Conversion of Coal-Fired Power Plants Using Energy Storage Systems: Experiences, Challenges, and Opportunities

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Conversion of Coal-Fired Power Plants Using Energy Storage Systems: Experiences, Challenges, and Opportunities

SUMMARY REPORT

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Executive summary

The United Nations' Intergovernmental Panel on Climate Change (IPCC) has confirmed that continued greenhouse gas emissions, particularly from thermoelectric power plants, will accelerate global warming. The consequences of this include extreme weather events such as heavy rainfall, floods, severe droughts, forest fires, melting polar ice, biodiversity loss, and growing economic costs to address these impacts. To mitigate these effects, significant, rapid, and sustained reductions in greenhouse gas emissions are essential. A key strategy in achieving this goal is reducing emissions from coal-fired power plants, either by retiring or retrofitting them. Notably, approximately two-thirds of APEC economies plan to phase out coal-fired power plants by 2030 or 2040, including Australia; Canada; Chile; Hong Kong, China; Indonesia; Japan; Korea; Malaysia; Mexico; New Zealand; Russia; Singapore; Thailand; and the United States. Among these, nine economies—Australia; Canada; Chile; Hong Kong, China; Japan; Russia; Singapore; and the United States—are already taking steps to implement this transition.

In line with these efforts, the APEC project "Conversion of Coal-Fired Power Plants Using Energy Storage Systems: Experiences, Challenges, and Opportunities" was developed to promote knowledge sharing, foster innovation, and build technical expertise among APEC economies. Organized by Chile's Ministry of Energy, and co-sponsored by Canada; Hong Kong, China; Korea; and the United States, this initiative included a two-day seminar in Santiago, Chile, in August 2024, followed by a comprehensive summary report. The seminar brought together 69 delegates from eight APEC economies: Chile; Chinese Taipei; Indonesia; Malaysia; Mexico; Thailand; the United States; and Viet Nam. Thirteen expert presentations provided insights into the region's efforts to transition coal-fired power plants to more sustainable energy solutions. Key discussions at the seminar focused on four main areas: (1) lessons learned from retrofitting coal-fired power plants with energy storage systems; (2) policy and regulatory challenges in plant closure and conversion; (3) environmental and social considerations in retrofitting; and (4) emerging business opportunities from coal plant conversions. The seminar underscored that converting coal plants is critical for reducing greenhouse gas emissions and combating global warming. Various retrofitting approaches were explored, such as integrating energy storage systems, green ammonia, and renewable energy, among others. However, challenges remain, including high conversion costs, infrastructure requirements, and the social impacts of job losses.

To support these transitions, several recommendations emerged from the seminar. These included fostering innovation in energy storage and clean energy technologies, engaging local communities early in the transition process, and providing regulatory incentives to encourage private sector investment. Policymakers were urged to develop strategies that balance environmental objectives with energy security while addressing local concerns. Workforce retraining, local economic development, and infrastructure investments were highlighted as critical components for a smooth transition. Finally, financial mechanisms, such as green bonds and carbon pricing, were also proposed to mitigate the social impacts of phasing out coal.

The insights and recommendations outlined in this document provide a valuable framework for APEC economies to accelerate the retirement or retrofitting of coal-fired power plants while leveraging energy storage systems.

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1. Introduction

The United Nations' Intergovernmental Panel on Climate Change (IPCC) has confirmed that continued greenhouse gas emissions, particularly from thermoelectric power plants, will accelerate global warming. The consequences of this include extreme weather events such as heavy rainfall, floods, severe droughts, forest fires, melting polar ice, biodiversity loss, and growing economic costs to address these impacts. To mitigate these effects, significant, rapid, and sustained reductions in greenhouse gas emissions are essential. A key strategy in achieving this goal is reducing emissions from coal-fired power plants, either by retiring or retrofitting them. Notably, approximately two-thirds of APEC economies plan to phase out coal-fired power plants by 2030 or 2040, including Australia; Canada; Chile; Hong Kong, China; Indonesia; Japan; Korea; Malaysia; Mexico; New Zealand; Russia; Singapore; Thailand; and the United States. Among these, nine economies—Australia; Canada; Chile; Hong Kong, China; Japan; Russia; Singapore; and the United States—are already taking steps to implement this transition. Retrofitting coal plants can allow the continued use of existing infrastructure, support local economies, and preserve jobs, reducing both environmental and socio-economic impacts.

In line with these efforts, the APEC project "Conversion of Coal-Fired Power Plants Using Energy Storage Systems: Experiences, Challenges, and Opportunities" was developed to promote knowledge sharing, foster innovation, and build technical expertise among APEC economies. Organized by Chile's Ministry of Energy, and co-sponsored by Canada; Hong Kong, China; Korea; and the United States, this initiative included a two-day seminar in Santiago, Chile, in August 2024, followed by a comprehensive summary report. The seminar included 69 delegates from eight APEC economies: Chile; Indonesia; Malaysia; Mexico; Chinese Taipei; Thailand; the United States, and Viet Nam. Thirteen expert presentations provided insights into the region's efforts to transition coal plants to more sustainable energy solutions.

Key discussions at the seminar focused on four main areas: (1) lessons learned from retrofitting coal-fired power plants with energy storage systems; (2) policy and regulatory challenges in plant closure and conversion; (3) environmental and social considerations in retrofitting; and (4) emerging business opportunities from coal plant conversions.

This document presents valuable insights from the economies that participated in the seminar and provides practical recommendations for all APEC members. It emphasizes strategies to phase out coal, repurpose energy infrastructure, and significantly reduce greenhouse gas emissions, with a particular focus on integrating energy storage systems as a key solution.

2. Objective of the report

The objective of this report is to provide a comprehensive summary of the key findings and recommendations discussed during the APEC seminar "Conversion of Coal-Fired Power Plants Using Energy Storage Systems: Experiences, Challenges, and Opportunities".

3. General information on the APEC Forum and the APEC Support Funds

This seminar was organized under the APEC Forum's Energy Working Group (EWG) and supported by the APEC Sub-Fund on Energy Efficiency, Low Carbon, and Energy Resiliency Measures (EELCER).

The EWG seeks to maximize the energy sector's contribution to the economic and social well-being of people in the APEC region while minimizing the environmental impacts of energy production and consumption. To this end, the EWG has established two collective goals:

- Improve energy intensity by at least 45% by 2035 compared to 2005 levels.
- Double the share of modern renewables in the energy mix by 2030, relative to 2010 levels.

To achieve these goals, the EWG engages in a variety of initiatives, including policy dialogues, workshops, and peer reviews for low-carbon energy policies. In 2023, APEC economies proposed 14 APEC-funded projects under the EWG, focusing on capacity-building and technical assistance programs. These initiatives play a pivotal role in supporting member economies' transition to sustainable economic growth.

Established in 2009, the APEC Sub-Fund on Energy Efficiency, Low Carbon, and Energy Resiliency Measures (EELCER) promotes energy efficiency and low-carbon solutions across the APEC region. In response to the increasing frequency of disasters, the EWG introduced the Energy Resiliency Principle in 2020, further endorsed by its members. This principle, along with the initiative to Enhance Energy Access in APEC, expanded the Sub-Fund's scope to include measures for improving energy resiliency and access.

4. General information on the Seminar

The APEC Seminar titled "Conversion of Coal-Fired Power Plants Using Energy Storage Systems: Experiences, Challenges, and Opportunities" was held on August 20-21, 2024, in Santiago, Chile. Key topics discussed at the seminar included:

- Day 1
  1) Topic 1: Lessons learned from converting coal-fired power plants with energy storage systems.
  2) Topic 2: Policy design and regulatory challenges in plant closure and conversion.
- Day 2
  3) Topic 3: Environmental and social considerations for retrofitting thermal power plants.
  4) Topic 4: New business opportunities emerging from coal plant conversion.

The seminar schedule ran from 8:30 a.m. to 4:40 p.m. on Day 1 and from 9:30 a.m. to 4:20 p.m. on Day 2. A detailed agenda for each day can be found in the annex.

A total of 69 delegates from eight APEC economies attended the seminar, representing Chile; Indonesia; Malaysia; Mexico; Chinese Taipei; Thailand; the United States, and Viet Nam. The attendees included government officials, academics, members of energy trade associations, and executives from companies involved in the coal-fired industry and energy storage systems. The gender ratio among participants was 35% female and 65% male.

Thirteen experts from six APEC economies participated as speakers at the seminar, including representatives from Chile; Indonesia; Mexico; Chinese Taipei; the United States, and Viet Nam. Most of the speakers were affiliated with government, academia, or energy companies related to the coal-fired industry and energy storage systems, with a gender ratio of 23% female and 77% male among the presenters.

5. Summary and main findings of presentations and panel discussions, by topic

The seminar was organized into four main topics:

- Topic 1: Lessons learned from converting coal-fired power plants with energy storage systems.
- Topic 2: Policy design and regulatory challenges in plant closure and conversion.
- Topic 3: Environmental and social considerations for retrofitting thermal power plants.
- Topic 4: New business opportunities emerging from coal plant conversion.

The summary and main findings are detailed by topic.

5.1 Lessons learned from converting coal-fired power plants with energy storage systems

The first topic was covered on the first day of the seminar, with presentations from five experts on the subject.

- Repurposing Fossil Assets with Hybrid Energy Storage Solutions (the United States).
- Site conversion: from coal to innovation (Chile).
- Pathways for repurposing coal power plants into storage systems through Carnot Batteries schemes (Chile).
- Feasibility study of retrofitting Coal Power Plants in Chile (Chile).
- Conversion of the Guacolda thermoelectric plant to green ammonia (Chile).

5.1.1 Repurposing Fossil Assets with Hybrid Energy Storage Solutions

The presentation “Repurposing Fossil Assets with Hybrid Energy Storage Solutions” by Dr Bhima Sastri, Director of Energy Asset Transitions in the United States Department of Energy, outlined strategies for transitioning fossil fuel assets to Energy Storage Systems (ESS) in that economy. This transition is driven by the need to reduce emissions and address the economic challenges of maintaining fossil fuel infrastructure. The U.S. has retired 546 coal-fired power units (102 GW) since 2010, with an additional 78 GW expected to retire by 2040. Repurposing these assets offers economic benefits, such as reduced decommissioning costs and job preservation, while also supporting local economies.

The presentation explored energy storage technologies, including chemical, electromechanical, mechanical, and thermal storage, emphasizing their integration into existing fossil fuel plants to improve grid reliability and enable renewable energy adoption. Case studies demonstrated successful transitions, such as Chile’s retrofitting of coal plants with molten salt energy storage systems, North Dakota’s shift from coal to hydrogen with carbon capture, and New Mexico’s conversion of a coal-fired plant to a hydrogen-fired facility with carbon captures storage (CCS).

Each fossil asset presents unique challenges and opportunities, requiring tailored approaches based on factors such as regulatory frameworks, existing technologies, renewable energy integration, ownership structures, incentives, and geographic conditions.

Dr Sastri underscores the need for continued innovation, collaboration, and supportive policies to facilitate the repurposing of fossil assets. By leveraging energy storage solutions, these assets can be transformed into sustainable energy systems, contributing to a resilient, low-carbon energy future.

5.1.2 Site conversion: from coal to innovation

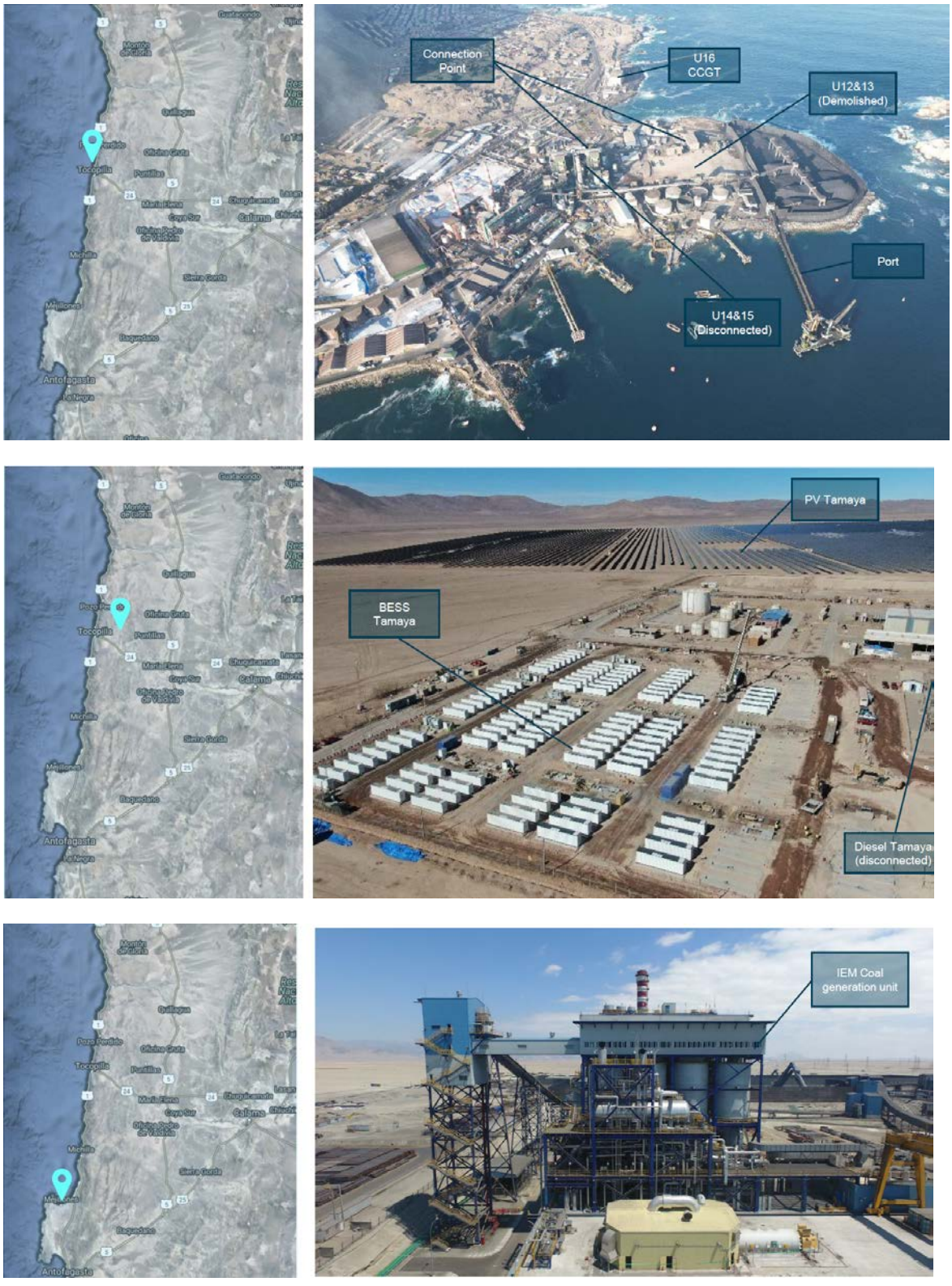
The presentation “Site conversion: from coal to innovation” by Ms Gabriela Alcazar, Business Developer Manager at Engie, outlined the company’s strategy for transitioning from coal to innovative energy solutions in Chile. Engie’s key objectives include achieving net-zero carbon emissions by 2045, capping greenhouse gas emissions from power generation at 43 Mt by 2030, increasing renewable production capacity to 58% by 2030, and phasing out coal activities entirely by 2027.

The presentation highlighted Engie’s global presence, with operations in 31 economies, 97,000 employees, and a turnover of €82.6 billion in 2023. In Chile, Engie plays a pivotal role in the energy sector, managing 2.6 GW of installed capacity, including 0.9 GW of renewable energy, and operating extensive transmission and natural gas networks.

Engie’s transformation strategy in Chile focuses on three key projects: Tocopilla, Tamaya y Mejillones.

- **Tocopilla**: The Tocopilla Thermal Complex will transition from coal generation to a standalone Battery Energy Storage System (BESS) with a capacity of 116 MW / 660 MWh. This project aims to reduce renewable energy curtailment and improve grid flexibility.
- **Tamaya**: The former diesel plant at Tamaya will be converted into a photovoltaic (PV) + BESS generation asset, with a PV capacity of 114 MW and a BESS capacity of 68 MW / 418 MWh. This project will promote local development and create job opportunities while reusing existing infrastructure.
- **Mejillones**: The Mejillones Thermal Complex will convert its last coal generation unit to gas and disconnect other coal units. This project will reduce emissions and provide ancillary services to the grid.

Figure 1 Location of thermal complexes Tocopilla, Tamaya and Mejillones



Source: Alcazar (2024).

Engie's approach emphasizes a just transition, prioritizing dialogue with employees, trade unions, and local communities to foster equitable development. The presentation concluded with a call for continued innovation and collaboration to achieve a secure, flexible, and carbon-neutral energy future.

5.1.3 Pathways for repurposing coal power plants into storage systems through Carnot Batteries schemes

Dr Jose Miguel Cardemil, Senior Researcher at the Energy Centre of the Pontifical Catholic University of Chile, presented research on "Pathways for Repurposing Coal Power Plants into Storage Systems Through Carnot Battery Schemes" outlining strategies for converting coal power plants into energy storage systems using Carnot Batteries. Coal-fired power plants make up a significant portion of global energy capacity, but their phase-out is critical to achieving climate goals due to their high carbon emissions. This transition also presents an opportunity to integrate innovative technologies.

Key considerations when planning the closure of coal-fired power plants include reducing carbon emissions, enhancing local environmental quality, and supporting communities and workers impacted by the closures.

The presentation explored various technological alternatives for repurposing coal-fired power plants, including conversion to alternative fuels (e.g. natural gas, biomass, ammonia), repowering (e.g., short-duration battery energy storage systems - BESS, thermal energy storage - TES, combined cycle systems, and carbon capture), and reconversion through storage systems like Carnot Batteries and Concentrated Solar Power (CSP).Carnot Batteries were highlighted as a promising solution for repurposing coal-fired power plants. This technology converts electricity into heat and then back to electricity, offering a cost-effective method for energy storage while utilizing existing infrastructure. Carnot Batteries were compared with other energy storage solutions, emphasizing their potential to reduce costs, enhance grid stability, and create job opportunities.

Case studies from APEC members (Canada; Chile; and the United States), as well as non-members (Spain and Germany), demonstrated successful pilot projects, showcasing the feasibility and benefits of transforming coal-fired power plants into energy storage systems.

Finally, it highlighted the economic and social advantages of repurposing coal-fired power plants, such as asset reuse, job creation, and improved grid resilience. However, challenges such as high decommissioning costs and the need for long-term commitment to transition efforts remain. Dr Cardemil advocated for innovative approaches that leverage existing infrastructure to advance a sustainable energy future.

5.1.4 Feasibility study of retrofitting Coal-Fired Power Plants in Chile

The presentation "Feasibility study of retrofitting Coal-Fired Power Plants in Chile" by Dr Pedro Valdivia-Lefort, Associate Professor Electrical Engineering Department at the University of Santiago Chile, explored the potential for converting coal-fired power plants in Chile to more sustainable energy solutions. The presentation focused on the Chilean plan for the retirement and retrofitting of coal power plants by 2040, highlighting the current status of this strategy. Dr Valdivia-Lefort discussed various alternatives for retrofitting coal-fired power plants, including Concentrated Solar Power (CSP) plants, synchronous condensers, and ammonia synthesis. The pros and cons of each option were outlined:

- **Concentrated Solar Power (CSP)**: A renewable, non-polluting solution, though it requires significant land and initial investment.
- **Synchronous condensers**: Enhance grid stability and support the integration of renewable energy sources.
- **Ammonia synthesis**: Repurposes coal-fired power plants to produce ammonia, making use of existing infrastructure.

To determine the most viable retrofit option, the study employed the Analytic Hierarchy Process (AHP) method, which evaluated alternatives based on criteria such as environmental and social impact, job creation, and equipment reutilization. Ammonia synthesis emerged as the most favourable option. A cost-benefit analysis of ammonia synthesis was also conducted, revealing key benefits such as reduced CO_2 emissions, equipment reutilization, and income from energy and ancillary services. The main drawbacks include high initial investment, operational costs, and maintenance.

In summary, retrofitting coal-fired power plants in Chile is both viable and advantageous, with ammonia synthesis emerging as a particularly promising solution. Nonetheless, additional sensitivity analyses are needed to enhance the precision of income forecasts and refine cost-benefit evaluations.

5.1.5 Conversion of the Guacolda thermoelectric plant to green ammonia

In the presentation "Conversion of the Guacolda Thermoelectric Plant to Green Ammonia" Mr Camilo Quiroga, Environmental Manager at Guacolda Energia, discussed the strategy for transitioning the Guacolda power plant in Chile from coal to green ammonia as part of the company's commitment to achieving carbon neutrality.

The Guacolda plant, located in the Atacama Region, has a capacity of 770 MW and plays a vital role in the local economy and employment. With Chile's commitment to phasing out coal by 2040—avoiding new coal projects and gradually converting or closing existing plants—the owners of Guacolda aim to convert the facility by co-firing coal with green ammonia. This transition is driven by several benefits, as ammonia combustion produces no CO_2, reduces particulate matter (PM) and sulphur dioxide (SO_2) emissions, and is easier to transport and store than hydrogen. Additionally, green ammonia can be utilized within existing infrastructure and is produced using renewable energy.

The conversion process will occur in two stages:

- **First Stage (2030)**: Retrofit two units to co-fire 30% ammonia and 70% coal, reducing CO_2 emissions from 0.95 to 0.67 tonnes CO_2/MWh.
- **Second Stage (2033)**: Modify all units to co-fire 50% ammonia and 50% coal, further decreasing emissions to 0.48 tonnes CO_2/MWh.

A feasibility study was conducted in 2023, with environmental and engineering assessments scheduled for 2025.

Key challenges and opportunities for the Guacolda conversion include:

- Investment: High initial costs associated with green ammonia production.
- Supply: Securing a stable and cost-effective ammonia supply.
- Regulations: The need for domestic regulations to support the green ammonia industry.
- Education and Training: Developing the technical skills needed for ammonia and hydrogen handling.

- R&D: Promoting the development of green hydrogen and ammonia technologies.

The conversion of the Guacolda power plant aims to provide a reliable, flexible, and sustainable energy solution while preserving jobs and supporting local communities.

The figure 2 shows the Guacolda Thermoelectric Plant with its five units and its geographical context in the city of Huasco, Atacama Region, Chile.

Figure 2 Guacolda plant and geographical context

Source: Quiroga (2024).

5.2 Policy design and regulatory challenges in plant closure and conversion

The second topic was covered on the first day of the seminar, with presentations from two experts on the subject.

- Chile's policy to promote the conversion of coal-fired power plants (Chile)
- Current status of coal thermal power development in Viet Nam, the roadmap, and challenges in the transition process (Viet Nam).

5.2.1 Chile's policy to promote the conversion of coal-fired power plants

In the presentation "Chile's Policy to Promote the Conversion of Coal-Fired Power Plants," Mr Alex Santander, Director of Strategic Planning and Sustainable Development at Chile's Ministry of Energy, outlined the comprehensive strategy to achieve carbon neutrality and a resilient economy by 2050. Key to this plan is the Chilean National Energy Policy (2015, updated in 2022) and the Climate Change Framework Law (2023), which set ambitious targets: generating over 80% of energy from renewable sources by 2030 and reaching 100% zero-emissions energy by 2050. The strategy also includes expanding energy storage capacity to 2 GW by 2030 and 6 GW by 2050.Chile has significant renewable energy potential, estimated to be 80 times greater than its current installed capacity of 33 GW. However, realizing this potential requires substantial investments in infrastructure, including 4,000 km of new transmission lines, 20 GW of renewable projects, and 4 GW of energy storage. Overcoming these challenges while ensuring territorial harmony is crucial for success.

The Chilean Ministry of Energy is spearheading efforts to reconvert five cities historically dependent on coal-fired power generation, including Tocopilla, Mejillones, Huasco, Puchuncaví, and Coronel. From 2018 to 2019, the public and private sectors agreed to halt new coal projects and phase out or convert existing coal units.

In 2021, Chile launched the Just Energy Transition Strategy, focusing on a people-centered transition, addressing local environmental impacts, and ensuring participatory governance. This includes updating emission standards for thermoelectric plants, promoting their conversion, and conducting socio-environmental studies in affected cities. The ultimate goal is to transition to a 100% clean electricity system by 2050, although challenges remain. These include retiring coal-fired power plants, reducing the use of synchronous machines, and integrating clean fuels like hydrogen into the energy mix.

5.2.2 Current status of coal thermal power development in Viet Nam, the roadmap and challenges in the transition process

The presentation “Viet Nam Energy Overview: Challenges in the Energy Transition Process,” by Mr Dao Minh Hoa from the Electricity and Renewable Energy Authority of Vietnam, discussed the efforts to transition to a sustainable energy system in this economy. Vietnam’s GDP has grown at 6.1% annually, with total installed capacity reaching 80.7 GW by 2022. Coal remains the dominant energy source, accounting for 32.3% of the energy mix, followed by hydropower at 21.9%. This economy aims for net-zero emissions by 2050 and has enacted policies focusing on energy efficiency, renewable energy, market reforms, and climate change mitigation. Coal-fired power plants, however, are a significant source of air pollution, and efforts

are underway to reduce emissions through clean coal technologies, carbon capture and storage (CCUS), ammonia and biomass co-firing, and energy storage solutions.

The Viet Nam´s energy strategy is outlined in Politburo Resolution No. 55 and the eighth Power Development Plan (PDP VIII), which focuses on transitioning to cleaner energy by 2050. These plans aim to phase out coal, upgrade plants to meet environmental standards, and increase renewable energy to 47% of the energy mix by 2050. The use of advanced technologies, including ammonia and biomass co-firing and energy storage systems, is also a priority. The transition to renewables will involve replacing coal plants with solar, wind, hydro, and geothermal energy. However, challenges abound. Coal continues to play a critical role in Vietnam's power generation, contributing 40% to 57% of electricity in 2024, and remains key for energy security. Coal plants are cost-effective, ensuring stability, but transitioning to alternatives like gas or nuclear presents practical and commercial hurdles. The shift away from coal will also impact over 100,000 workers and local economies, requiring careful management to avoid resource waste and job losses while promoting renewable energy development.

5.3 Environmental and social considerations for retrofitting thermal power plants

The third topic was covered on the second day of the seminar, with presentations from three experts on the subject.

- Social impacts and just transition related to the conversion of coal-fired power plants (Chile).
- Indonesia's Energy Transition Planning (Indonesia).
- Reconversion of the workforce in the context of a Just Socio-Ecological Transition: Case Study of Puchuncavi (Chile).

5.3.1 Social impacts and just transition related to the conversion of coal-fired power plants

The presentation "Social Impacts and Just Transition Related to Conversion of Coal-Fired Power Plants", by Dr Matilde Spoerer from Chile's Ministry of Energy, outlined the challenges and opportunities associated with transitioning from coal-fired power plants to cleaner energy systems, focusing on social impacts and the importance of a just transition.

Chile is targeting carbon neutrality by 2050, aiming for 100% renewable energy in the electric sector and a 60% reduction in greenhouse gas emissions. Key measures include phasing out coal, with 11 plants closed between 2019 and 2024, four more by 2025, and all coal units closed or converted by 2040. The transition involves local communities through early dialogue, citizen participation, and local development initiatives. A Just Transition Strategy emphasizes economic development, environmental sustainability, and participatory governance. Local Action Plans will be developed collaboratively with civil society, the public sector, businesses, and unions. Additionally, a Decarbonization Plan focusing on 2030 is being developed to guide the gradual reduction of emissions from the electricity sector.

Challenges identified in the energy transition include addressing social inequalities, ensuring energy security during the closure of coal-fired power plants, and mitigating environmental and territorial impacts. Converting coal-fired power plants reduces environmental damage, but the perceived benefits may not be enough for affected communities.

Dr Spoerer emphasized the opportunity for benefit-sharing, ensuring that local communities receive fair advantages from energy projects. This can foster local development and well-being while promoting cooperation between the private sector and communities. Social dialogue is crucial to ensure an inclusive transition to a sustainable energy future.

5.3.2 Indonesia's Energy Transition Planning

The presentation "Indonesia's Energy Transition Planning", by Mr Tony Susandy from the Ministry of Energy and Mineral Resources of Indonesia, outlined Indonesia's roadmap towards achieving net-zero emissions by 2060. The current energy landscape in Indonesia shows a strong reliance on fossil fuels, particularly coal and oil, for electricity generation. However, the plan aims to significantly increase the share of renewable energy sources (NRE) in the energy mix. This increase is being driven by several key initiatives, including:

- **Coal-fired Power Plant (CFPP) Retirement**: A roadmap is in place to accelerate the phase-out of CFPPs, to replace them with renewable energy sources, considering electricity supply and demand. A process is described for selecting CFPPs for early retirement based on criteria like age, capacity, emissions, and the availability of funding and technology. The process prioritizes those with lower carbon intensity. As a matter of fact, 8,770 MW coal-fired power plants have been retired so far.
- **Dedieselization Program**: This program focuses on reducing fossil fuel consumption by optimizing solar PV and battery energy storage systems (BESS), extending operational hours to 24 hours.
- **Rural Electrification Program**: This initiative aims to expand access to renewable-based electricity in rural and remote areas, utilizing solar PV and BESS. A phased rollout is planned.
- **NRE Development**: The plan emphasizes the development of various NRE sources (solar, wind, hydro, geothermal, bioenergy) through the national power plan (RUPTL), aiming for a 20.9 GW NRE capacity addition by 2030. A super grid is identified as crucial for effective integration. The potential for NRE is significant, although currently only a small fraction is utilized.

Figure 3 Coal-fired Power Plant (CFPP) retirement, geographical approach

Source: Susandy (2024)

The presentation highlighted Presidential Regulation No. 112/2022, which provides the framework for these initiatives, emphasizing the importance of just transition, and the use of auction-based procurement for renewable energy projects.

Mr Susandy concluded that Indonesia's energy transition plan is ambitious, aiming for a significant reduction in GHG emissions and a shift towards renewable energy. The roadmap outlines clear strategies and targets, but achieving these goals will require substantial investment, technological innovation, and coordinated efforts across various sectors.

5.3.3 Reconversion of the workforce in the context of a Just Socio-Ecological Transition: Case Study of Puchuncavi, Chile

The presentation "Labour Conversion in the Context of Just Socio-Ecological Transition: Case of Puchuncavi" by M. Arife Mansur from the Valparaiso Regional Secretariat of the Ministry of Energy of Chile, examined the socio-economic impacts of the closure of the AES Andes coal-fired thermoelectric complex in Puchuncavi, and proposes a just transition strategy.

The Chilean Ministry of Energy, committed to sustainable energy development and carbon neutrality by 2050, recognizes the need to address the job losses resulting from the plant's closure. Considering that, the Pontifical Catholic University of Valparaíso initiated a study to gather baseline data for a just transition plan. This involved surveying 400 individuals (workers, community members, and officials) and compiling data on 10,000 subcontracted workers.

The study's objective was to collect and systematize information on employability, training, and labour reconversion needs. Key findings reveal a workforce predominantly male and young, largely from the local area, with a significant portion (30%) earning only the minimum wage and many (20%) living in slums. While around 50% have received training and possess relevant certifications, 60% recognize the necessity for reconversion and express a willingness to participate in further training programs.

Ms Mansur emphasized the importance of thoughtful planning for future actions. These actions should encompass job creation and training programs, broader measures to promote social well-being, and efforts to attract investments in sustainable technologies and productive opportunities. Additionally, she underscores the need for participatory governance to ensure the effective implementation of the just transition strategy. The ultimate goal is to achieve a fair and equitable transition for the Puchuncavi community.

To sum up, it is important to develop and implement a just transition plan that addresses the socio-economic impacts of decarbonization, ensuring that affected workers and communities are supported through training, job creation, and sustainable development initiatives.

5.4 New business opportunities emerging from coal plant conversion

The fourth topic was covered on the second day of the seminar, with presentations from three experts on the subject.

- Key Strategies for Converting Coal-Fired Plants in the 2050 Net-Zero Transition Plan in Chinese Taipei (Chinese Taipei).
- Business opportunities in Chile in the energy sector (Chile).
- Financing mechanisms for power plant conversion (Mexico).

5.4.1 Key Strategies for Converting Coal-Fired Plants in the 2050 Net-Zero Transition Plan in Chinese Taipei

The presentation “Key Strategies for Converting Coal-Fired Plants in the 2050 Net-Zero Transition Plan in Chinese Taipei” by Dr Keng-Tung Wu, from Chung Hsing University, outlined the strategies and challenges involved in transitioning coal-fired power plants to achieve net-zero emissions by 2050.

The presentation began by detailing Chinese Taipei's energy structure in 2023, heavily reliant on imported fossil fuels (96.7%), primarily crude oil and petroleum products. Coal contributes significantly to both energy supply and consumption.

Chinese Taipei's 2050 net-zero transition policy is based on four main strategies (energy, industrial, lifestyle, and social transitions) supported by technology research and development (R&D) and climate legislation. The legislative framework involves amending the Greenhouse Gas Reduction and Management Act to include a 2050 net-zero emissions target, along with measures like carbon pricing and voluntary offset trading.

The core of the presentation focused on converting coal-fired plants, highlighting Taipower Co.'s strategy of using natural gas as a bridge towards net-zero. This involves natural gas combined cycle plants and explores hydrogen co-firing with natural gas as a pathway to zero emissions, acknowledging challenges related to NOx emissions and power output reduction. Innovative methane pyrolysis technology, which produces hydrogen with lower energy consumption, is presented as a potential solution. An alternative approach using biomass co-firing with carbon capture and storage (BECCS) was also discussed, emphasizing the need for innovative application strategies given the current small scale of biomass energy in Chinese Taipei. A Finnish case study of biomass co-firing in a power plant was used as an example.

The presentation concluded by summarizing these strategies under the acronym RETIS (Regulations, Economy, Technologies, Integration, Social Enterprise), and emphasizing the need for a comprehensive and integrated approach to achieving a just and effective energy transition.

5.4.2 Business opportunities in Chile in the energy sector

The presentation “Investment Opportunities at the Chilean Electric System” by Mr Juan Pablo Purcell from Invest Chile, outlined the potential for foreign direct investment (FDI) in Chile’s energy sector, focusing on the transition to renewable energy and the decarbonization of the electric system.

Using the case of Chile as an example for other APEC economies, the presentation begins by outlining the broad benefits of Foreign Direct Investment (FDI) for Chile, including economic growth, job creation, and improved living standards. It then presents macroeconomic data showing a steady flow of FDI into Chile over the years, despite global economic fluctuations.

A key focus is Chile's state-led decarbonization strategy, aiming for zero emissions in the electricity sector by 2050, with significant reductions in greenhouse gas emissions and a substantial increase in renewable energy capacity. This ambitious plan includes a phased retirement of coal-fired power plants, illustrated by projected installed capacity reductions. The current energy mix (2023) shows 63% renewable generation, predominantly from hydro and solar photovoltaic, with room for further growth.

The presentation identified significant opportunities for investment in renewable energy projects, including solar, wind, and run-of-river hydro. It also emphasizes the potential for green hydrogen production, showcasing a state strategy that leverages Chile's abundant renewable energy resources and existing infrastructure, particularly for water desalination.

Finally, investment opportunities were detailed within the energy transition, encompassing the reconversion of thermopower plants (through co-firing and energy storage solutions), transmission infrastructure upgrades, and the broader green hydrogen value chain (production, finance, off-takers, and consumption technologies). The presentation concludes by reiterating Invest Chile's role in facilitating these investments in this economy.

5.4.3 Financing mechanisms for power plant conversion

The presentation “Financing Mechanisms for Power Plant Conversion” by Mr Jorge Gutierrez from Carbon Trust, discussed strategies and financial tools for transitioning from coal-fired power plants to renewable energy sources. It outlines key mechanisms to support companies in this shift, focusing on experiences, challenges, and opportunities.

The presentation began with the analysis of coal asset portfolios, which involves reviewing policies, developing transition scenarios (such as renewable energy replacement or plant repurposing), and conducting techno-economic analyses to assess feasibility. A prioritization framework, using RAG (Red-Amber-Green) analysis and multi-criteria analysis (MCA), helps determine the best approaches.

A comprehensive economic assessment was emphasized, considering climate finance needs (like compensation for early retirement), environmental costs and benefits (emission reductions, land use impacts), and social costs/gains (job displacement, community impact). Mr Gutierrez also explored sustainable finance, categorizing it into climate, green, impact, and social finance, and mapping the financial ecosystem. This includes debt instruments such as green bonds, sustainability-linked bonds, and climate transition bonds, which play a critical role in achieving sustainability goals.

Several financing mechanisms were presented to facilitate managed coal phaseouts, including managed transition vehicles, coal retirement credits, ratepayer-backed securitizations, power hedges, and concessional financing. The presentation also discussed carbon pricing, such as taxes and emissions trading systems, and its role in incentivizing emission reductions and technological innovation. It addressed challenges like distributional impacts and international competitiveness, guiding aligning transition bonds with decarbonization goals to avoid greenwashing.

In conclusion, Mr Gutierrez offered a comprehensive overview of financial tools and strategies for managing the transition from coal to renewable energy. It emphasizes the need for a holistic approach, engaging stakeholders and ensuring a just transition for communities affected by the shift, ultimately aiming for a sustainable and resilient energy future.

6. Conclusions

6.1 General conclusions

The conversion of coal-fired power plants represents a critical pathway to reducing greenhouse gas emissions and combating global warming. This document has focused on exploring energy

storage systems as a retrofitting solution, drawing insights from the experiences and challenges faced by APEC economies that participated in the seminar, including Chile; Indonesia; Malaysia; Mexico; Chinese Taipei; Thailand; the United States, and Viet Nam. The opportunities identified during the two-day seminar provide valuable lessons that can also benefit other APEC economies unable to attend.

The seminar offered a deep dive into the potential of coal-fired plant conversions through innovative technologies, particularly energy storage systems. It provided a platform to reassess existing policies and examine how APEC economies can further promote these alternatives to enhance their energy transitions.

One of the key conclusions is that converting coal-fired power plants is consistently a better alternative than shutting them down. This approach not only enables the reuse of heavily industrialized areas and the preservation of jobs in coal-dependent regions but also represents a sound economic decision.

Discussions throughout the seminar emphasized the vital role of innovative energy storage systems in ensuring the efficiency and reliability of converted power plants. These systems support grid stability, balance supply and demand, and facilitate the integration of renewable energy sources.

6.2 Conclusions by topic

Topic 1: Lessons Learned from Converting Coal-Fired Power Plants with Energy Storage System

The global shift toward repurposing coal-fired power plants into sustainable energy solutions was a central focus. For instance, in the United States, converting coal-fired power plants into energy storage systems provides economic benefits, including reduced decommissioning costs, job preservation, enhanced grid reliability, and smoother integration of renewable energy. While in Chile, a range of retrofitting technologies was explored, such as energy storage systems, photovoltaic plus battery solutions, Carnot batteries, and green ammonia. These approaches deliver emission reductions, foster local economic development, and improve grid flexibility.

These examples underscore the potential of transitioning from fossil fuels to cleaner, more efficient energy systems while addressing economic and environmental challenges.

Topic 2: Policy design and regulatory challenges in plant closure and conversion

This topic analysed the policies of Chile and Viet Nam, highlighting distinct challenges shaped by their energy mix and long-term goals. For instance, Chile aims for carbon neutrality by 2050 with 80% renewable energy by 2030. Through the Just Energy Transition Strategy, Chile focuses on phasing out coal-fired power plants while addressing challenges such as high infrastructure costs and territorial concerns. On the other hand, Viet Nam faces heavy reliance on coal for energy security and economic stability. While efforts to improve energy efficiency and increase renewables are underway, coal remains a cost-effective option. Viet Nam's roadmap involves upgrading coal-fired power plants to meet environmental standards and exploring alternatives like gas and nuclear, but these transitions pose significant challenges, including potential job losses affecting over 100,000 workers and their communities.

Topic 3: Environmental and social considerations for retrofitting thermal power plants

The seminar highlighted the critical importance of addressing social and environmental aspects of energy transitions. Regarding Chile´s situation, coal-fired power plant closures have significant social implications. The Just Transition Strategy prioritizes community involvement, economic development, and environmental sustainability to ensure energy projects benefit local populations. Indonesia faces similar challenges due to its reliance on fossil fuels. Indonesia has developed a roadmap to phase out coal-fired power plants and promote rural electrification, but it must manage the social impacts of closures and maintain energy security during the transition.

Topic 4: New business opportunities emerging from coal-fired power plant conversion

The transition from coal to renewable energy presents a wide range of business opportunities, particularly in retrofitting coal-fired power plants. Cases of Chinese Taipei, Chile, and Mexico were analysed. Chinese Taipei aims to achieve net-zero emissions by 2050 through advanced technologies such as natural gas, hydrogen co-firing, biomass with carbon capture, and the adoption of innovative policy frameworks. Chile is prioritizing the attraction of Foreign Direct Investment (FDI) to accelerate the decarbonization of its electricity sector. Meanwhile, Mexico emphasizes the use of financial mechanisms like green bonds, sustainability-linked bonds, and managed transition vehicles to fund coal phase-outs while mitigating associated economic and social impacts.

7. Recommendations

Recommendations for APEC economies are presented on each topic

Topic 1: Lessons learned from converting coal-fired power plants with energy storage systems:

- Foster innovation and collaboration in energy storage solutions and alternative fuels to enhance coal-fired power plant retrofitting efforts.
- Investigate the effectiveness of combining various technologies, such as ammonia synthesis and carnot batteries, in coal-fired power plant retrofits to optimize performance and reduce emissions.
- Engage with communities and workers early in the transition process to ensure an equitable shift. Prioritize investments in training programs and infrastructure to facilitate a smooth move towards a low-carbon economy.

Topic 2: Policy design and regulatory challenges in thermal power plant closure and conversion:

- Policymakers should draw lessons from successful coal-fired power plant conversions with energy storage systems, incorporating best practices into new policies.
- Develop policies that address territorial and environmental concerns while promoting the transition to cleaner energy systems, ensuring the preservation of local ecosystems and communities.
- Strike a balance between energy security needs and long-term sustainability goals, ensuring that energy transitions do not compromise energy access or affordability.
- Support innovation and just transition initiatives by creating clear regulatory frameworks and providing incentives for research and development in energy technologies.
- Recognize the critical need for investments in infrastructure, including transmission lines and energy storage systems, to support the transition to renewables. Additionally,

allocate resources for retraining workers and ensuring energy security during the transition.

Topic 3: Environmental and social considerations for retrofitting thermal power plants:

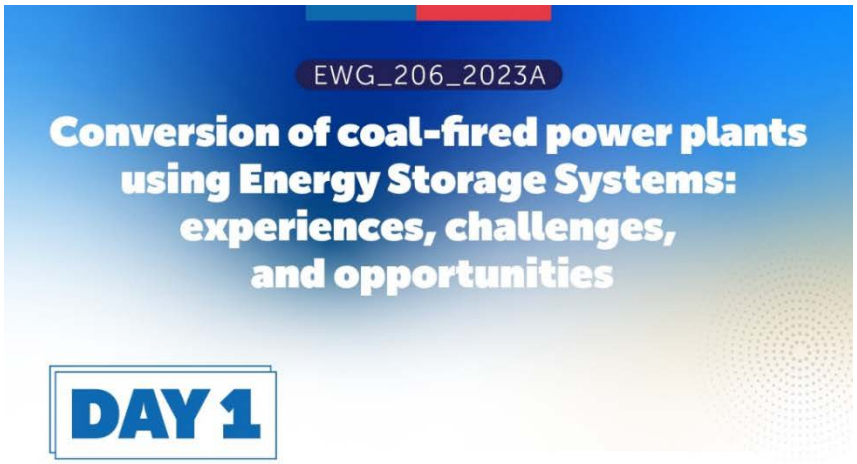
- Accelerate the deployment of renewable energy projects to complement the transition away from coal.
- Strengthen the Just Transition Strategy by focusing on retraining and upskilling the workforce, particularly in coal-dependent regions.
- Ensure that affected communities are actively involved in the planning and decision-making processes, prioritizing job creation, skill development, and initiatives that promote social well-being.

Topic 4: New business opportunities emerging from coal-fired power plant conversion:

- Foster partnerships between the public and private sectors to ensure a successful energy transition that benefits all stakeholders and drives shared prosperity.
- Explore and invest in innovative technologies to reduce emissions and promote long-term sustainability.
- Encourage private sector investment in coal-fired power plant conversion by offering clear regulatory incentives and expanding energy infrastructure, particularly in energy storage and co-firing technologies.
- Develop sustainable financial mechanisms, such as carbon pricing and transition bonds, to support the phase-out of coal while mitigating social impacts and providing support for affected communities throughout the transition process.

8. Annex

Seminar agenda



DAY 1

8:30 a 9:00 hrs	Registration.
9:00 a 9:30hrs	Welcome address.

TOPIC 1

OPPORTUNITIES AND LESSONS LEARNED FROM THE CONVERSION OF COAL-FIRED POWER PLANTS THROUGH ENERGY STORAGE SYSTEMS

9:30 a 10:00 hrs	**Repurposing Fossil Assets with Hybrid Energy Storage Solutions.** Mr. Bhima Sastri | U.S. Department of Energy | USA.
10:00 a 10:30 hrs	**Site conversion: from coal to innovation.** Ms. Gabriela Alcázar | Engie | CHILE.
10:30 a 11:00 hrs	**Pathways for repurposing coal power plants into storage systems through Carnot Batteries schemes.** Mr. José Miguel Cardemil | Energy Center UC | CHILE.
11:00 a 11:30 hrs	**Coffee break.**
11:30 a 12:00 hrs	**Feasibility study of retrofitting Coal Power Plants in Chile.** Mr. Patricio Valdivia | University of Santiago Chile | CHILE.
12:00 a 12:30 hrs	**Conversion of the Guacolda thermoelectric plant to green ammonia.** Mr. Camilo Quiroga | Guacolda Energía | CHILE.
12:30 a 13:00 hrs	**Speakers' Panel Discussion.**
13:00 a 15:00 hrs	**Lunch break.**

TOPIC 2

POLICY DESIGN AND REGULATORY CHALLENGES IN THERMAL POWER PLANT CLOSURE AND CONVERSION

15:00 a 15:30 hrs	**Chile's policy to promote the conversion of coal-fired power plants.** Mr. Alex Santander | Ministry of Energy | CHILE.
15:30 a 16:00 hrs	**Current status of coal thermal power development in Viet Nam, the roadmap and challenges in the transition process.** Mr. Dao Minh Hoa | Electricity and Renewable Energy Authority | VIET NAM.
16:00 a 16:30 hrs	**Speakers' Panel Discussion.**
16:30 a 16:40 hrs	**Closing Remarks.**

DAY 2

9:30 a 10:00 hrs Registration.

10:00 a 10:10 hrs Welcome address.

TOPIC 3

ENVIRONMENTAL AND SOCIAL REQUIREMENTS FOR RETROFITTING THERMAL POWER PLANTS WITH ENERGY STORAGE SYSTEMS

10:10 a 10:40 hrs **Social impacts and just transition related to the conversion of coal-fired power plants.**
Ms. Matilde Spoerer | Ministry of Energy | CHILE.

10:40 a 11:10 hrs **Indonesia's Energy Transition Planning.**
Mr. Tony Susandy | Ministry of Energy and Mineral Resources | INDONESIA.

11:10 a 11:40 hrs **Reconversion of the workforce in the context of a Just Socio-Ecological Transition: Case Study of Puchuncaví, Chile.**
Ms. Arife Mansur | Ministry of Energy | CHILE.

11:40 a 12:10 hrs **Speakers' Panel Discussion.**

12:10 a 14:10 hrs **Lunch break.**

TOPIC 4

NEW BUSINESS OPPORTUNITIES THROUGH COAL POWER PLANT CONVERSION

14:10 a 14:40 hrs **Key Strategies for Converting Coal-Fired Plants in the 2050 Net-Zero Transition Plan in Chinese Taipei.**
Mr. Keng-Tung Wu | Chung Hsing University | CHINESE TAIPEI.

14:40 a 15:10 hrs **Business opportunities in Chile in the energy sector.**
Mr. Juan Pablo Purcell | InvestChile | CHILE.

15:10 a 15:40 hrs **Financing mechanisms for power plant conversion.**
Mr. Jorge Gutiérrez-García | Carbon Trust | MEXICO.

15:40 a 16:10 hrs **Speakers' Panel Discussion.**

16:10 a 16:20 hrs **Closing Remarks.**

APEC Asia-Pacific Economic Cooperation