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Coal Transition Pathways in ASEAN: Advancing Energy Transition in CFPPs Through Technology Readiness and Policy Support

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Highlights

- The contribution of coal in ASEAN's power generation will remain significant in the decades to come, even though it is projected to decrease under the AMS Targets Scenario.
- Coal transition technologies, such as coal upgrading, biomass and ammonia co-firing and CCUS, offer a pragmatic pathway to reduce emissions while maintaining energy security.
- Indonesia, Malaysia, the Philippines, Thailand and Viet Nam have begun pilot initiatives, but full-scale deployment remains limited by infrastructure, policy and financing gaps.
- ASEAN currently lacks harmonised regulations, fuel standards and CO_2 infrastructure, slowing the adoption of clean coal technologies across the region.
- Coordinated regional action, national roadmap integration, and targeted policy support are critical to accelerating the clean coal transition and enabling a future that reduces reliance on coal.

Introduction

According to the 8th ASEAN Energy Outlook, energy demand is projected to increase 2.6-fold from 2022 to 2050. Nevertheless, with the achievement of ASEAN Member States' (AMS') goals for renewable energy and energy efficiency targets, the demand growth can be limited to 36% by 2030 and nearly 98% by 2050 compared to 2020 levels [1]. It should be noted that the figures for 2020 were influenced by the COVID-19 pandemic, which caused a temporary dip in energy consumption across the region. Despite the sustained demand growth for bioenergy and other renewables, fossil fuels will continue to dominate ASEAN's final energy use. Coal consumption is expected to increase from 47.71 Mtoe in 2020 to 145.83 Mtoe in 2050, at an annual increase of about 3.8% [1]. The share of coal in Southeast Asia's overall energy demand will gradually rise to about 17.3%, 18%, 19.2% and 19.6% in 2025, 2030, 2040 and 2050, respectively [1]. Although optimistically, its contribution to the power generation sector will drop to 7% by 2050 under the AMS Targets Scenario from 30.6% in 2025 [1]. While natural gas and renewable forms of energy will replace some of the coal currently used to generate power, the share of coal will remain significant in the short and medium terms.

The prolonged reliance on coal consumption has led to severe environmental concerns due to its post-combustion emissions. The burning of coal emits far more carbon dioxide (CO_2) per unit of energy than the combustion of other fossil fuels [2]. Looking through the full energy chain analysis that considers all the energy investments in plant construction and its production, CO_2 emissions are 0.79 $MtCO_2$/TWh from hard coal and 0.91 $MtCO_2$/TWh from lignite, which are higher than from oil (0.76 $MtCO_2$/TWh) and natural gas (0.38 $MtCO_2$/TWh) [3]. In alignment with the objectives of the Paris Agreement, which seeks to constrain the increase in global average temperature to preferably below 1.5°C above pre-industrial levels, numerous policy measures and initiatives have been implemented to facilitate the reduction or complete phase-out of coal-fired power plants (CFPPs). However, eliminating CFPPs in the near future without thorough planning would significantly disrupt regional energy security, as they have long served as a reliable source of baseload within the region's energy system [4].

The coal transition is emerging as a key strategy to mitigate the environmental impacts of coal consumption by developing solutions to reduce its adverse effects [5], [6]. Central to this transition is the shift to cleaner, more sustainable energy sources, improving efficiency, and adopting new technologies that reduce emissions from coal combustion. There are several innovations to assist coal transition initiatives that can be categorised based on the stages of energy conversion: pre-combustion, combustion and post-combustion [7]. The focus of the pre-combustion and combustion stages is to improve energy conversion efficiency (i.e., less input for the same energy output), while the post-combustion stage aims to reduce unavoidable emissions produced from the first two stages. In practice, this approach includes, but is not limited to, coal upgrading as a pre-combustion measure, biomass and ammonia co-firing as combustion-stage solutions, and carbon capture, utilisation and storage (CCUS) as a post-combustion strategy for capturing residual emissions.

Overview of Coal Transition Initiatives in ASEAN

Various technologies are being adopted throughout the process in CFPPs, from coal conditioning up to post-processing emissions handling. A roadmap for cleaner coal utilisation in ASEAN [8] mentioned the focus on increasing efficiency (2019-2025), clean transformation (2026-2030) and comprehensive upgrade for large-scale clean coal technologies (CCT) (2031-2040). Several efforts have been made to develop these transition technologies for cleaner coal combustion among major coal users in ASEAN, particularly in Indonesia, Malaysia, the Philippines, Thailand and Viet Nam.

Coal Upgrading

The pre-combustion transformation of coal includes efforts to increase the value added in coal utilisation to overcome operational and environmental issues. Coal upgrading technology has seen broad application in addressing the problems of high ash-forming minerals and moisture content, low heating value and hazardous emissions (i.e., SOx, NOx and toxic metals) [9]. Lignite and sub-bituminous coal, which are abundant in ASEAN countries, could shape interest in upgrading low-rank coal, influenced by the increasing demand for power and the limited supply of premium coal [10].

Indonesia has demonstrated an advanced policy framework for coal upgrading under Government Regulation No. 77/2014, MEMR Regulation No. 25/2018 and Law No. 2/2025. Currently, there are five known facilities for coal upgrading in operation in Indonesia: PT ZJG Resources Tech Indonesia, PT Asiatic Universal Indonesia, PT Borneo Pasifik Global, PT Prima Coal Chemical and PT Kartika Prima Abadi, which mostly focus on drying, dewatering or other value-added processing of low-rank coal [11]. Other AMS might have shown interest in specific operational coal upgrading plants, but there is limited commercial-scale implementation and announced projects to date.

Biomass and Ammonia Co-Firing

Co-firing presents an immediate, cost-effective option to efficiently and cleanly reduce coal consumption by partially replacing it in boiler systems. Since co-firing technologies are highly dependent on existing boiler technologies, there will be a tradeoff between emissions reduction and operational requirements that limit the designed power output [12], [13]. Various alternative fuels are suitable for co-firing, with biomass being the most prevalent option.

Indonesia leads the region in biomass co-firing efforts. It has the largest biomass co-firing plant, PLTU Paiton 1-2, which by November 2023 was generating 134,530 MWh of green energy, and the highest power plant co-firing rate at 7.14% in Hotelkamp Power Plant [14]. Malaysia, through the Malakoff Corporation, has initiated biomass co-firing at the Tanjung Bin Power Plant, starting with a 0.5% trial in December 2022 and aiming for a 15% co-firing ratio by 2027 [15]. Thailand's Electricity Generating Authority (EGAT) is testing 2% wood pellet co-firing at the Mae Moh Power Plant, with plans to increase to 15% in the coming years [16]. Viet Nam's Power Development Plan 8 sets a target of 1,523-2,699 MW for biomass power by 2030 [17]. Although biomass co-firing is being widely explored, the limited sustainable biomass resources, competition with food production and land use changes remain significant challenges.

Among the other alternative fuels, which are getting more attention for their possible co-firing benefits, are ammonia (NH_3). The co-combustion of carbon-free fuels is gradually becoming a major energy source for the 21st century with the maturity of preparation, storage and transport technologies [18], [19], [20].

Indonesia has several ammonia co-firing pilot projects. In October 2022, PLTU Gresik Unit 1 (100 MW) conducted Southeast Asia's first ammonia co-firing trial, achieving a 20% ammonia blend in collaboration with Japan's IHI Corporation [21]. Building on this success, PLN Indonesia Power advanced to a 3% green ammonia co-firing trial at the Labuan 2×300 MW coal plant in 2025, using ammonia produced from green hydrogen, which reduced coal consumption by 4.5 tons/hour and showed potential for annual CO_2 reductions of 70,640 tons [22]. These projects align with Indonesia's National Hydrogen and Ammonia Roadmap and the National Electricity Master Plan (RUKN) [23], [24].

Malaysia conducted groundbreaking technical demonstrations through TNB Research's 2022 test experiments in Kajang, achieving 60% ammonia co-firing rates across three coal types [25]. The trials, conducted with Petronas Hydrogen and IHI Power System, confirmed proportional reductions in CO_2 and SO_2 emissions, providing critical data for scaling up commercial applications. Meanwhile, Thailand and Viet Nam have been conducting feasibility studies and have signed MoUs with MHI and Doosan, respectively, to explore ammonia co-firing [26], [27].

The potential for ammonia co-firing extends as several ASEAN countries are beginning to explore its feasibility. Research indicates that ammonia co-firing could significantly reduce CO_2 emissions from coal-fired power plants while maintaining operational reliability. However, the development of ammonia supply chains, storage infrastructure and handling protocols remains a key challenge for widespread implementation across the region.

CCUS in CFPPs

CCUS covers post-combustion capture of CO_2 from coal plant flue gas (using solvents, membranes or other methods) and its storage in geological formations or utilisation. For coal plants, the main approach is to retrofit solvent-based capture units onto existing plants or build new plants with built-in carbon capture and storage (CCS) (e.g., oxy-combustion with CO_2 capture).

Indonesia completed Southeast Asia's first CCS regulatory framework in late 2023; however, currently, there is no large-scale CFPP capture facility in operation [28]. Although Indonesia's PLN estimates that CO_2 capture costs around USD 40 per ton, significantly higher than the USD 12–20 per ton in gas plants, it still plans to install capture systems at selected coal plants [29]. The government aims to launch about 15 CCUS projects by 2030, utilising major sedimentary basins with an estimated 573 Gt of storage capacity [29].

Malaysia has set a target to develop three CCUS hubs up to 15 Mtpa total storage capacity by 2030, and around 40 to 80 Mtpa of total storage capacity by 2050 [30]. Thailand has conducted conceptual studies on CCUS at its major lignite plant in Mae Moh. EGAT researchers estimate that it has the technical feasibility to sequester 0.364 $MtCO_2$/year, but as of yet there are no physical installations [31]. Viet Nam has launched its first CCUS feasibility study for coal plants, commissioning Black & Veatch in late 2024 to assess capture technologies at three major PetroVietnam facilities. It is hoped that the findings will inform the national roadmap and support the 2025 "Coal-to-Clean" plan calling for pilot projects by 2030 [32], [33]. While CCS is mentioned in national plans and climate targets, no dedicated incentives or funding schemes currently exist.

Building on these national efforts, the ASEAN Centre for Energy (ACE) published the ASEAN CCS Deployment Framework and Roadmap. This comprehensive framework assesses the region's status across three core pillars, which are policy, legal/regulatory systems and storage capacity [34].

Table 1 Several regulations and initiatives pertaining to coal transition technologies in the AMS

Country	Policy/Regulation /Framework	Technology Focus	Current Progress
Indonesia	Government Regulation No. 77/2014, MEMR Regulation No. 25/2018, Act No 2/2025	Coal upgrading deployment	Five commercial coal upgrading facilities are operating. Additional pilot-scale and feasibility studies are being explored under downstreaming mandates.
	RUPTL 2021-2023	Biomass co-firing scale-up	Largest plant at PLTU Paiton 1-2, highest co-firing ratio of 7.14% at Hotelkam, RUPTL mandates 10% biomass co-firing by 2030.
	National Hydrogen and Ammonia Roadmap, RUKN	Ammonia co-firing development	Co-firing ratio of 3% NH_3 trial at Labuan in 2025, pilot at Jawa 9–10 with Doosan MOU, 20% blend studies ongoing.
	Presidential Regulation No. 14/2024, RPJPN 2025-2045	CCUS feasibility and rollout	PLN plans to capture CO_2 at three major plants with a target of 15 CCUS projects by 2030.

Country	Policy/Regulation /Framework	Technology Focus	Current Progress
Malaysia	National Energy Transition Roadmap (NETR)	Biomass and ammonia co-firing deployment	Biomass co-firing ratio of 0.5% trial at Tanjung Bin; target 15% by 2027, ammonia co-firing of 60% NH_3 lab test in 2022, 1% NH_3 + 2% biomass pilot by 2026, feasibility study with Petronas/IHI.
		CCUS hub development	Targeting three CCUS hubs (15 Mtpa by 2030), ongoing pilots by Petronas/Shell.
Thailand	Power Development Plan (PDP) 2022–2037, Alternative Energy Development Plan (AEDP)	Biomass co-firing pilot and scale-up	Biomass co-firing ratio of 2% at Mae Moh; targeting 15%.
	PDP & AEDP, MoU: EGAT–MLH–BLCP	Ammonia study planning	MoU signed at Map Ta Phut, pilot target of ~20% NH_3.
	EGAT–CCUS MoU (2023)	CCUS studies	EGAT CCS studies (Mae Moh, Lampang), MMRP2 Lignite plant planned with CCS in 2030.
Viet Nam	Revised Power Development Plan VIII (PDP8)	Biomass expansion	Biomass capacity target 1,523-2,699 MW by 2030.
	Decision 165/QD-TTg (2024) – Hydrogen Strategy	Ammonia co-firing research	Policy for pilots by 2030, long-term target of 20–100% ammonia substitution by 2045.
	Decision 266/QD-TTg (2025) – Coal-to-Clean Roadmap	CCUS R&D	VPI–Black & Veatch CCUS study, pilots planned for three CFPPs, national target for CCUS pilots by 2030.

Limited Technologies and Policy Support Remain Bottlenecks

Although clean coal transition technologies are recognised as essential to meeting net zero targets, their deployment across ASEAN is hindered not by ambition alone but by practical constraints in technology, infrastructure and regulation.

Technological Readiness and Operational Maturity

Technological advancements in the power sector are a critical enabler for the successful implementation of the coal transition, but progress is slow due to limited demonstration and pilot projects. Transition technologies in Southeast Asia emain largely at the pilot or study stage, with limited demonstrations and no commercial-scale units available.

For instance, ammonia co-firing was first tested only in 2022, while biomass co-firing has seen broader application, mainly in Indonesia (7.3 GW) [35], but remains minimal elsewhere. Coal upgrading and CCUS technologies are even less mature, with no regional deployments and only basic studies.

Most coal plants in the region are older subcritical units that require significant retrofitting to accommodate these technologies. While biomass co-firing can require new fuel handling and boiler modifications, ammonia co-firing needs specialised burners and combustion controls, and CCUS retrofits involve integrating capture units and high-pressure CO_2 equipment. All of these modifications involve complex engineering. In addition to this, utilities and regulators face technical knowledge gaps, and building the necessary expertise and operational capacity will take time, further slowing deployment.

Resource Constraints and Infrastructure Gaps

Infrastructure and resource limitations pose major hurdles to coal transition technologies in ASEAN. Biomass co-firing depends on securing vast and sustainable feedstock, which will raise concerns over deforestation and land use conflicts, while regional supply chains and standards remain underdeveloped. Ammonia co-firing faces even greater challenges, as ASEAN lacks green ammonia production capacity and must rely on imports or new facilities, with no large-scale terminals or plants yet in place. Similarly, CCUS deployment is constrained by the absence of CO_2 pipelines, storage infrastructure and clear legal frameworks, leaving projects stalled until regional transport and storage systems are developed.

Policy and Regulatory Limitations

ASEAN's coal transition is hindered by the absence of clear mandates, incentives and legal frameworks. Most governments lack binding targets for coal transition technologies. For example, a lack of regulations and incentives is noted as hindering the adoption of biomass co-firing across ASEAN [35]. Likewise, explicit rules for ammonia blending are still absent in regulatory frameworks in ASEAN. In terms of CCUS, only Indonesia and Malaysia (Sarawak) have regulations for project initiation, leaving others with no strong signals to invest in these transitions [34].

Stakeholders emphasise that many governments still need a much deeper understanding of clean coal options, implying gaps in regulatory capacity and long-term planning [36]. The absence of clear licensing processes, liability rules and environmental standards for CO_2 transport and storage, along with the lack of common ASEAN standards for biomass quality and ammonia safety, creates regulatory fragmentation and deters project developers.

The national energy plans of the AMS often still assume coal growth, without integrating transition pathways. Only a few countries have introduced indicative timelines or targets for gradually reducing coal in their power planning. For instance, despite net zero pledges, many power development plans (PDPs) provide limited detail on committed actions such as coal retirement timelines or the deployment of transition technologies, though some AMS have seen a decline in the proportion of coal in their power generation mix. This policy gap means companies are uncertain about future coal policies. This uncertainty is further compounded by the fact that clearly developed roadmaps to adopt fuel switching and CCUS technologies in CFPPs remain insufficient in ASEAN countries.

Recommendations for the AMS to Advance Clean Coal Transition

1. Integrate coal transition pathways into national energy planning

The AMS should revise their PDPs and publish national coal transition roadmaps that integrate CCTs into phased coal transition strategies. These roadmaps must include measurable targets (e.g., ammonia blend ratios, CCS capacity) and timelines for retiring or retrofitting coal units while aligning with national climate goals like NDCs and net zero pledges. Formalising these plans alongside renewable strategies will clarify the shifting role of coal and enhance investor confidence.

2. Implement policy mechanisms and market signals to drive adoption of carbon pricing

ASEAN should adopt carbon pricing to reflect the true costs of coal emissions and boost the competitiveness of co-firing and CCUS. Complementary subsidies like grants, tax breaks and feed-in premiums can drive early deployment. Thailand's carbon pricing study for CCS offers a model for regional adoption. Meanwhile, setting emission and performance standards, requiring new plants to be CCUS-ready, and mandating minimum co-firing shares will embed clean technologies into plant operations and encourage cleaner combustion.

3. Standardise technology specifications and quality assurance

Reliable, safe and efficient deployment of coal transition technologies can be ensured by adopting common technical standards and quality benchmarks. This includes standardised fuel specifications for upgraded coal, biomass and ammonia, as well as uniform CCUS protocols for capture, transport and storage. Regional harmonisation will reduce costs, ease permitting and accelerate technology deployment.

4. Strengthen regional knowledge sharing and capacity building

Establishing an ASEAN coal transition workshop or similar platform will facilitate technical training on coal upgrading, biomass and ammonia co-firing, and CCUS technologies, leveraging expertise from international partners. Regular publication of technology readiness indexes and best practices will enable monitoring, tracking of progress and sharing lessons learned. Capacity building efforts should target policymakers, plant operators and local supply chain actors to ensure effective technology adoption, foster a skilled workforce and strengthen institutional knowledge.

5. Enhance ASEAN regional coordination and infrastructure planning

Governments can enhance regional cooperation by establishing joint standards for coal transition technologies, such as biomass and ammonia fuel specifications and CCUS retrofit guidelines, and by harmonising permitting and safety regulations. Pooling R&D can reduce costs and risks, while coordinated planning of cross-border CO_2 transport and storage can optimise infrastructure. Existing frameworks like the APAEC Phase II: 2021-2025 of the Programme Area Clean Coal Technology [37], can support harmonising permitting and safety regulations regionally to prevent bottlenecks and accelerate project approvals.

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