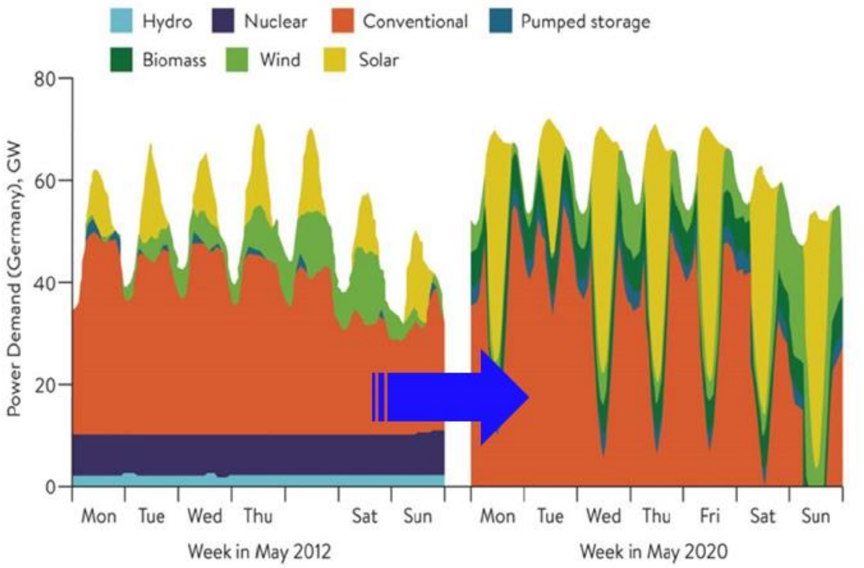


Figure 11. Envisaged electricity supply curves by fuel (week wise) upon renewables integration (Source: IEA-CCC[15])

[15] Presentation of IEA-CCC at AFOC CCT Workshop in Bangkok, August 2019

5.1 Electricity supply and demand balancing mechanism with control measures

Japan has been divided into two areas with different frequencies, that is, the reference frequencies of 50Hz in East Japan and 60Hz in West Japan[16]. In the respective areas, the frequency is being controlled in the range of ± 0.2 to ± 0.3 Hz to the reference frequency. It is managed by controlling the amount of generated power at the same rate while the supply-demand situation would change every moment. Therefore, the general power transmission and distribution business operators in each area provide reserves to address supply and demand fluctuations in each time cycle and prediction errors in demand and renewable energy output in a short-term cross-section and balance supply and demand and control the frequency.

On the generation side, frequency control is undertaken by thermal and hydroelectric power plants. Among these, hydropower has seasonal restrictions. In other words, the output balance required for frequency control is limited by flood conditions. Accordingly, thermal power plants are the primary balancing sources to address the required frequency control throughout the year.

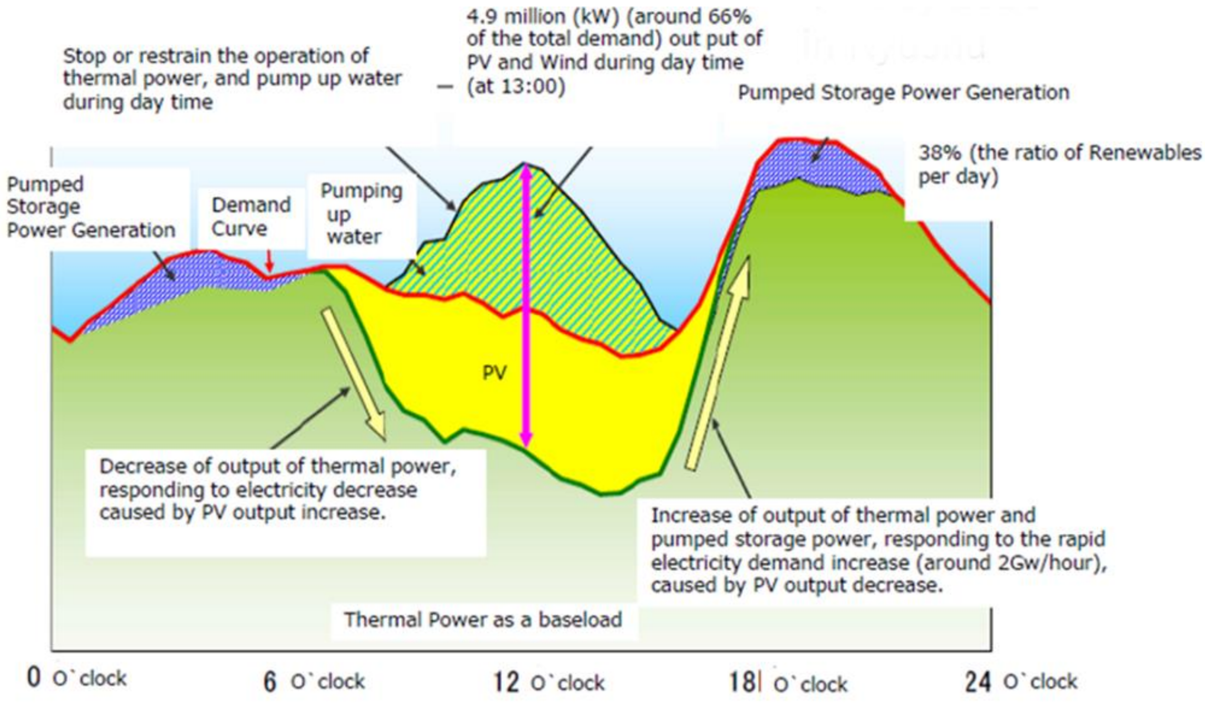


Figure 12. Example of Daily Load Curves with Operation of Flexible Power Sources (Source: Kyushu EPCO[17])

[16] Japan's "One country, two frequencies" has a historical background. It originates to the late 19th century when first generators were introduced in Japan.
[17] Contribution of Kyushu EPCO for the presentation by JCOAL at "Indian Power Stations (IPS) 2017", the annual conference by NTPC India held in Delhi, India in February 2017.

5.1.1 Type of reserve capacity

The following table shows that the types of reserves are classified into three types according to the output response characteristics (activation time and duration). The operating reserve is secured at about 8% of the maximum power demand assumption value on the day before and about 5% on the day, considering the risk of power loss due to supply and demand assumption errors, mechanical failures, etc., and short-term demand fluctuation risks.

In addition, about 3% of the time demand is secured for the spinning reserve as a part of the operating reserve.

Table 3. Classification of Available Reserve[18] Source: OCCTO[19]

Item	Definition	Applicable facility
Spinning Reserve	A supply capacity that can immediately start responding to load fluctuations and a decrease in system frequency when the power is turned off increases the output within about 10 seconds and generates electricity until the operating reserve is activated.	Remaining capacity of generator in free governor mode during a partial load operation
Operating Reserve	Supply capacity that can be started in parallel and within a short time (within about 10 minutes) to take the load and continue to generate power until the standby reserve is started and the load is taken.	・Remaining capacity of the generator during a partial load operation ・ Hydropower and gas turbines waiting to stop
Standby reserve	Supply capacity that takes several hours from startup to parallel and loading.	・Thermal power plant on stand-by

5.1.2 Supply and demand balance and frequency control

Figure 13 shows an image of various controls related to supply and demand balance and frequency, and Table 4 shows multiple control methods for frequency fluctuation components. Demand fluctuations (load fluctuations) in the power system are classified into three types according to the fluctuation components. The controls shown in Table 4 are implemented according to each fluctuation component.

[18] Interim report of the committee on balancing power sources, OCCTO, March 2016

[19] Organization for Cross-regional Coordination of Transmission Operators (OCCTO) is an organization established in Japan in 2015 for the on-going power sector reform and stable and sustainable supply of electricity through overseeing the cross-regional situation and issues around balancing power sources that is crucial for the grid stability. https://www.occto.or.jp/en/index.html

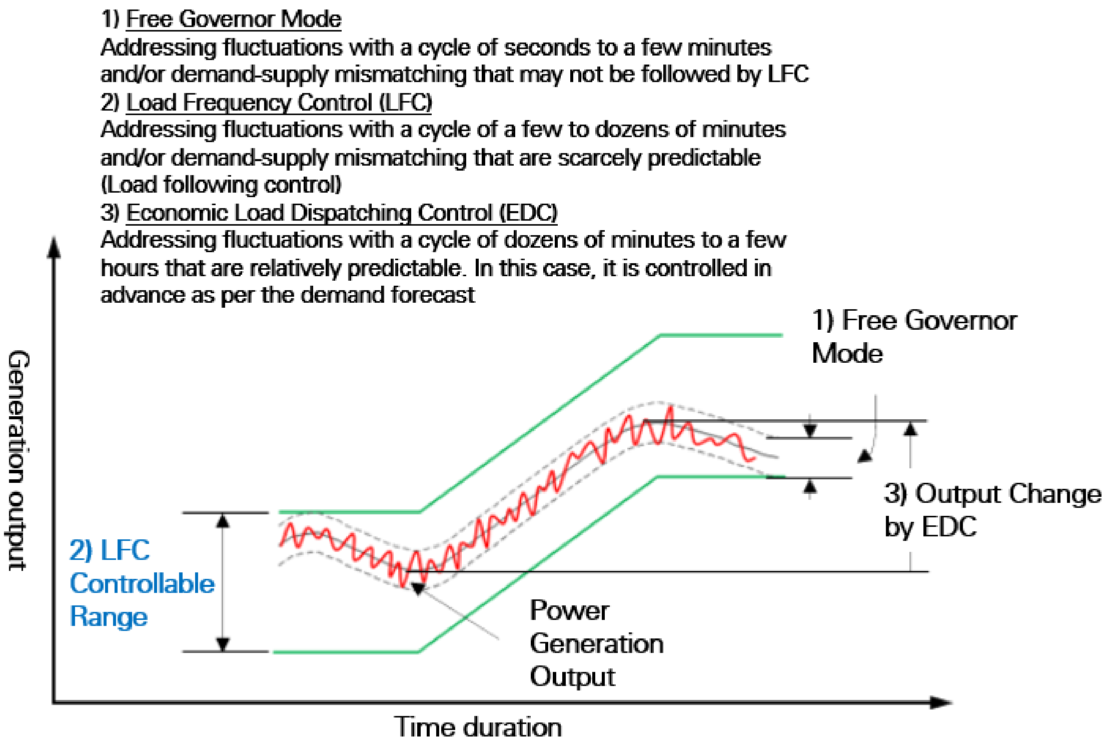


Figure 13. Image of various controls related to supply and demand balance and frequency (Source: OCTTO)

Table 4. Various controls related to supply and demand balance and frequency (Source: OCCTO)

Measures	Description
Free Governor Operation Mode	The system frequency is adjusted by a governor, which is a device that automatically adjusts the amount of steam and water that are the power so that the rotation speed of the generator is maintained at a constant speed regardless of load fluctuations. An operation that increases or decreases the output according to changes.
Load Frequency Control (LFC)	To maintain the frequency of the power system and the power flow of the interconnection line at regular times at the specified values, the amount of frequency change and the amount of change in the interconnection line power due to load fluctuations are detected and the output of the generator is controlled.
Economic load Dispatching Control (EDC)	Control that distributes the load to each power plant (each generator) to achieve the power system's most economical, stable, and rational operation.

5.2 Enhanced roles of balancing power sources for the enhanced power supply and demand control

Japan has relatively recently started unbundling the power sector, and the unbundling has been still developing while the mass introduction of renewable energy power generation is progressing. In this regard, it is deemed that the national mechanism of balancing power sources has become increasingly important.

5.2.1 What are balancing power sources?

Under the simultaneous planned value equalisation system, the power generation company and the retail electric power company match the plan and result in 30-minute units. However, in the actual situation, there would be prediction errors. In addition, there is a gap between power supply and demand due to ad hoc fluctuations and power losses. The supply capacity used by general power transmission and distribution business operators to achieve electricity supply of the same amount simultaneously is called "balancing power sources". The three events that require balancing power sources are shown below.

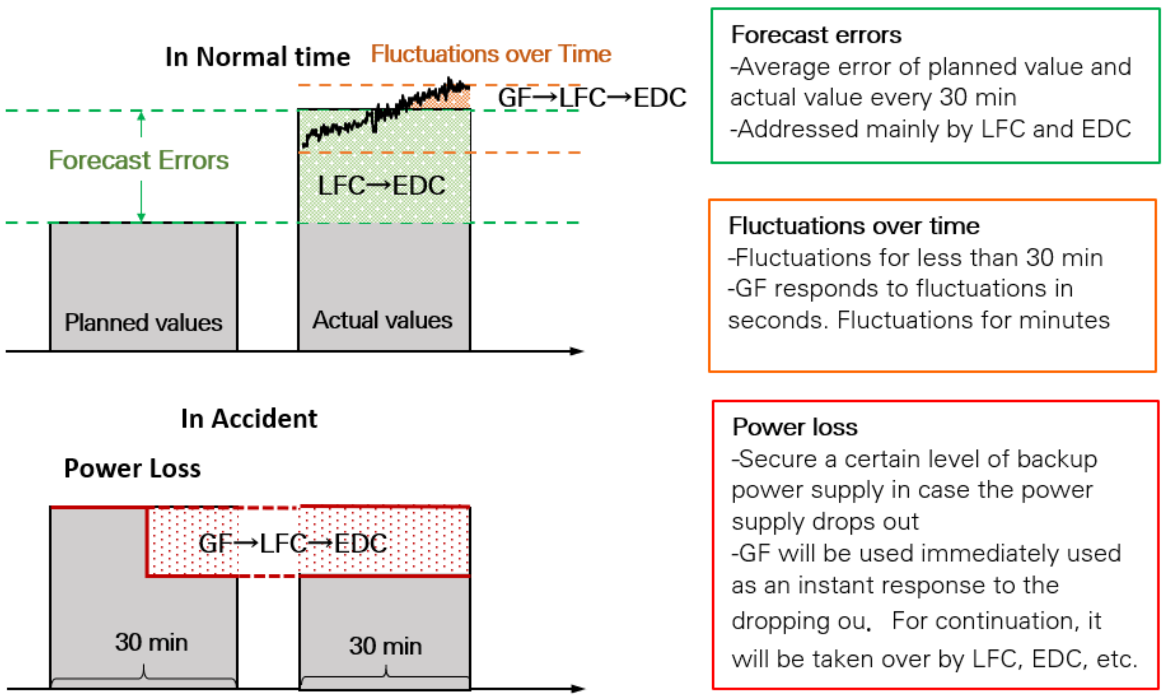


Figure 14. Significant events to be addressed by balancing sources (Source: OCCTO)

Table 5. Events to be addressed through balancing power sources (Source: OCCTO)

<u>Prediction errors</u>

A retail electric power company creates a demand plan by forecasting demand, but since it is not possible to formulate a plan that exactly matches the actual demand, there will be a difference between the forecast and the actual result after GC. This is called "prediction error", and supply and demand are matched by using balancing power sources.

In addition, the difference between the predicted value of renewable energy output and the actual value, which was predicted two days before the actual supply and demand day under the FiT, is also dealt with by balancing power sources.

<u>Fluctuations over time</u>

The actual demand is constantly changing, and the output of renewable energy is also changing from moment to moment. Even if the forecast and the actual result fall in the same 30-minute average value, small fluctuations occur in a time shorter than 30 minutes. This is called "time fluctuation", for which measures of balancing power sources are also taken.

<u>Power loss</u>

In case of power supply sags due to some unpredictable troubles, balancing power sources will address to mitigate the supply-demand gap incurred.

<u>GC (Gate closure)</u>

GC in the balancing market mechanism is the point in time when submission or update of a balancing energy bid for a standard product on a common merit order

5.2.2 Classification of balancing power sources

Figure 15 shows an image of the classification of securing power sources, etc., by general power transmission and distribution business operators. The balancing power sources are the power supply I and power supply II, which are classified into three categories according to the presence or absence of the frequency control function, etc. They are classified into six categories in total.

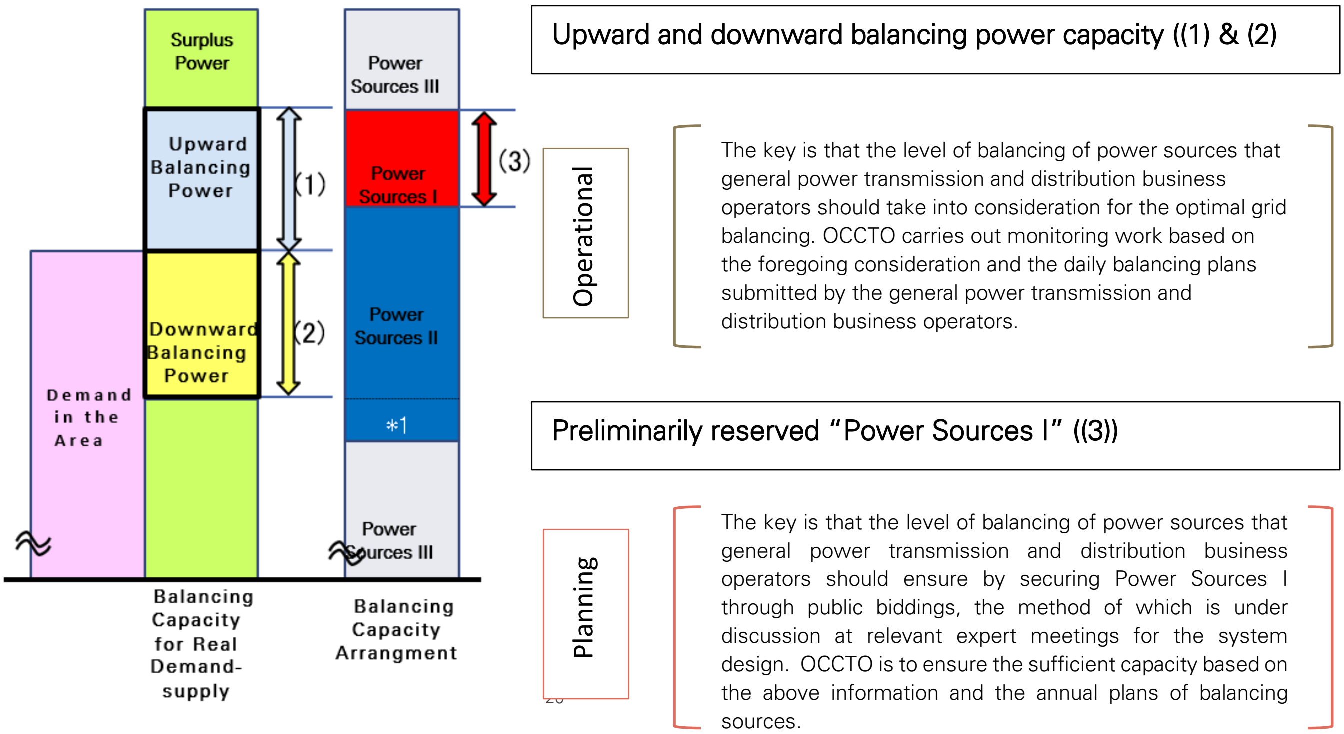


Figure 15. Type classification of power supply, etc. secured by general power transmission and distribution business operators (Source: OCCTO)

5.3 Electricity market (wholesale electricity market, capacity market, supply, and demand balancing market)

Table 6 and Figure 16 is about the composition of the Japanese electricity market and the transaction schedule in the electricity market, respectively. Currently, there is a wholesale electricity market in Japan as a market for trading electricity, and the amount of electricity (kWh value) is traded. In the future, when the capacity market and supply and demand balancing market are created, trading of kW value and ⊿kW value will start.

[20] Power sources I is the sources that general power transmission and distribution business operators do not use for balancing (excluding emergencies).

Table 6. Overview of Japan's Electricity Market Mechanism Design (Source: OCCTO)

Market Type	Roles	Major Market Participants	Envisaged incoming resources
Capacity Market	Transaction of supply capacity (kW value), which is nationally important	Market Authority (Cross-regional coordinating organization)* *Retail Electricity Providers in the case of Decentralised Network	Resources that can suppress demand during peak hours during high demand periods if several times a year (e.g. contracts with on-request temporary power adjustments)
Wholesale Market	Transaction of power capacity (kWh value) that is to compensate supply deficit to balance with demand	Retail Electricity Providers	Resources that can provide planned kWh at low cost while taking time to respond (e.g. economic DR, etc.)
Balancing Market	Compensating the supply-demand gap after the gate is closed, responding to supply-demand fluctuations of less than 30 minutes, and trading of adjustment power capacity (△ kW value + kWh value) for frequency maintenance	Transmission and Distribution Operators	Resources that can respond to frequent commands (eg adjustment power, etc.)

- When trading a part of the kW value in the balancing market, it is difficult to procure the kW value efficiently because there would be multiple procuring entities and procurement markets for the kW value. In addition, the presence of multiple pricing in the kW value reduces the price indexability of the capacity market.
- In this context, it is envisaged as an excellent option to have all the kW values nationally required traded in the capacity market, and then trade all the ⊿kW values required by general power transmission and distribution business operators in the balancing market.
- It is crucial that separate consideration will be made about the scope of kW value traded in the capacity market, securing balancing power sources, and the range and degree of the cost to be borne by operators.

Figure 17 shows the roles and functions of the electricity market participants in the supply and demand market balancing. In the supply and demand market, sellers (power generation companies, aggregators) and buyers (general power transmission and distribution companies) are trading companies with the ability to adjust as products. The seller provides "balancing power (⊿kW)" that meets the market transaction requirements and executes the contract from the one with the lowest bid (called "multi-price auction"). The power resources sellers bring to the market are categorised into generators, batteries, and load equipment.

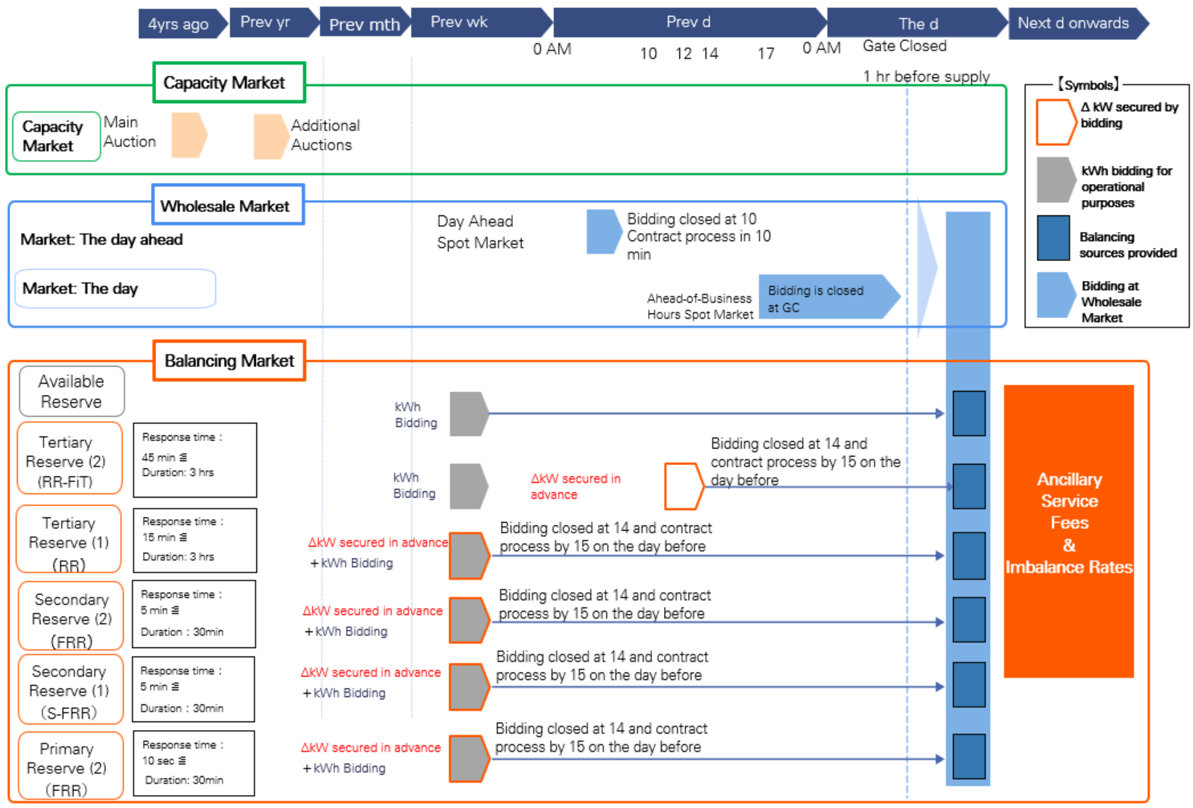


Figure 16. Electricity Market Trading Flow by Type of the Market (Source: OCCTO)

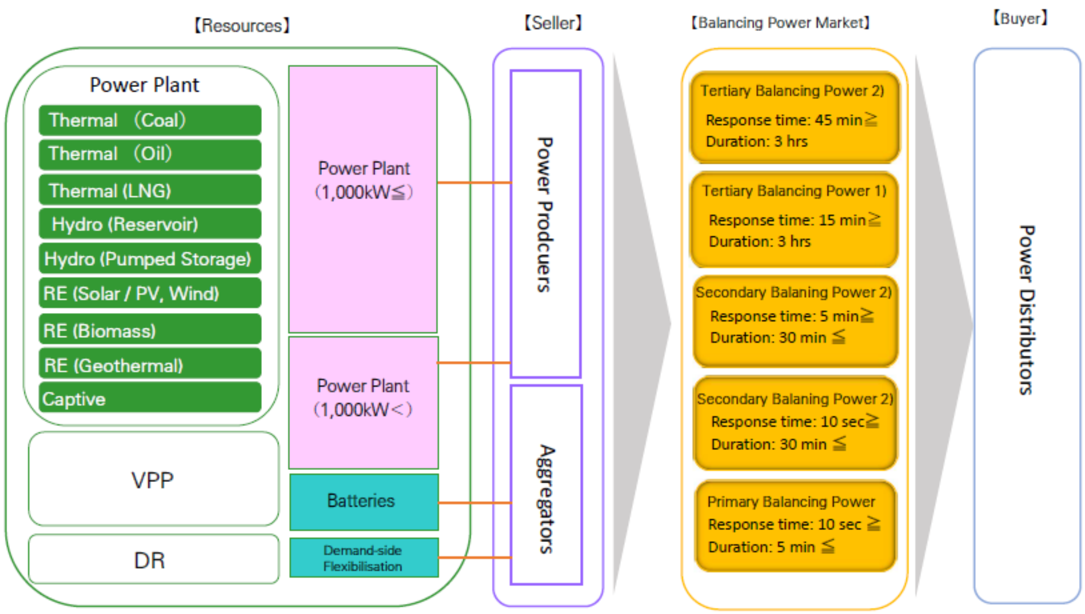


Figure 17. Roles and Functions of the Balancing Market Participants (Source: METI)

The requirements for the products for the supply and demand market balancing are shown below. Currently, five products with different response times, durations, frequency balancing powers, etc., are being considered. In addition, new resources such as demand-on-response (DR) and virtual power plants (VPP) are also expected to be available.

Table 7. List of By-function Product in the Supply-demand Balancing Market (Source: OCCTO)

	Primary Reserve	Secondary Reserve (1)	Secondary Reserve (2)	Tertiary Reserve (1)	Tertiary Reserve (2)
Name in the UK	Frequency Containment Reserve (FCR)	Synchronized Frequency Restoration Reserve (S-FRR)	Frequency Restoration Reserve (FRR)	Replacement Reserve (RR)	Replacement Reserve -for FIT (RR-FIT)
Dispatch & Control	Offline (Self-end Control)	Online (LFC Signal)	Online (EDC Signal)	Online (EDC Signal)	Online
Monitoring	Online (Partial offline arrangement is possible	Online	Online	Online	Online (Dedicated)
Lines	Dedicated Lines (No need if monitoring is conducted offline)	Dedicated lines	Dedicated lines	Dedicated lines	Dedicated online system or Offline Simple Command System
Response Time	10 sec. ≦	5 sec. ≦	5 sec. ≦	15 sec. ≦	45 sec. ≦
Duration	5 min.≧	30 min.≧	30 min.≧	Product Blocking Time (3 h	Product Blocking Time (3 hrs)
Resources in Parallel	Required	Required	Voluntary	Voluntary	Voluntary
Dispatch Intervals	N/A (Self-end Control)	0.5 sec. to Dozens of seconds	1 min. to a few minutes	1 min. to a few minutes	30 min.
Monitoring Intervals	1 sec. to a few seconds	1 to 5 sec.	1 to 5 sec.	1 to 5 sec.	Under consideration
Providable Power Capacity (Tradable maximum power capacity)	Power capacity with changeable range of output in 10 sec. (Upper limit: GF width in terms of equipment performance)	Power capacity with changeable range of output in 5 min. (Upper limit: LFC width in terms of equipment performance)	5 min. ≦	15 min. ≦	45 min. ≦
Tradable minimum power capacity	5MW (1 MW if monitoring is conducted offline)	5MW	Power capacity with changeable range of output	Power capacity with changeable range of output	Power capacity with changeable range of output
Traded unit	1kW	1kW	1kW	1kW	1kW
Upward / Downward	Upward / Downward	Upward / Downward	Upward / Downward	Upward / Downward	Upward / Downward

Note: It has been under consideration and discussion initiated by the Government of Japan whether such dedicated lines and simple command systems can be connected to the system of the CDCC (Central Dispatch Control Center). In the meantime, the simple command system is used to send and receive uplink information. As of now, it is envisaged that the entry of DR will be a major part of it, which will not affect the calculation of area demand value. However, there is a possibility that the accuracy of area demand calculation may decrease due to the connection of power generation systems such as VPP in the future. Therefore, consider setting an upper limit on the connection capacity that does not require uplink information.

5.4 Overseas cases of demand-on-response (DR) mechanism

Table 8 summarises the demand-on-response (DR) market mechanism in France, while Figure 18 shows the example of introducing DR from PJM of the United States.

In France, as a measure to secure kW for peak demand, transactions are being actively carried out in the AOE program (equivalent to Japan's power source I'), a market dedicated to DR. On the other hand, transactions as balancing power have a transaction record as Primary Reserve (equivalent to primary) and Rapid Reserve (equivalent to tertiary ①). In the US PJM, the capacity market occupies the majority, and there are few transactions in the supply and demand balancing market (Ancillary Services).

Table 8. Overseas DR Market: The Case of France (Source: OCCTO[21])

Market Type	Product	Reference Year	Product name in Japan	Bid Scale	Winning Bid Scale	DR Share
Balancing Market	Primary Reserve (R1)	2018	Primary Reserve	530 MW	561 MW	75 MW
	Rapid Reserve	2019	Tertiary Reserve (1)	1,000 MW	1,500 MW	Appox. 50% of the winning scale
	Complementary Reserve	2019	Tertiary Reserve (2)	500 MW	70 MW	-
Capacity Market	Capacity Market	2019	Capacity Market	89.3 GW	-	1.7 GW
	AOE (DR call for tender)	2018	DR Dedicated Market	2.2 GW	733 MW	733 MW

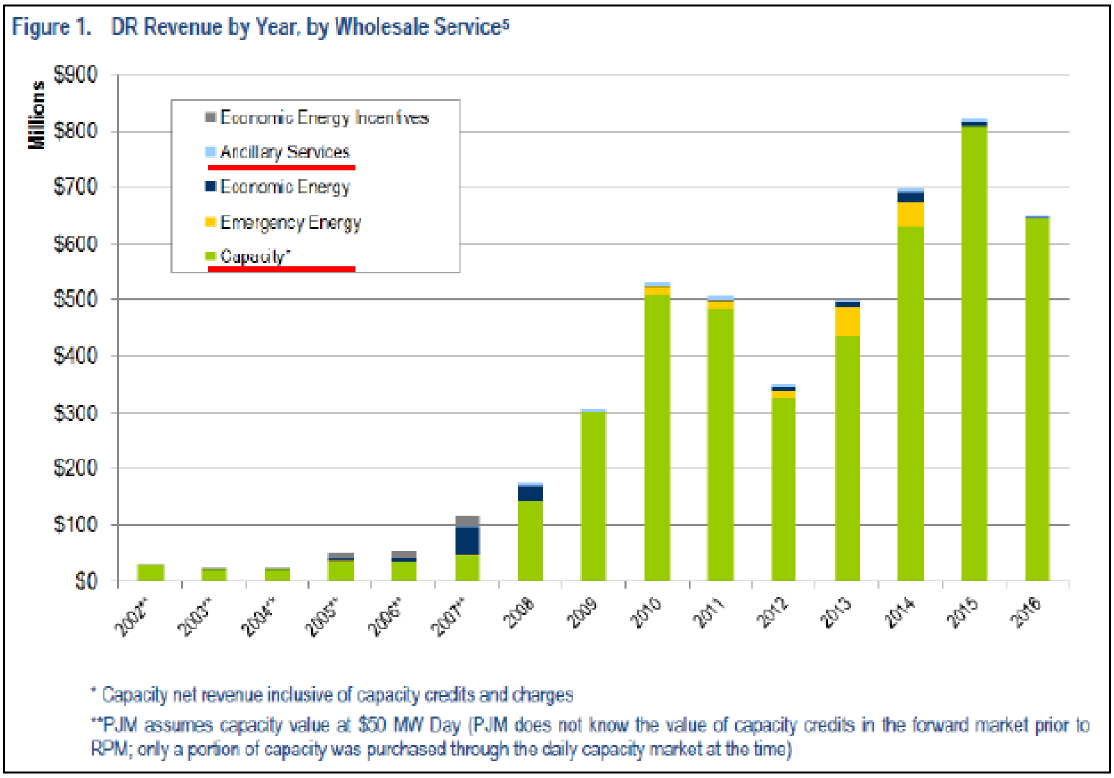


Figure 18. Overseas DR Market: The Case of the United States (Source: OCCTO)

[21] The table was made based on the information available at RTI (France)'s website and the original interviews and surveys OCCTO conducted in 2018.

5.5 Flexibilisation at a coal-fired power plant

Flexible generation sources consist of conventional power plants and dispatchable renewable generators such as biomass or geothermal plants. The fundamental requirement: They must have the ability to ramp up rapidly and ramp down the output to follow net load, quickly shut down and startup; and operate efficiently at a lower minimum level during high renewable energy output periods

Coal-fired power plants, primarily pulverised coal-fired power plants, have a time delay for pulverising coal and a time delay due to the large heat capacity of the boiler body and used to be deemed to unserved as flexible power sources. However, a coal-fired power plant can serve as a flexible power source by conducting flexible operations as long as appropriate measures are taken.

The points of flexibilisation include improvement of load change rate, reduction of minimum coal combustion load, and shortening of startup time.

The first step in improving the load change rate is to improve the coal output characteristics of the mill. In the case of a vertical mill, the classifier at the outlet of the mill has been changed from a fixed type to a rotary type, the roller has been changed from a spring type to a hydraulic type, and the airport has been changed from a fixed type to a rotary type and increasing the mill motor capacity and applying an inverter, and the control device has also been improved. By doing so, the coal output characteristics are improved. In the case of a ball mill, a method of controlling the amount of coal held in the mill by adjusting the coal level is also conceivable. Figure 19 shows a schematic diagram of a vertical mill and a ball mill.

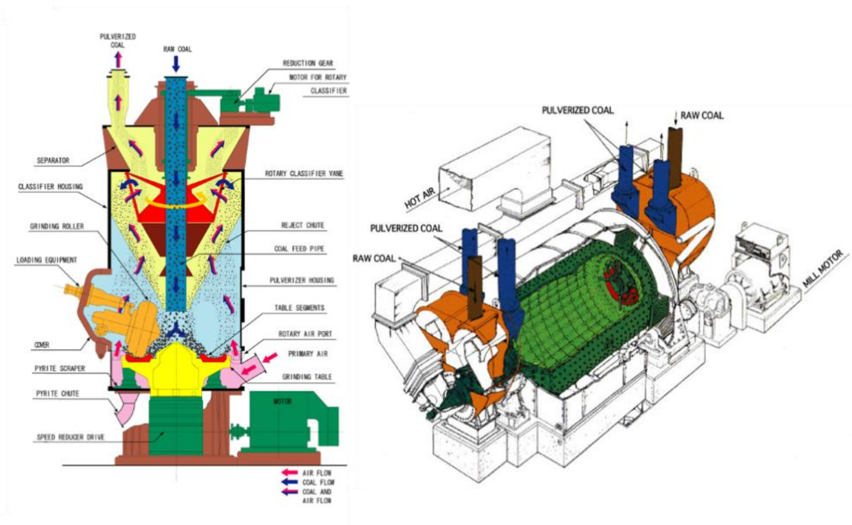


Figure 19. Overview of Vertical Mill and Ball Mill (Source; IHI[22])

[22] IHI Corporation, Japan. https://www.ihi.co.jp/en/

Improvement of steam temperature control is also essential, and as superheated steam temperature control, a method of increasing the number of superheater spray stages from 2 stages to 3 stages and finely controlling them is adopted. In the reheater steam temperature control, the reheater gas recirculation fan method, parallel path damper method, reheater inlet water spray method, etc., are adopted. However, to prevent efficiency decrease, the parallel path damper method is adopted. Alternatively, the reheater bypass steam spray method may be adopted. An example of a system for improving steam temperature control is shown in Figure 20.

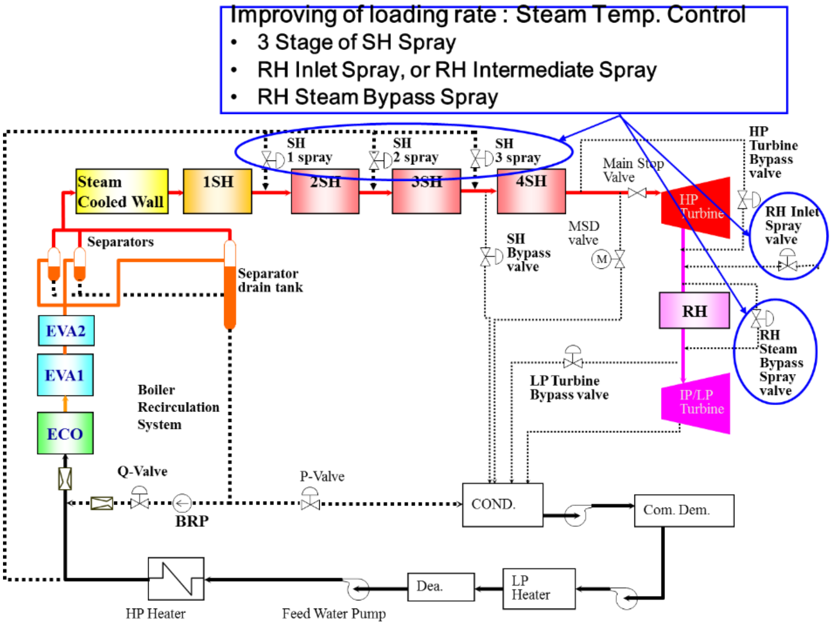


Figure 20. A Case Example of Steam Temperature Control Improvement (Source: JCOAL)

It is also important to reduce the minimum load for coal combustion and expand the operating load range. In a pulverised coal-fired boiler, pulverised coal crushed by a mill is transported to a burner by air. Therefore, even if the boiler load is low, the amount of air for transportation is secured, so that the amount of air cannot be reduced, the concentration of pulverised coal in the burner portion is diluted, and combustion becomes difficult. To solve this, it is necessary to separate the pulverised coal in the burner portion into a high concentration side and a low concentration side to improve combustibility. This burner is the Wide Range Burner, and it is possible to reduce the minimum load for coal burning. In addition, since the burner turndown is widened, the load band that does not require the start and stops of the mill is enlarged, and the operability is improved.

Figure 21 shows a schematic diagram of the Wide Range Burner. In addition, the figure shows an enlarged example of turndown when the Wide Range Burner is adopted.

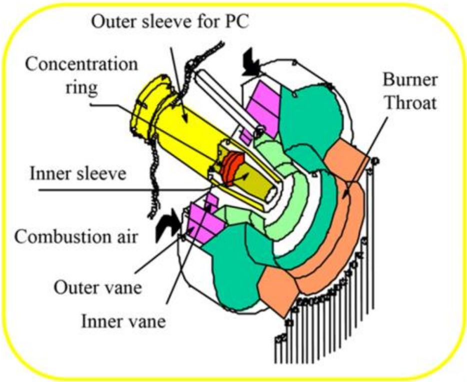


Figure 21. Overview of the Wide Range Burner (Source: IHI)

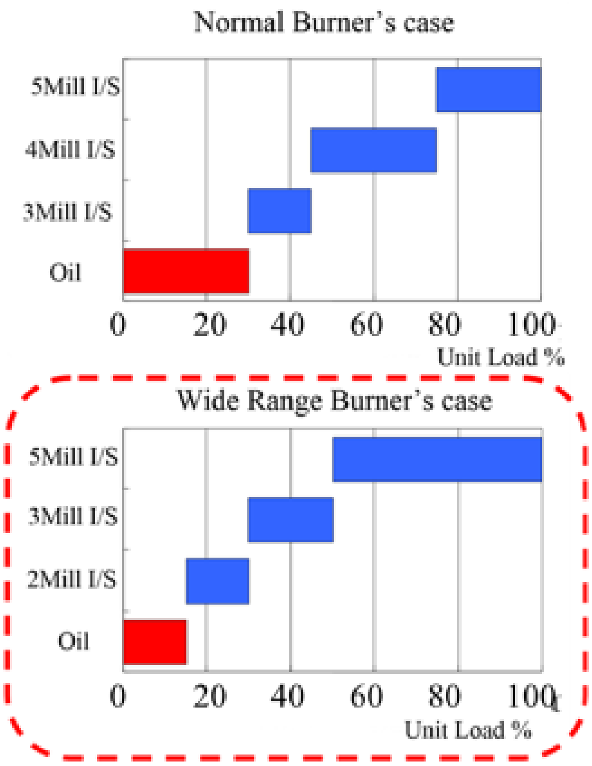


Figure 22. Turndown expansion example with wide range burner (Source: IHI)

Attention is to be paid that as the load decreases, the efficiency also decreases. In this context, a comprehensive judgment is required to determine whether flexibilisation measures are taken before implementation. In a constant pressure operation plant, adopting a transformer operation makes it possible to suppress a decrease in efficiency at the time of partial load.

When installing a denitration device such as a selective catalytic NOx reduction device (SCR), if there are restrictions on the gas temperature used, it is necessary to install an economiser bypass gas system to secure the gas temperature required for using SCR even when the load is low.

Since it is required to start and stop frequently for flexibilisation, it is important to shorten the start time, for which it is necessary to raise the steam temperature quickly, and it is important to plan the startup bypass system.

The startup bypass system includes a superheater bypass and a turbine bypass. The superheater bypass makes it possible to obtain high-temperature steam early by extracting low-temperature steam at startup from the middle of the superheater and steaming the superheater tube. Turbine bypass is a bypass line that directly connects the steam at the turbine inlet to the condenser. The steam that bypasses the high-pressure turbine passes through the reheater to cool the reheater, bypassing the low-pressure turbine and connecting it to the condenser. There is a high and low-pressure turbine bypass. Since the high-low pressure turbine bypass can cool the reheater tube, a large amount of fuel can be input, leading to a reduction in startup time. Which activation bypass system to use is determined based on installation cost and operability. Figure 23 shows an example of the startup bypass system.

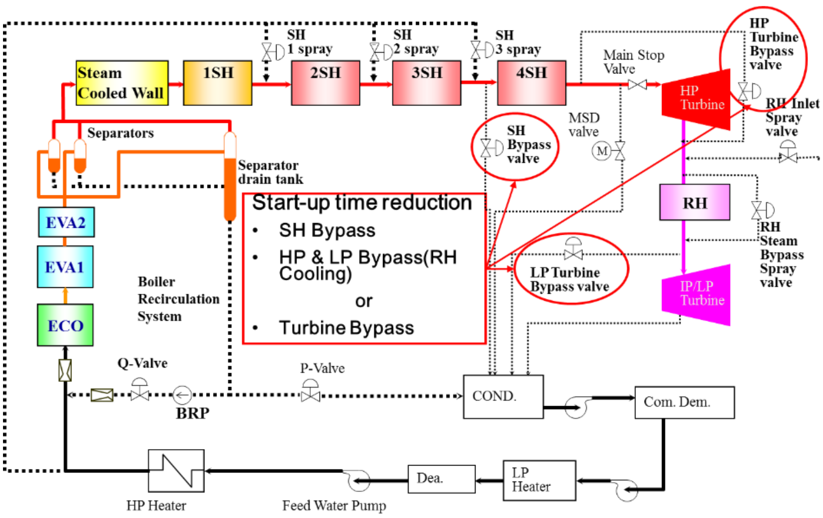


Figure 23. An Example of Start-up Bypass System (Source: JCOAL)

As clarified in the preceding chapter, load followability in existing power plants is crucial to sustaining grid stability during massive renewable integration. A coal-fired power plant is not an exception and as shown, it is just possible as long as appropriate measures are taken so that any inconveniences to the operation and production of power at the plant will be minimised while contributing to the grid stability. Improving the load change rate, reducing the minimum loading rate of coal combustion, and shortening the startup time is possible by modifications and modified operations related to many equipment and facilities such as mills, burners, boilers, water/steam systems, air/gas systems, and turbine-related equipment as well as a control instrument. Consultations with the original manufacturers of the equipment are highly recommended to identify the optimal measures for sustainable flexibilisation at the concerned power plant.

Chapter 6: CCT and HELE for environmental compliance of coal-fired power plants.

6.1 Working on regional and global environmental conservation through CCT and HELE

For the continuous use of coal, it is important to take measures to improve the environment at the local and global levels. Figure 24 shows the technical system diagram of CCT and HELE. The left side is mainly related to regional environmental measures, and the right side is related to global environmental measures.

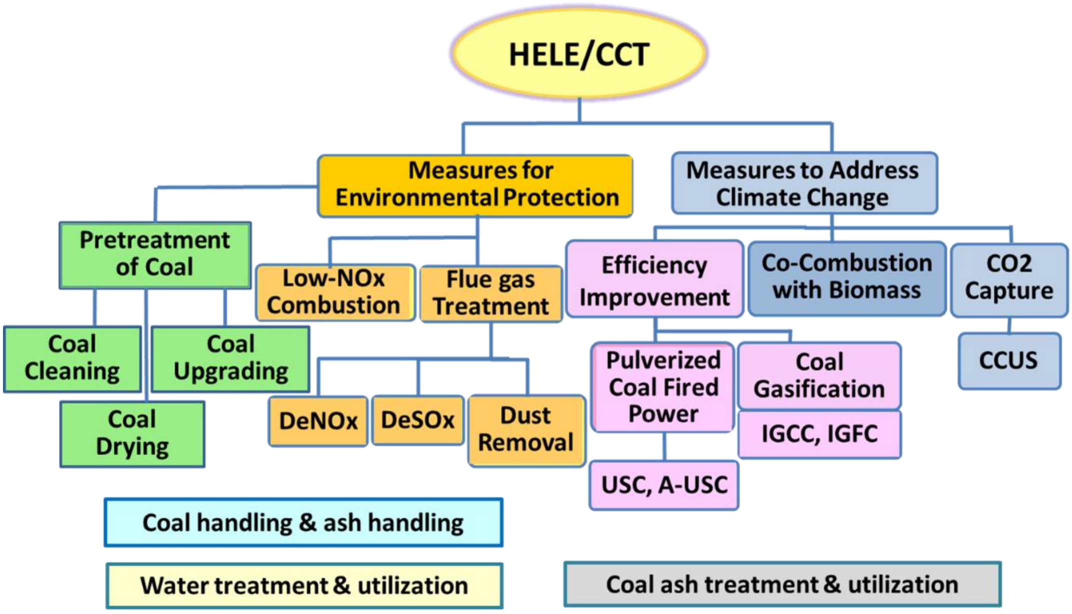


Figure 24. Overview of HELE / CCT (Source: JCOAL)

Reduction of dust, SOx, and NOx is particularly important as a regional environmental measure, and many reduction measures are being implemented worldwide. As a measure against dust, a dry electrostatic precipitator (ESP) is generally used. When strengthening dust countermeasures, it is necessary to expand the installation space, but by adopting a moving electrode type electrostatic precipitator (MEEP), it is not required to expand the installation space and performance can be improved. Figure 25 shows the schematic structure of MEEP.

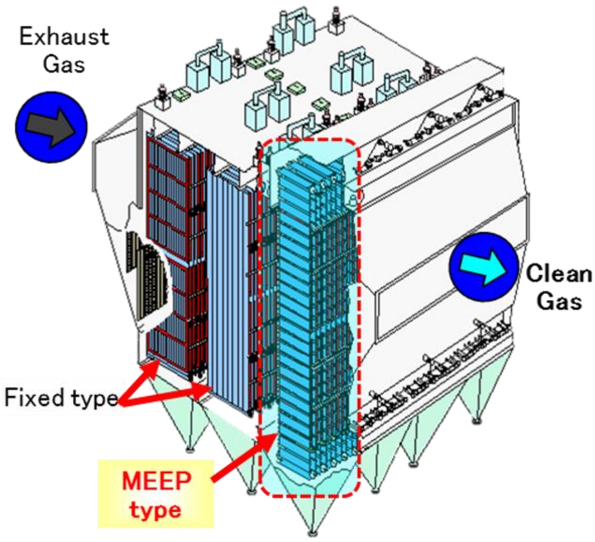


Figure 25. An Overview of MEEP (Source: Mitsubishi Power[23])

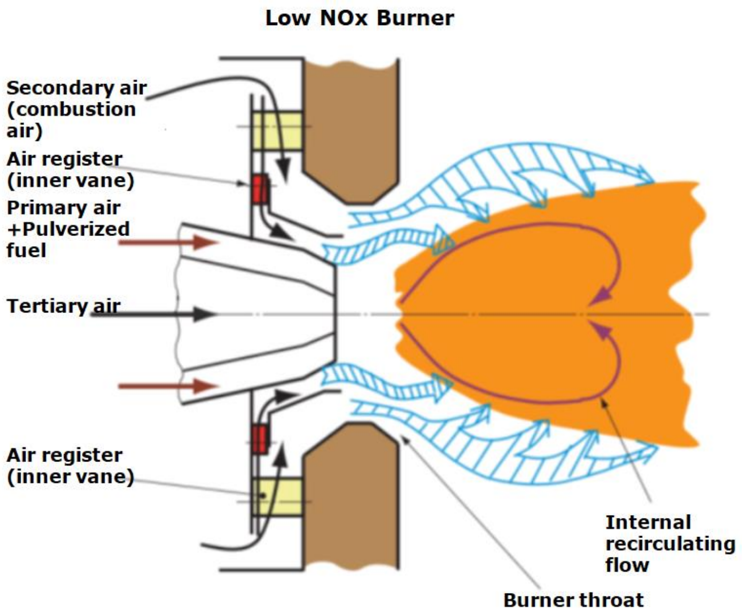
As a SOx reduction measure, the limestone gypsum method, which is wet desulphurisation equipment (FGD), is generally used. In the limestone gypsum method, the by-product gypsum can be used as a raw material for gypsum board, cement, and the like. In addition, the seawater method may be adopted as a simple and inexpensive method. In addition, when reducing the amount of water used, a dry desulfurisation device may be adopted.

Figure 26. Limestone Gypsum Method FGD (Source: Mitsubishi Power)

NOx reduction measures can be divided into steps using boilers and measures using denitration equipment. Measures for boilers include adopting low NOx burners, reducing excess air rate, adopting in-furnace NOx reduction technology, and adopting non-catalytic denitration equipment. Depending on the regulation value, these measures may be able to be taken without installing a denitration device. If NOx regulation is strict, a selective catalytic NOx reduction device (SCR) is

[23] Mitsubishi Power, Ltd. https://power.mhi.com/

required, but the amount of catalyst can be set according to the regulation value. Figure 27 shows typical NOx reduction measures.



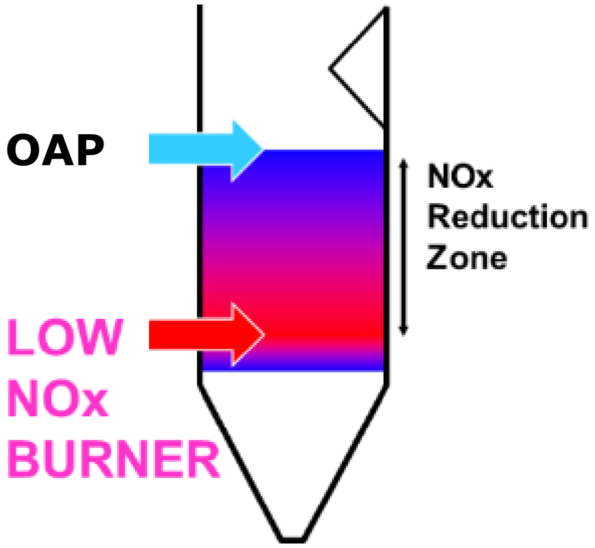


Figure 27. NOx Reduction Measures: Low NOx Burner (IHI), In-Furnace NOx reduction technology (IHI), SCR (Mitsubishi Power)

In these regional environmental measures, it is necessary to select an appropriate method according to the environmental regulation value. Still, a comprehensive check is also important for strengthening the environmental regulation value in the future. Figure 28 shows a typical flue gas treatment system (AQCS) in a wet desulphurisation system.

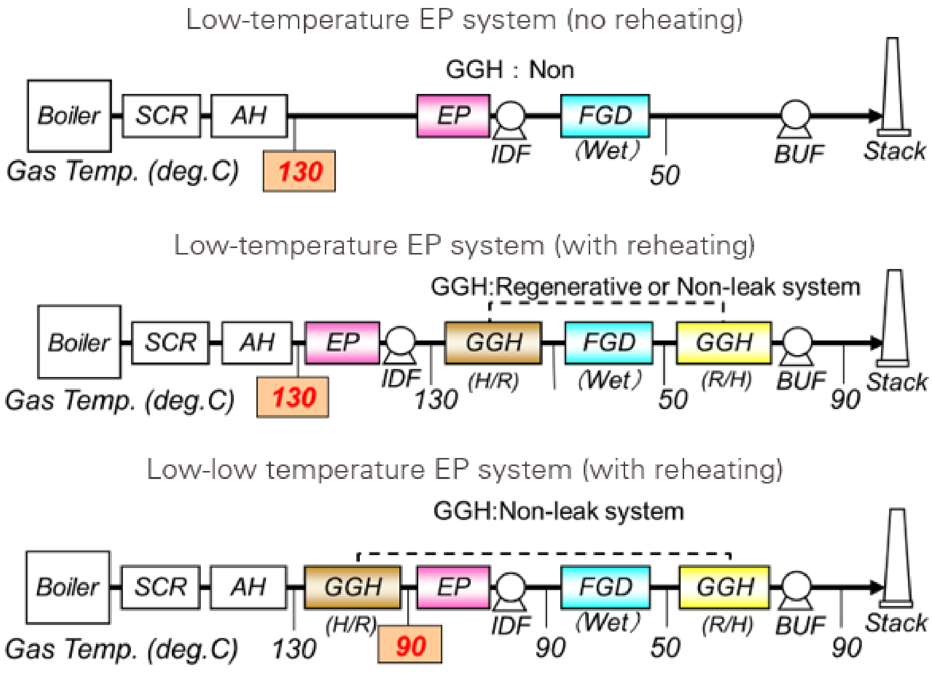


Figure 28. Schematic Diagram of AQCS by Type (Mitsubishi Power)

Although there is a mercury emission standard in the environmental regulation value, mercury emission is also reduced in AQCS, and mercury emission from the exhaust gas is reduced by promoting the oxidation of mercury with a denitration catalyst is also possible. Figure 29 shows the concept of reducing mercury emissions.

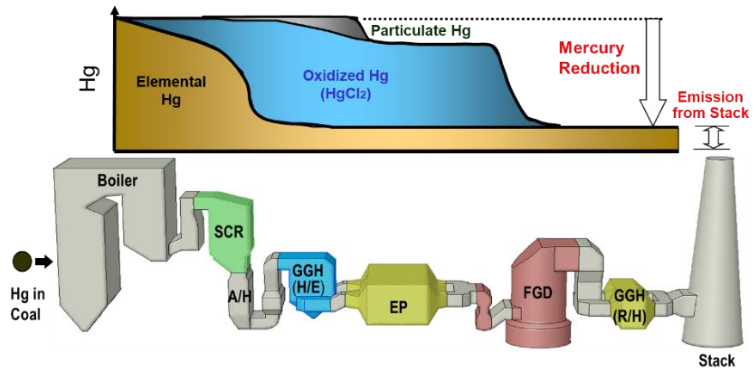


Figure 29. A system with Reduced Mercury Emissions (Source: Mitsubishi Power)

As a global environmental measure, CO_2 emissions are reduced to prevent global warming. Since coal-fired fuels emit more CO_2 than other fossil fuels, we have been reducing CO_2 emissions by improving efficiency.

As a typical example of improving the efficiency of coal-fired power plants, efficiency improvement has been promoted from a subcritical pressure plant to a supercritical pressure (SC) plant and from an SC plant to an ultra-supercritical (USC) plant. Recently, further development and practical application of high-efficiency plants such as advanced ultra-supercritical pressure (A-USC), integrated gasification combined cycle (IGCC), and integrated gasification fuel cell cycle (IGFC) have been promoted.

Biomass is also being used as a measure to prevent global warming. This is because biomass is carbon-neutral, so using it instead of fossil fuel will lead to CO_2 reduction. The circulating fluidised bed boiler (CFB) technology with possibly increased biomass cofiring rate will improve the global environment through application to small and medium-sized thermal power generation facilities where it is difficult to improve efficiency with pulverised boilers and grid connection is not available. Figure 30 shows the options for biomass utilisation technology.

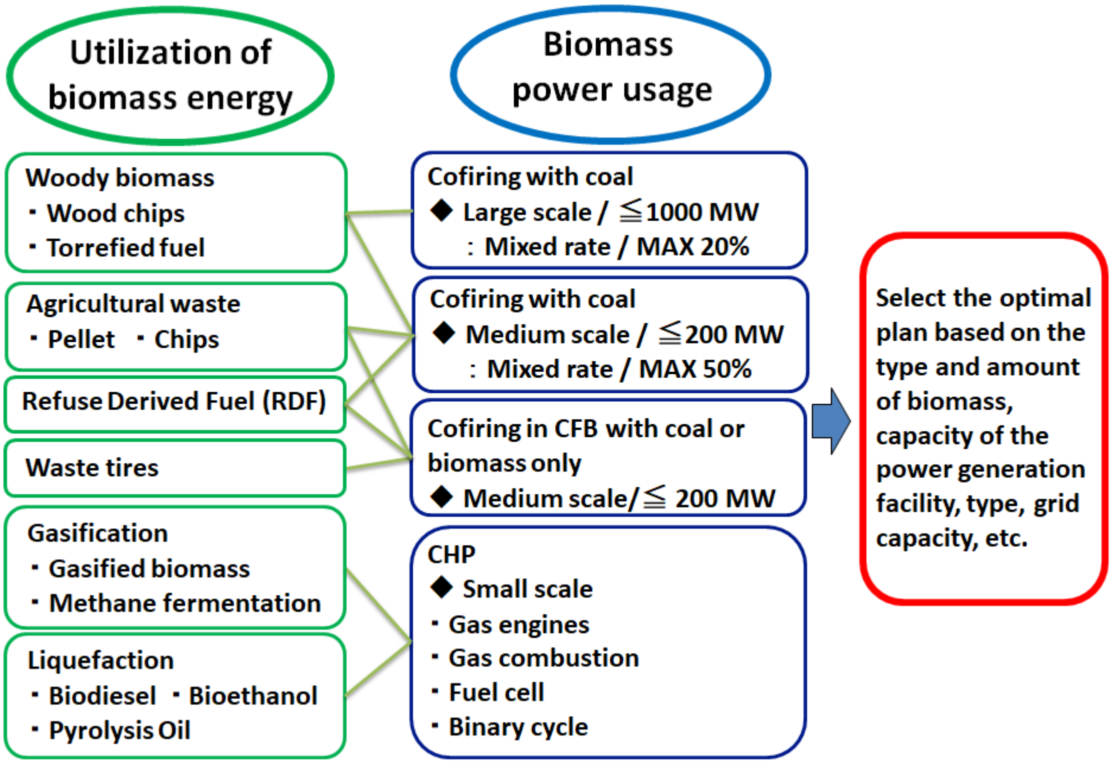


Figure 30. Overview of biomass firing technology choices (Source: JCOAL)

Figure 31 shows Japan's primary energy and power supply plans. The plan for 2030 is to supply 20% of electricity from renewable energy.

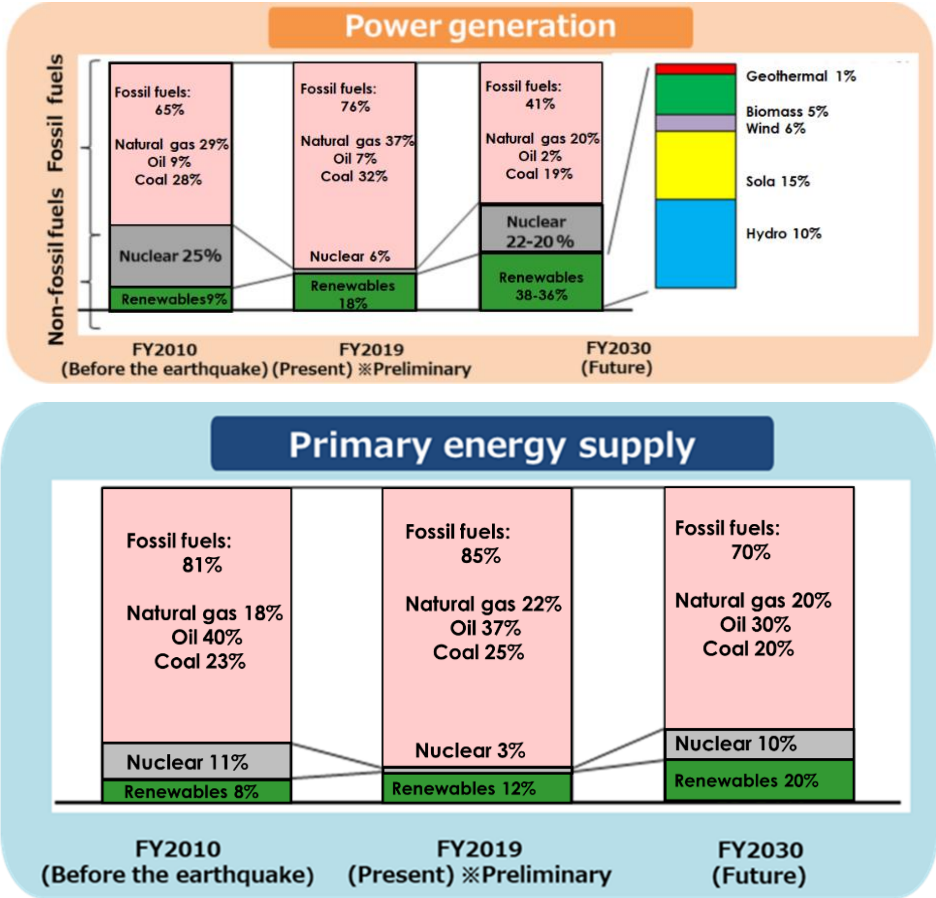


Figure 31. Japan's primary energy and power supply plan (Source: METI[24])

6.2 Forward-looking initiatives to ensure the steady and sustainable energy transition

Carbon recycling, abbreviated as CR, is a philosophy and concept that underpins our global endeavours toward carbon neutrality. With CR, carbon dioxide is understood as a carbon source, so capturing and recycling these material activities are being facilitated. Carbon dioxide (CO_2) is to be utilised for producing recycled materials and fuels by mineralisation, artificial photosynthesis, and methanation and this will also control CO_2 emissions to the air. That way, it is anticipated that CR and CCUS will bolster the emissions reduction.

[24] Press Release by METI on July 27, 2021. Available at https://www.meti.go.jp/press/2021/07/20210726007/20210726007.pdf

6.2.1 Carbon recycling (CR) Initiatives by Japan

In 2019, Japan formulated the "Carbon Recycling 3C Initiatives" to facilitate the development and commercialisation of Carbon Recycling technologies.

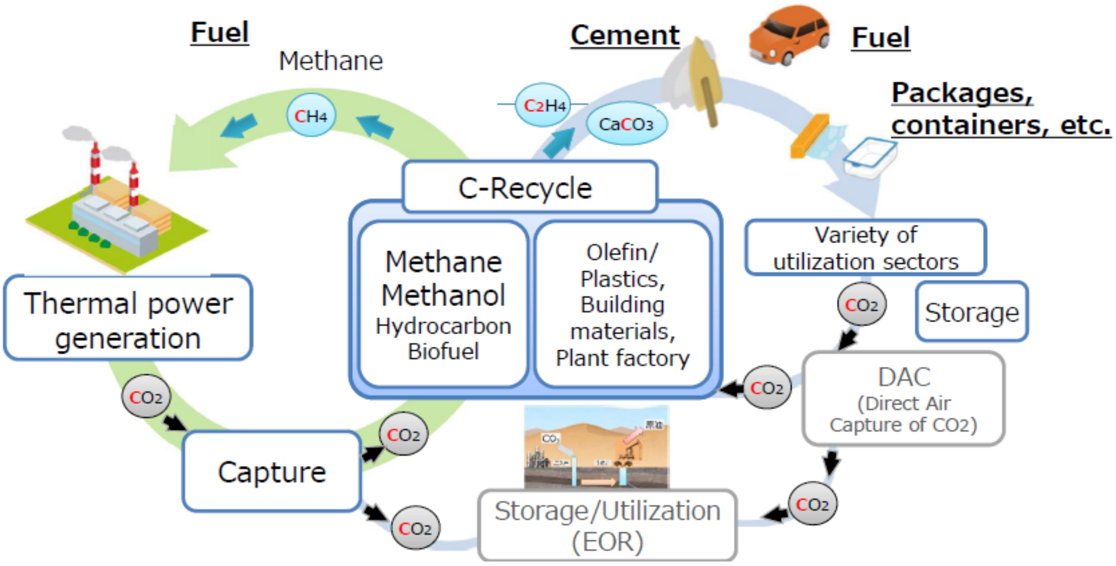


Figure 32. Conceptual view of carbon recycling (CR) (Source: METI[25])

The CR Initiatives by the Government of Japan consist of three major activities, i.e., Caravan, Center of Research, and Collaboration.

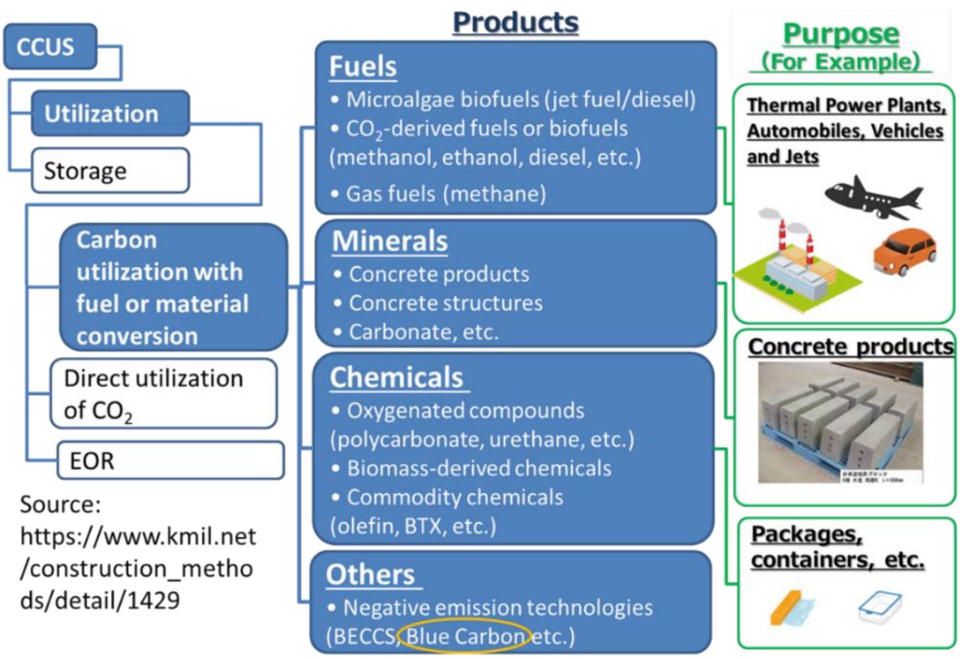


Figure 33. Overview of CCUS and CR (Source: JCOAL)

[25] Presentation on "Carbon Recycling 3C Initiative" by METI in October 2020

"Caravan" enhances bilateral and multilateral relationships by sharing information through various occasions such as international conferences and workshops. As for the "Center of Research", two key sites have been designated as the center of research under the initiative. The two centres, i.e., Osakkikamijima for IGCC / IGFC & CCS and Tomakomai for CCS are essential for the outreach for overseas stakeholders with the progress and outcomes of their projects as well as for the ongoing R&D activities.

"Collaboration" is the third and another important component of the CR Initiatives. It is to expand industry-academic-government research projects in the field. Figure 34 shows the three-phased CR Roadmap by the Government of Japan.

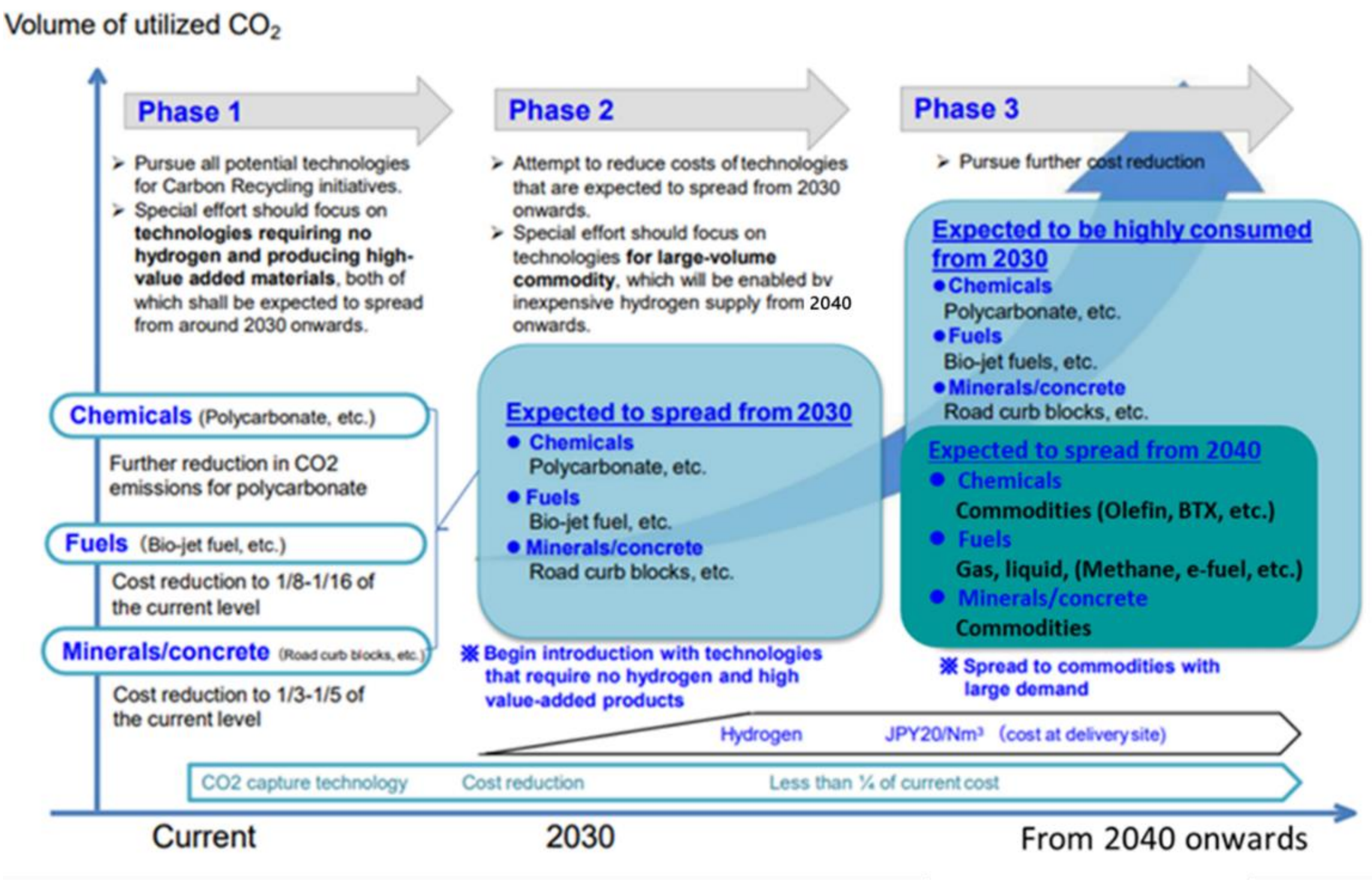


Figure 34. CR Roadmap of the Government of Japan (Source: METI)[26]

[26] Press Release by METI on July 27, 2021. Available at https://www.meti.go.jp/press/2021/07/20210726007/20210726007.pdf

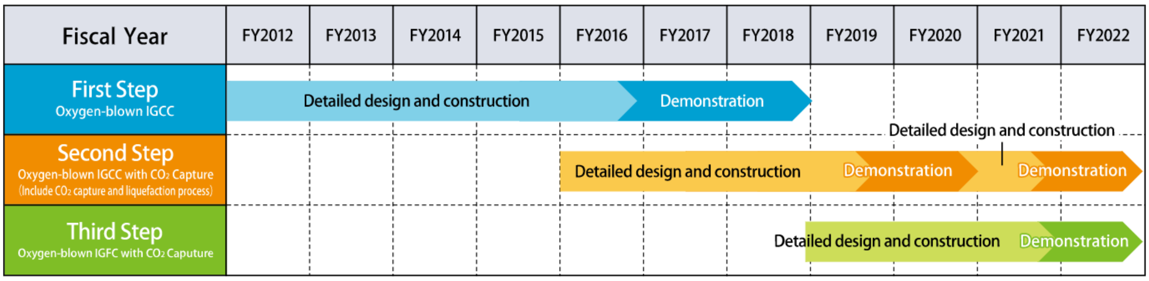
The two key Centers of Research under the CR Initiatives

1) Osaki Coolgen

Figure 35. Location of Osakikamijima (Source: METI[27])

Osaki Coolgen is a grand project involving key technology-owning companies and relevant institutions to develop IGCC, IGFC, and CCUS in Osakikamijima, Hiroshima Prefecture in Western Japan.

This project consists of three steps. They have achieved the targets of the first step of obtaining sufficient performance of oxygen-blown integrated coal gasification combined cycle (oxygen-blown IGCC), which is a core technology of the forthcoming integrated coal gasification fuel cell combined cycle (IGFC) that can be the ultimate high-efficiency technology generating electricity with a gas turbine, steam turbine, and fuel cells. Currently, they are conducting the demonstration of oxygen-blown IGCC with CO_2 capture, followed by the installation of fuel cells to the IGCC system to enhance the efficiency in IGFC with CO_2 capture. The phased demonstration of IGCC, IGCC with CO_2 capture, and IGFC with CO_2 capture are planned to complete in early 2023[28].



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[27] Press Release by METI on July 27, 2021. Available at https://www.meti.go.jp/press/2021/07/20210726007/20210726007.pdf

[28] Osaki Coolgen Corporation, https://www.osaki-coolgen.jp/en/project/overview.html

Figure 36. Osaki Coolgen Project Schedule (Source: Osaki Coolgen[29])

Now as a Center of Research for CR, another component has been added. Algae carbon recycling technology has been tested. Microalgae can be utilised as raw materials for producing diesel fuel, jet fuel, plastics, feed, etc. The following is the outline of the Algae Carbon Recycling Technology Demonstration program.

Algae Carbon Recycling Technology Demonstration

-Project period: 2017-2020

-Total project cost: 1.92 billion yen

-Project operator: IHI・ Fuel production target: 100s-1,000 kL/y in 2030

-Absorbed CO_2 amount expected: 12-13 tCO_2/year

Figure 37. Outline of the Algae Carbon Recycling Technology Demonstration (Source: METI)[30]

2) Tomakomai CCS

Figure 38. Location of Tomakomai in Japan[31]

The other key Center of Research under the CR Initiatives, Tomakomai CCS Project, conducted by the Ministry of Economy, Trade, and Industry (METI), New Energy and Industrial Technology Development Organization (NEDO), and Japan CCS Co., Ltd (JCCS), is the first large scale CCS demonstration in Japan. The entire plant was constructed in FY2012-2015, followed by the injection starting from April 2016 at a scale of 100 thousand tonnes per annum. They achieved

[29] Osaki Coolgen Corporation, https://www.osaki-coolgen.jp/en/project/overview.html
[30] Presentation on "Carbon Recycling 3C Initiative" by METI in October 2020
[31] https://simple.wikipedia.org/wiki/Tomakomai,_Hokkaid%C5%8D

the initial target cumulative injection of 300 thousand tonnes on November 22, 2019. Now the project is in the phase of post-injection monitoring.

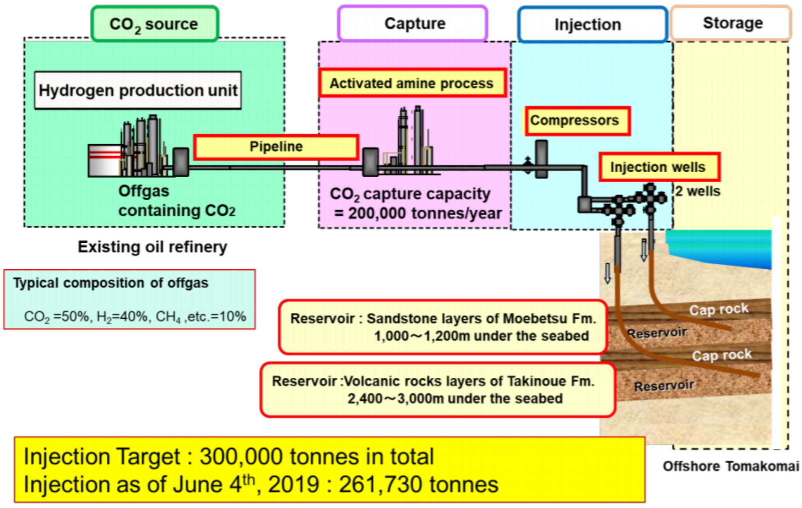

Figure 39. Overview of process, progress, and outcomes of the Tomakomai CCS Project (Source: Japan CCS[32])

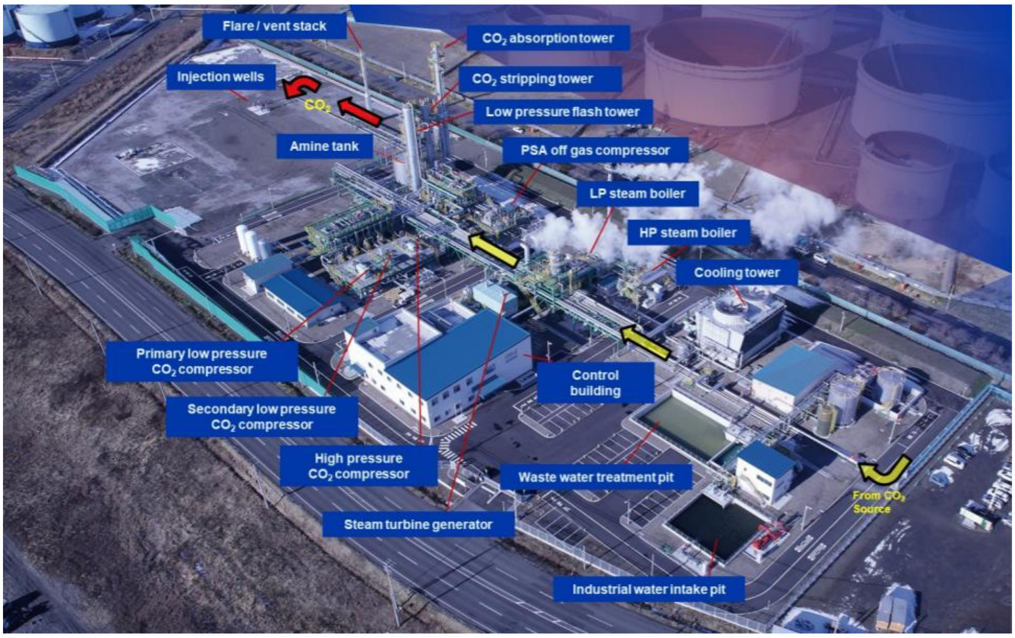

Figure 40. Bird's-eye View of the Tomakomai CCS Project Site (Source: Japan CCS)

The following are confirmed as the outcomes of the foregoing demonstration activities. Further development, application, and implementation are anticipated based on the results of the project.

- Full chain CCS system from capture to storage has been demonstrated

[32] Japan CCS Co., Ltd. https://www.japanccs.com/en/
The project was supported by New Energy and Industrial Technology Development Organization (NEDO).

- No seismicity (Mw>-0.5) has been detected in/around the depth range of the reservoirs before and after the start of the injection
- Natural earthquakes have not caused any damage to the facilities or reservoirs of the project
- The first monitor 3D survey successfully detected an anomaly at cumulative CO_2 injection of 61,000 to 69,000 tonnes into the Moebetsu Formation, matching simulation results
- The project has been conducted with the understanding and support of the local community, thanks to the forward-looking way of outreach activities by the project partners
- The CO_2 cumulative injection target of 300,000 tonnes has been achieved as scheduled, which means completing the demonstration project.

Chapter 7: Policy Implications and Recommendations

Different regions go through different energy transition pathways. In a growing region like ASEAN, meeting the demand is as important as achieving emission reductions. As discussed in the previous chapters, coal remains to be a considerable resource in the region and therefore, it is crucial to redefine the new role of coal moving forward to this new era of decarbonisation.

To further advance a higher adoption of low carbon technologies on coal, it is deemed that changes in the existing coal policies are needed. This chapter clusters the policy recommendations on cleaner coal utilisation in the ASEAN region into three main areas: 1) Increasing efficiency through HELE utilisation, 2) Pollution and emission regulatory, institutional, and technology enhancement, and 3) Carbon capture, utilisation, and storage (CCUS) deployment.

Increasing efficiency through HELE utilisation

- A regulatory framework to mandate newly built and retrofitted coal-fired power plants to use the more advanced supercritical and ultra-supercritical technologies
- Promote the dispatch of electricity generated from cleaner and more efficient coal plants for the baseload, and keeping the older plants running at minimum
- Provide financial mechanisms to support the shift to HELE technologies in new plants, and the upgrade of the less efficient systems in existing plants
- Provide support to HELE projects in terms of design and construction by easing the permitting and supply chain barriers to these processes
- Provide capacity building that will develop local talents and improve their operation and maintenance capabilities
- Strengthen research on load balancing to fully capitalise on the reliability of coal power to regulate the fluctuations of renewable power
- Improve public awareness on the economic benefits and improvements of coal-fired power plants utilising high efficiency, low emission technologies

Pollution and emissions regulatory, institutional, and technology enhancement

- Establish more stringent emission standards for coal-fired power plants to push clean coal technology deployment

- Promote the use of pollution control and removal systems with higher efficiency in existing coal-fired power plants by providing incentives to adopters
- Strengthen research on new pollution control techniques and promote their gradual deployment
- Cofiring of carbon-neutral fuels such as biomass at coal-fired power plants to mitigate pollution and CO_2 emissions
- Enhance local government initiatives and formulation of well-coordinated assessment, monitoring, and evaluation schemes to make the foregoing endeavors about regulatory and technology aspects work

Carbon capture, utilisation, and storage deployments

- Improve public awareness on the feasibility and implication of deploying carbon capture, utilisation, and storage (CCUS) in the region
- Undertake storage assessments and characterisation
- Provide legal and regulatory framework in undertaking pilot, demonstration, and commercial deployments in terms of liability and transboundary transport and storage
- Research the potential of CO_2 transport and storage networks among ASEAN states to enhance the economies-of-scale and lower the investment costs, and perform regional source-sink mapping
- Research the appropriate financial and/or carbon pricing mechanisms to advance the deployment of CCUS in existing and new coal-fired power plants

These recommendations must also be accompanied by rigorous policy supports and enforcement of each member state to ensure proper transition towards sustainable coal use in the ASEAN region. The general concept of this report is to demonstrate strategies on how the region can continuously utilise coal resources in a cleanest-possible manner, in parallel of renewable energy use and energy efficiency, to ensure energy security and cushion the impact of integrating large capacity of renewables in the grid.

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