APEC Workshop on Promoting New Smart Materials for Sustainable Energy

APEC Energy Working Group

November 2025

Asia-Pacific
Economic Cooperation

APEC Workshop on Promoting New Smart Materials for Sustainable Energy

APEC Energy Working Group

November 2025

APEC Project: EWG 203 2024A

Produced by
Ms. Pham Quynh Mai
Ministry of Industry and Trade
Viet Nam

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

APEC#225-RE-04.12

Table of contents

Contents

APEC WORKSHOP ON PROMOTING NEW SMART MATERIALS FOR SUSTAINABLE ENERGY

Ha Noi, Viet Nam

12 – 13 June 2025

Workshop Summary Report

I. Introduction

On June 2025, the ***"APEC Workshop on Promoting New Smart Materials for Sustainable Energy"*** was held in Hanoi, Viet Nam. The project was led by Viet Nam and co-sponsored by China; Japan; Korea; Papua New Guinea; Chinese Taipei; and Thailand. Speakers and participants came from the private sector, business associations, international organizations, research institutions, and APEC economies' relevant Ministries and government agencies.

Through sharing information, experiences, best practices, the ***"APEC Workshop on Promoting New Smart Materials for Sustainable Energy"*** aimed to provide capacity building for member economies, especially developing ones in promoting innovation of new materials and technologies to promote sustainable energy through disseminating information and knowledge about the latest scientific advancements and technologies associated with new materials for sustainable energy; identifying and sharing experiences in addressing challenges under promotion of new materials; as well as promoting network opportunities through fostering collaborations, partnerships, and shared initiatives.

II. Background

While climate change is in the spotlight with highly rising global temperature and increasing erratic and severe weather patterns, it is increasingly recognized that more joint efforts should be made for sustainability in general, sustainable energy in particular. In that sense, smart materials such as smart rooftops, thermoelectric, photovoltaics, pyroelectrics, chromoactive, photoluminescent, as well as other innovations, help to conserve renewable energy smartly and sustainably.[1] However, APEC member economies, especially developing ones might have limited capacity, technologies, resources, as well as experiences to promote innovation and/or mechanism for innovation, especially in developing and adopting new smart materials. Through identifying the challenges, the workshop aims to disseminate information and knowledge about the latest scientific advancements and technologies associated with new materials for sustainable energy; identifying and sharing experiences in addressing challenges under promotion of new materials; as well as promoting network opportunities through fostering collaborations, partnerships, and shared initiatives.

This project is in line with the Chair's Statement of the 13th APEC Energy Ministerial Meeting (EMM 13), APEC members economies are committed to "promoting energy security, and ensuring access to affordable, reliable, sustainable, and modern energy for all, … including by fostering collaboration, such as voluntary sharing of emerging and available technologies under mutually agreed terms, capacity building, transparent and interoperable regulatory frameworks, and exchange of best practices and experience".

This project is in line with the EWG's strategic plan 2019 – 2023 that states "strengthen coordination and cooperation through sharing best practices, accelerating innovation and promoting the deployment of advanced technologies, including renewable energy, energy efficiency, cleaner and more efficient fossil fuels, hydrogen, and nuclear energy for interested economies, adhering to nuclear safety, security, safeguards, and peaceful use".

III. Key Issues

1. Overview of energy/ sustainable energy, and new smart materials for sustainable energy

Dr Pengfei Xie, Professor, Assistant President, China Industry - Education Platform for Energy Storage (Tianjin University), APEC Sustainable Energy Center (APSEC): The speaker provided an overview of critical advancements in innovative materials for electrochemical energy storage in the APEC region through the establishment and development of two important platforms for

[1] Bhattacharjee J, Roy S. Smart materials for sustainable energy. Natural Resources Conservation and Research. 2024; 7(1): 5536. https://doi.org/10.24294/nrcr.v7i1.55 36

sustainable energy in the region including the APEC Sustainable Energy Center (APSEC), formally established in 2014 at the 11th APEC Energy Ministers' Meeting; and the Chinese Energy Storage Platform (NESP), based at Tianjin University, as one of China's premier industry-education integration innovation platforms, serving as a cornerstone of China’s decarbonization strategy, which display significant institutional support and strategic importance of the research and development efforts to realize innovative materials for sustainable energy.

The speaker focused on the critical global demand for efficient energy storage, which is driven by the escalating need for renewable energy sources, proliferation of electronic devices, and rapid growth of electric mobility. The electrochemical energy storage (EES) systems face a number of challenges such as safety concerns related to thermal runaway, degradation mechanisms affecting longevity, and the imperative for more advanced battery management systems. To mitigate these issues and enhance performance, NESP has been at the forefront of investigating and developing novel materials.

A significant highlight is a pioneering breakthrough in sodium-ion battery technology. The speaker introduced the "sieved carbon" approach, presented as a disruptive innovation for high-energy sodium-ion batteries. This new paradigm for sodium storage has successfully overcome existing limitations, demonstrating remarkable performance metrics. The sieved carbon anode product boasts an initial efficiency exceeding 90%, a compaction density greater than 0.95 grams per cubic centimetre (g/cm^3), and a specific capacity remarkably over 450 milliampere-hours per gram (mAh/g). Crucially, the energy density of a single cell utilizing this material surpasses 180 Watt-hours per kilogram (Wh/kg), positioning it among the international leading standards.

Based on these advancements, there remain further innovative materials for diverse battery applications. For example, NESP has made progress in dense silicon-carbon anodes for high-energy density lithium-ion batteries, where they have established a complete set of industrial technologies, including specialized equipment for mass production. The resulting micron-scale silicon-carbon anode material has achieved an initial efficiency of over 88% and a battery volumetric energy density exceeding an impressive 1048 Watt-hours per liter (Wh/L).

Furthermore, the conceptualization and development of "lithium-sulfur catalysis," help yielding liquid and all-solid-state lithium-sulfur batteries with an energy density of over 500 Wh/kg, high-rate capability (5C), and ultra-stable cycling (6,000 cycles), facilitated by the innovative concept of "interface anchoring."

Finally, the speaker showcased an innovative preparation technology for fluoride materials. The "dry-wet separation" method for 4V high-voltage fluoride materials represents a significant breakthrough in electrode, electrolyte, and battery manufacturing processes. This technology enables secondary lithium batteries to achieve a specific energy over 600 Wh/kg and thermal batteries a specific power exceeding 20 kilowatts per kilogram (kW/kg) with an activation time under 80 milliseconds. These collective developments underscore NESP's commitment to advancing smart materials that promise more efficient, safer, and sustainable energy storage solutions, crucial for the global energy transition.

2. **Identifying opportunities, challenges, and approaches to promote the adoption of new smart materials for sustainable energy from various perspectives**

Mr Vu Quang Dang, Energy Independent Consultant, Viet Nam: The speaker provided a comprehensive overview of Viet Nam’s strategic direction towards green cement production, highlighting the critical role of alternative fuels (AF) and alternative materials (AM) in achieving their sustainability targets. Viet Nam sets an ambitious green cement targets for 2030, as mandated by the Decision No. 1266/QD-TTg in 2020, including five key pillars: energy efficiency (e.g., reducing energy consumption to ≤ 730 kcal/ton of clinker), emission reduction (e.g., CO2 ≤ 650 kg/ton cement), widespread adoption of waste heat recovery (WHR) systems, and significant increases in the use of AF (≥ 15% by 2030 and 30% by 2050) and AM (≥ 20% by 2025 and 30% by 2030, derived from fly ash and industrial wastes). This detailed framework underscores Viet Nam’s commitment to a more sustainable industrial future.

The speaker briefed the potential for Refuse Derived Fuel (RDF) production within Viet Nam's waste management value chain. The RDF process flow plan, from primary crushing and drying to pelletization, helps to realize the transformation of various waste streams into a valuable energy source for industrial applications. In 2022, 44.2 out of 51.0 million tons per year (Mtpy) of combined Municipal Solid Waste (MSW) and Industrial Solid Waste (ISW) generated is collected. This translated to a total RDF potential of 20.0 million tons per year, while the current total RDF demand (from waste-to-energy plants and cement factories) stands at only 3.2 Mtpy, indicating a substantial untapped resource.

The adoption of RDF has potential positive impacts on the Vietnamese cement sector, including avoiding up to 14.9 million tons of carbon dioxide (CO2) emissions and displacing approximately 2.3 million tons of coal annually. Additionally, the ash produced from RDF (comprising 20-30% of the RDF feedstock) can be utilized as an alternative material in cement production, offering a valuable dual benefit of waste valorisation and resource conservation. The emergence of a pilot carbon market in Viet Nam, scheduled from 2025-2028, is also regarded as a forthcoming incentive that could further drive carbon emission reductions from cement factories.

On the other hand, there remain barriers hindering wider RDF adoption in Viet Nam. These include a notable lack of government incentives for cement companies to produce and use RDF, leading to insufficient investment capital support, limited tax reduction schemes, and delays in obtaining necessary permissions. The process of acquiring permits for co-processing using RDF for cement companies is particularly complicated and lengthy, involving various environmental requirements, compliance with stringent regulations, and the need for equipment modifications. Furthermore, a major structural challenge is the absence of an existing, mature RDF market in Viet Nam, which means cement companies currently struggle to procure RDF directly. This situation is exacerbated by limited MSW processing facilities and restrictions on inter-provincial MSW transportation, creating significant bottlenecks in the supply chain.

The speaker shared two insightful case studies. The former is the Pilot Lam Thach Co-processing Project in Viet Nam, which demonstrates significant reductions in coal consumption (10%) and production costs (3-5%), with a short payback period of 5 years. The latter showcases a successful collaboration in the Philippines' alternative fuel, featuring Universal Robina (a food manufacturer), Holcim, and the Government of Obando, displaying an excellent model of collaboration between the private and public sectors, emphasizing community development and environmental stewardship in waste management, offering valuable lessons to promote the adoption of alternative fuels in the cement sector.

Mr Phung Quoc Huy, Senior Researcher, Asia Pacific Energy Research Center (APERC): The speaker provided a crucial analysis of increasing demand for critical minerals, an indispensable source for the global transition to cleaner energy technologies. Modern clean energy solutions are significantly more mineral-intensive than their fossil fuel-based ones. While smart materials offer innovative solutions for sustainable energy applications (e.g., smart rooftops, photovoltaics, thermoelectric, etc.,), they themselves are heavily reliant on a consistent and robust supply of critical raw materials, such as copper, lithium, nickel, cobalt, graphite, and rare earths, etc., all of which are fundamental to the rapidly expanding smart materials nexus in various clean energy applications. For instance, a typical electric car requires six times more mineral inputs than those of a conventional car. An onshore wind plant demands nine times more mineral resources than a gas-fired power plant.

In that sense, there remains an alarming demand for selected critical minerals and a projected supply-demand gap. Data presented graphically from 2021-2023, along with projections for the coming decades, clearly demonstrates a substantial and high-growing demand across major critical minerals, particularly under advanced technologies scenarios. This analysis reveals a looming gap between supply and demand that poses a formidable challenge to scaling up clean energy infrastructure globally. Furthermore, the speaker highlighted the concentrated geographical distribution of both raw material production and refined minerals, indicating potential vulnerabilities and geopolitical risks inherent in these highly centralized supply chains compared to the more diversified fossil fuel supply chain.

To mitigate these challenges and ensure a more stable supply of resources, the presentation emphasized an urgent need for innovative technologies. Proposed solutions include advanced mining techniques such as deep-sea mining, with examples from economies like China; Japan; and Norway, and, aimed at tapping into new reserves. More critically, the recovery of rare earth elements (REEs) from secondary sources like coal and waste materials, particularly in Canada and the US, is highlighted as an essential strategy to reduce reliance on primary extraction. Additionally, redesigning and utilizing smart minerals to reduce materials intensity and enhancing efficiency through the development of alternative materials are identified as key strategies to mitigate disruptions in the critical minerals supply chain, thereby ensuring the uninterrupted progress of the sustainable energy agenda. In this sense, the advancement in smart materials hold the promising potential to optimize resource use and potentially reduce the overall consumption of these scarce minerals, fostering a more circular and resource-efficient clean energy transition.

3. **Promoting innovation to promote the adoption of new smart materials for sustainable energy**

Mr. Harris, Head of Survey and Testing Center for Electricity, New, Renewable Energy and Energy Conservation, Indonesia: The speaker focused on outlining Indonesia's ambitious policy and strategic commitments towards achieving Net Zero Emission (NZE) by 2060, inextricably linked with Indonesia's sustained economic growth. Indonesia is committed to strengthening their independence through self-sufficiency in vital sectors, including energy. This principle, drawn from the "8 Points of Asta Cita" and formalized by the Presidential Decree No. 1/2025 for accelerating energy security, forms the philosophical bedrock of Indonesia's energy transition. The speaker utilized the "4A Parameter in Energy Resilience" framework – Availability, Accessibility, Affordability, and Acceptability – to benchmark Indonesia's energy resilience index, which stood at 6.64 out of 10 in 2023, and articulated the strategies in place to systematically improve each of these critical parameters.

Indonesia promotes robust commitments to reducing greenhouse gas (GHG) emissions in the energy sector. The economy aims for a substantial reduction of 358 million tons of carbon dioxide equivalent (CO_2e) by 2030, a target aligned with its "Enhanced Nationally Determined Contribution" (NDC). The largest contribution to achieving this ambitious reduction is expected from the widespread adoption of Renewable Energy (RE) sources (accounting for 51% of the targeted reduction) and aggressive Energy Efficiency (EE) measures (contributing 37%). He outlined a multi-pronged core strategy for reaching NZE by 2060, encompassing massive electrification across all sectors, significant development of new and renewable energy (NRE), managed moratorium and early retirement of existing coal power plants, the strategic development of new energy sources such as hydrogen, ammonia, and nuclear, the implementation of Carbon Capture, Utilization, and Storage (CCS/CCUS) technologies, and robust energy efficiency programs.

Indonesia also develops a detailed electricity generation roadmap, projecting a Net Capable Power (DMN) of 443 Gigawatts (GW) by 2060. This roadmap envisions a power mix where 42% of Variable Renewable Energy (VRE) is equipped with 34 GW of storage, and 58% comes from Non-VRE dispatchable sources. Indonesia sets specific and ambitious targets for various NRE sources, including solar (109 GW), wind (73 GW), and hydro (71 GW), alongside substantial investments in emerging technologies like hydrogen (25 GW) and nuclear power (35 GW). The speaker highlighted the staggering financial implications, projecting a total interregional generation and transmission investment demand of USD 1.104 trillion, averaging USD 30 billion per year, underscoring the immense financial commitment necessary for this transformative transition. Various NRE development programs are showcased, including rooftop and ground-mounted solar, floating PV, onshore and offshore wind, hydro/hybrid systems, pumped storage, and sustainable biofuels like biodiesel, bioethanol (Sustainable Aviation Fuel - SAF), along with government drilling initiatives for geothermal energy.

Indonesia encounters a few challenges impeding this extensive energy transition. These challenges include the immense need for substantial infrastructure investment in transmission and distribution networks to connect dispersed renewable energy sources with demand centres. There is a necessity for robust regulatory frameworks, citing the recently issued Ministerial Regulation Number 5 of 2025 on power purchase agreements for renewable energy as a step in the right direction. Limitations in economics and funding, often due to high initial investment costs and perceived risks, pose significant hurdles. Furthermore, the nascent stage of domestic industry readiness for manufacturing RE equipment and components, along with the crucial need for sustained social acceptance from local communities for large-scale RE projects (particularly hydro and geothermal), are identified as key areas requiring focused attention and strategic interventions.

Finally, the speaker emphasized the indispensable role of international support and collaboration in realizing Indonesia's ambitious energy transition goals. For example, the Just Energy Transition Partnership (JETP) has helped Indonesia to successfully mobilize an impressive USD 21.6 billion in funding commitments. The Asia Zero Emissions Community (AZEC) initiative has had 68 cooperation agreements and secured an initial fund of USD 500 million from the Japanese government, underscoring the collective, multi-stakeholder effort required to overcome the complexities of such a profound energy transformation. These international partnerships are deemed crucial for ensuring the smooth and successful implementation of Indonesia's comprehensive energy transition strategy.

Dr Nguyen Dang Tung, Assistant Professor of Materials Science cum Director of Career and Industry, College of Engineering and Computer Science, Vin University, Viet Nam: The speaker provided an overview of how Artificial Intelligence (AI) can serve as a powerful catalyst for accelerating the development of smart materials, thereby driving global sustainability efforts. He began by framing the current global context as being at the confluence of "twin revolutions": the urgent imperative for a global energy transition and the exponential rise of AI. AI is not merely an advanced tool, but also a fundamental enabler for achieving ambitious energy goals, particularly through its transformative potential in materials science. "Smart materials" in the context of sustainable energy, is understood as encompassing both novel materials for energy applications (such as perovskites for high-efficiency solar cells, solid-state electrolytes for safer and energy-dense batteries, and Metal-Organic Frameworks (MOFs) for carbon absorption) and innovative, "green" processing methods that reduce toxicity and environmental impact.

AI is believed to be capable of fundamentally reshaping materials science, moving from a traditional, laborious trial-and-error approach to a predictive and design-oriented methodology. AI and Machine Learning (ML) can analyse vast amounts of complex data to identify intricate patterns and make highly accurate predictions, thereby significantly accelerating the pace of materials discovery. The speaker also introduced a conceptual "AI for Materials Discovery Framework," illustrating how AI can seamlessly integrate and enhance various stages of the discovery process, including literature review, data extraction, experimentation, and characterization. This framework leverages both human expertise and advanced AI/robotic automation, incorporating sophisticated techniques like database retrieval and the application of Large Language Models (LLMs) to efficiently extract critical synthesis conditions and X-ray Diffraction (XRD) patterns from extensive scientific literature.

A key highlight of the presentation was examples of the innovative integration of AI with "Green Chemistry" and "High-throughput Robotics" such as the application of AI in the synthesis of Metal-Organic Frameworks (MOFs), which are porous materials utilized for critical functions like CO2 capture, water harvesting, and catalysis. Robotic liquid handlers, guided by AI, enable the simultaneous execution of numerous experiments based on custom-made experimental designs, dramatically accelerating the discovery process and material optimization. Furthermore, AI also can contribute directly to environmental friendliness by suggesting alternative, less polluting chemicals in synthesis processes, such as the use of zinc chloride instead of zinc nitrate to avoid nitrate pollution. The speaker showcased the application of Contrastive Language-Image Pre-Training (CLIP) for improved binary classification in few-shot settings, enhancing the accurate analysis and identification of crystalline versus non-crystalline materials.

The speaker stressed benefits of this "AI-Material Synergy". This synergistic approach dramatically accelerates discovery timelines, transforming processes that traditionally take years into months. It also significantly reduces the cost associated with materials discovery and development, making innovation more accessible. Moreover, this synergy enables the design of materials with superior and tailored properties for specific applications, thereby unlocking entirely new possibilities for sustainable technologies.

Ms Marie Joy Gameng, Science Research Specialist 2, Energy Policy and Planning Bureau (EPPB), the Philippines: The speaker presented a comprehensive overview of the Philippines' energy landscape and its strategic initiatives to leverage innovation and smart materials in pursuit of a sustainable, secure, and clean energy future. The Philippines primary energy mix indicates a significant reliance on imported sources. There is a robust portfolio of existing

Renewable Energy (RE) projects, contracted under Republic Act (RA) 9513, showcasing substantial potential and installed capacities across various RE sources, including hydropower, ocean energy, geothermal, wind, solar, and biomass, thereby underscoring the commitment to renewable energy transition.

The Philippines' Department of Energy's (DOE) contributes to promulgating overarching strategic plans such as the Philippine Development Plan 2023-2028 and the Philippine Energy Plan (PEP) 2023-2050. The strategic direction for the energy sector is founded on three core pillars: ensuring access to affordable energy; enhancing reliability and resiliency of the energy system; and promoting clean and sustainable Energy. The PEP 2023-2050 outlines a forward-looking "Future Energy Scenario in Capsule," which emphasizes ambitious renewable energy growth targets (aiming for 35% RE share in the power generation mix by 2030, with an aspiration to reach 50% by 2040), robust energy efficiency and conservation (EEC) measures, significant penetration of emerging and innovative technologies (including a 50% electric vehicle (EV) penetration by 2040), the strategic deployment of Information and Communications Technology (ICT) for smart grid development, and comprehensive initiatives for Energy Resiliency. The legal framework supporting these ambitions, the RE Act of 2008 (RA 9513), is highlighted for its provisions on accelerating RE exploration and development through fiscal and non-fiscal incentives, achieving energy self-reliance, and mitigating the effects of climate change.

The speaker highlighted the concrete applications of "Smart Materials in the Philippine Energy Sector". Smart materials are substances exhibiting a change in one or more properties in response to external stimuli, acting as a "GAME CHANGER" for energy sustainability by enabling optimized resource use through intelligent management systems. She showcased several promising initiatives and ongoing research in this area, including the development of nano particle thin film solar cells using quantum dot technology (partnership between Mariano Marcos State University (MMSU) and Regius Energy Corporation (UK); GaAs-based (Gallium Arsenide) solar cell devices (a joint initiative by UP Diliman (UPD) and Ateneo de Manila University (ADMU)); and polymer-based smart materials designed for advanced functions like self-healing in vehicle and electronic components, and as protective layers to enhance solar panel longevity and efficiency. She also introduced the AuREUS System, an award-winning renewable energy innovation by Carvey Maigue from Mapúa University, which utilizes upcycled agricultural waste, with potential applications in building windows, walls, or solar panels. Furthermore, the presentation highlighted initiatives in smart buildings and environment-friendly materials, emphasizing the integration of Internet of Things (IoT) and AI for real-time load monitoring, predictive maintenance, and comprehensive energy management.

However, the Philippines face challenges such as high capital costs associated with pilot demonstrations, existing gaps in comprehensive policy support, limited local research and development (R&D) funding, prevalent skills gaps in the workforce, and insufficient market awareness regarding new technologies. Despite these challenges, significant opportunities exist in improving overall energy efficiency, enhancing system performance, promoting decarbonization stability, increasing investment uptake, fostering robust public-private partnerships, expanding international cooperation, and developing dedicated smart building and solar material programs. The proposed ways forward include the introduction of applicable policies for new smart materials, the establishment of co-financing opportunities, providing specific policy and investment tax incentives for green materials, supporting local innovation startups, building capacity through targeted training programs for local engineers and researchers, and implementing demonstration projects with local government units and in government buildings to promote wider adoption and integrate these innovations into the economy's energy infrastructure.

Professor Nguyen Van Tuan, Lecturer, Hanoi University of Civil Engineering (HUCE), Viet Nam: The speaker focused on multifaceted role of smart building materials in advancing sustainable energy development, particularly highlighting their potential to transform the construction sector. The construction sector has massive contribution to global energy consumption and greenhouse gas (GHG) emissions. The production and use of building materials alone are responsible for significant percentages of global CO2 emissions (40%), energy consumption (33%), solid waste generation (40%), and water usage (20%). Given Viet Nam's projected increase in demand for construction materials, expected to rise by 1.5

times, the urgency for innovative and sustainable material solutions becomes more critical.

According to the speaker, "smart building materials" are defined as those possessing inherent abilities to self-adapt, self-heal, self-regulate, positioning them as pivotal enablers for achieving sustainable energy goals within the construction industry. He elaborated various categories of these materials and their specific contributions. The first category is self-cleaning materials, designed with the inherent capability to remove dirt and pollutants from their surfaces with minimal or no external intervention, leading to reduced maintenance costs and an extended lifespan for structures. Examples include self-cleaning concrete and smart paints with photocatalytic properties. In the context of sustainable energy, such materials applied to photovoltaic (PV) panels can significantly increase energy efficiency by 3-10% annually due to reduced dust accumulation, while also cutting water consumption for cleaning by 50-80% compared to traditional methods.

Another important category discussed is self-healing materials. Inspired by natural biological systems, these innovative materials possess the structural capacity to repair internal or external damage over time, thereby prolonging the lifespan of buildings and infrastructure and minimizing the need for material replacement and ongoing maintenance. These materials encompass self-healing polymers, ceramics, and concrete, which can automatically mend cracks or minor structural damages, enhancing overall durability, safety, and energy efficiency. From a life cycle assessment (LCA) perspective, self-healing materials can lead to a 20-50% reduction in the total CO_2 emissions of a building or component and a 20-40% reduction in primary energy demand over their entire lifespan.

A third key category highlighted is bio-based materials (natural materials). These materials are derived directly from natural, renewable sources with minimal complex industrial processing, largely retaining their original chemical properties. Examples include bamboo, timber, rammed earth, and various mud/straw composites. Their contributions to sustainable energy development are substantial, primarily due to their inherently low embodied energy (the energy consumed during extraction, production, and transportation), their capacity to act as carbon sinks by sequestering CO2, and their ability to improve indoor environmental quality.

The speaker introduced a case study adopting earth-based materials in construction within the mountainous regions of Viet Nam. They encounter significant logistical and cost challenges associated with constructing houses for impoverished communities in remote, high-altitude areas using conventional building materials. To address this, they promote an innovative, interdisciplinary research and application model focused on utilizing locally sourced compressed earth blocks to construct affordable and sustainable housing. This model integrates expertise from structural engineering, material science, architecture, mechanical engineering, economics, and environmental science.

It is reiterated that smart building materials are pivotal for achieving sustainable energy goals and fostering a more resilient and environmentally responsible construction industry. These materials not only help reduce the energy intensity of individual buildings but also play a strategic role in the broader transformation of the construction sector towards a more sustainable model. Their main contributions include significantly lowering operational energy consumption, enhancing overall building performance and lifespan, promoting the seamless integration of renewable energy sources, and supporting the transition towards circular economy models and net-zero emissions, ultimately contributing to a greener and more sustainable built environment for future generations.

4. Exploring mechanism to promote the adoption of new smart materials for sustainable energy

Mr Chen Yi, Program Officer, China Energy Administration: Under the support of the Chinese government and collaborative efforts across the industry, China's photovoltaic industry has maintained robust and stable growth and achieved high-quality development throughout the supply chain. Transitioning from policy-driven to market-led, China's photovoltaic industry has made transformative breakthroughs in technology, scale, and cost, emerging as a key driver and global leader in energy transition.

China has witnessed a rapid industrial scale expansion with the cumulative photovoltaic installed capacity reaching 887GWd, with annual power generation of 837.1 billion kWh, accounting for nearly half of the global total capacity and stayed the world largest for ten consecutive years.

The development of China’s photovoltaic industry is supported by the enactment of the Renewable Energy Law of China in 2006 and the promulgation of Energy Law in 2025. Policy incentives such as the 2013 Opinions on Promoting the Healthy Development of the Photovoltaic Industry, introducing mechanisms, such as feed-in tariffs, to drive scaled development and the 2025 Circular on Deepening Market-Oriented Reform of New Energy Feed-in Tariffs to Promote High-Quality Development, providing new energy (including photovoltaics) feed-in tariffs, have been consistently supporting and guiding the sustained and healthy development of the photovoltaic industry. Since 2024, the new energy (including photovoltaic) feed-in tariffs abolish government pricing and are entirely market-determined, which contributes to the transition from "policy-driven" to "market-driven".

China has also made standardization efforts in the photovoltaic industry, including aligning with the new goals of carbon peaking and neutrality, establishing a systematic photovoltaic standard system, based on "functional categorization, technical universality and lifecycle coverage". The standard system penetrates the whole life-cycle and industrial chain, encompassing general and foundational standards, engineering integration, grid-connected operations and facilities. So far, China has formulated and issued over 670 active standards in the photovoltaic field, including over 240 economy’s standards and over 120 industry standards, ranging from foundational and general standards, to materials, cells and modules, systems, power generation projects, and applications. In addition, there are also standards for local areas, societies and enterprises.

The speaker introduced case studies such as the project of Baofang Agri-Photovoltaic Integrated Industrial Base, which adopts intelligent photovoltaic inverters and intelligent tracking technology, increasing power generation compared to conventional power stations. Another project is the world’s largest hydro-wind-solar hybrid project, Yalong River Basin Hydro-Solar-Wind Hybrid Demonstration Base, with total installed capacity of 33GW, including 21GW operational and 12GW under construction, establishing a complementary multi-energy clean energy development model.

Mr Atchariya Jangchay, Engineer, Professional Level; Department of Alternative Energy Development and Efficiency (DEDE), Thailand: From the perspective of the Thailand's Department of Alternative Energy Development and Efficiency (DEDE), the speaker presented an overview of mechanisms to promote the adoption of new smart materials for sustainable energy, highlighting Thailand's Energy Efficiency Plan, and policies for the building sector, and the showcase of DEDE's 70th Anniversary Building as a model of zero-energy performance.

The Energy Efficiency Plan is central to Thailand's efforts to meet its climate and energy goals. The plan sets ambitious targets for reducing energy intensity, aiming for a 36 percent reduction by 2037 and 40 percent by 2050, using 2010 as the baseline year. This corresponds to substantial energy consumption reductions equivalent to tens of thousands of kilotons of oil equivalent per year. The plan reflects updated projections of GDP growth, carbon neutrality targets, and the increasing role of electric vehicles. Strategies cover compulsory actions such as enforcing energy codes in industry, buildings, and agriculture, as well as voluntary initiatives like public awareness, human resource development, and research and development in technologies. Complementary policies also focus on innovation, the integration of smart technologies, and financial incentives to stimulate investment.

Thailand promotes the development and enforcement of the Building Energy Code (BEC) to realize energy efficiency. This code applies to large buildings and sets standards for energy use, with progressive targets to bring new and retrofitted buildings closer to international recognition. The BEC promotes innovations such as Zero Energy Buildings (ZEBs), which achieve net zero annual energy consumption by combining reduced demand with renewable energy production. Simulation studies have demonstrated that ZEBs can cut energy consumption by up to 74 percent compared with reference buildings, depending on the building type.

The DEDE's 70th Anniversary Building serves as a flagship demonstration of these principles in action. Designed as a six-storey office building with a floor area of 2,650 square meters, it incorporates both passive and active design strategies.

Passive elements include natural ventilation, shading, and daylight harvesting, while active systems use advanced air conditioning technologies, building automation, and high-efficiency lighting. Renewable energy is supplied by a rooftop photovoltaic installation of over 100 kilowatts, supported by a lithium-ion battery system. The building is also equipped with advanced monitoring systems for energy and water use, ensuring efficient operation and continuous improvement through post-commissioning evaluation. With an energy use intensity of just under 60 kWh per square meter per year, it approaches the performance of a net zero energy building, while also emphasizing occupant well-being through universal design, comfort, and indoor air quality measures.

The project demonstrates that while zero-energy buildings require higher upfront costs compared to code-compliant buildings, the long-term savings in electricity costs make them financially viable. The payback period is estimated at around 13 to 17 years depending on the inclusion of solar energy systems. This highlights the role of innovative financing mechanisms to bridge the gap between initial investment and long-term benefits. Thailand employs a range of financing tools, supported by the Energy Conservation Promotion Fund. These include subsidies, grants, revolving funds, tax incentives, and soft loans, combined with requirements for measurement and verification to build investor confidence. Target groups for financing include building owners, factories, and energy service companies, all of which play an essential role in scaling up adoption.

Mr Anupong Sukee, Scientists, Practitioner Level, Department of Alternative Energy Development and Efficiency (DEDE), Thailand: In this presentation, the speaker focused on Thailand’s experience in developing sustainable fuel for energy, with a particular focus on municipal solid waste (MSW) and agricultural residues. Over the years, Thailand has faced growing challenges in managing its waste, both in terms of volume and methods of disposal. In 2024, the economy’s waste generation rate reached 1.12 kilograms per person per day. While some of this waste was reused or properly disposed of, a significant portion was still improperly managed, which highlighted the need for innovative solutions in waste-to-energy conversion.

One of the technologies explored is Hydrothermal Carbonization (HTC), which transforms raw MSW into a usable solid fuel. The process involves dewatering, drying, and pelletizing the waste to create a more efficient energy source. Compared with Refuse Derived Fuel (RDF), the HTC-produced solid fuel has superior properties. Its lower heating value is higher, at nearly 5,898 kcal/kg compared with 4,500 kcal/kg for RDF. It also demonstrates much lower moisture content, at only 3.87 percent, and significantly reduced chlorine levels, making it a cleaner and more sustainable energy option.

In addition to MSW, Thailand has also recognized the enormous potential of agricultural residues for energy production. With vast amounts of rice husks, bagasse, corn stalks, cassava waste, rubber tree wood, and coconut residues generated each year, these resources represent millions of tons of untapped biomass. Transforming these residues into synthetic gas or solid fuel presents opportunities not only to diversify energy supply but also to reduce the economy's reliance on fossil fuels.

A particularly notable initiative is the Biomass to Energy and Biochar Community Project, developed under the BEBC En SAFE Life Foundation. This project uses anaerobic kilns to convert biomass into energy while also produce biochar, which can enhance soil quality and further support sustainable agricultural practices. The design incorporates innovative features, such as specialized kiln structures that improve efficiency and allow for low-carbon energy production at the community level.

Thailand has placed importance on spreading knowledge and building capacity through community workshops. These sessions introduce local populations to innovative energy technologies, encouraging participation in the transition toward renewable energy. By engaging communities directly, Thailand ensures that the adoption of alternative energy sources is not limited to industrial or urban centers but also reaches rural areas where agricultural waste is abundant.

5. **Roles of multi-stakeholders, access to finance, and capacity building to promote the adoption of new smart materials for sustainable energy**

Mr Vu Quang Dang, Energy Independent Consultant, Viet Nam: The speaker focused on the opportunities and challenges related to financing access for alternative fuel projects in Viet Nam's cement sector. Cement production, one of the most energy-intensive industries, is under increasing pressure to adopt sustainable practices, both to remain competitive and to contribute to Viet Nam's climate commitments. The adoption of alternative fuels, particularly Refuse Derived Fuel (RDF), emerges as a key solution that offers not only economic but also social and environmental benefits.

From an economic perspective, RDF provides a clear pathway for reducing production costs. While coal prices have risen significantly in the aftermath of the COVID-19 pandemic, RDF remains substantially cheaper, thereby offering companies a competitive advantage. Beyond cost savings, the use of RDF supports the production of low-carbon cement, as RDF sourced from paper, rubber, plastic, and other materials generates lower carbon emissions compared to coal. The environmental benefits are equally important since RDF enables the use of municipal and industrial solid waste within cement production, thereby reducing the need for landfills and preventing waste from being incinerated or improperly disposed of.

To finance these transitions, several sources of capital are available. Domestic and offshore bank loans remain traditional options, while bonds—particularly green and sustainability-linked bonds—have become more prominent in aligning capital raising with environmental goals. Government support, through tax incentives, the Energy Efficiency Fund, the Just Energy Transition Partnership (JETP), and the emerging carbon market, also provides valuable backing. Additionally, companies can turn to the stock market, either through initial public offerings or by issuing additional shares; and to Energy Service Companies (ESCOs), which offer performance-based energy contracts.

A particularly promising avenue for the sector lies in concessional loans from foreign development institutions such as the Asian Development Bank, AFD (Agence Française de Développement), the International Finance Corporation, and the World Bank. These loans are often structured as blended finance, combining grants, climate finance, and green finance, and are typically characterized by long tenors, grace periods, and streamlined approval processes. They also provide access to foreign currency, which is crucial for importing advanced equipment. However, non-sovereign loans, though attractive, still present barriers that companies must navigate, including eligibility requirements and institutional readiness.

The speaker illustrated a notable case study of Viet Nam's first corporate bond to receive an AAA rating, awarded in November 2024. Valued at VND 700 billion (approximately USD 27.6 million), the bond carried a fixed annual coupon rate of 5.5% over a ten-year tenor and was fully guaranteed by the Credit Guarantee and Investment Facility. Arranged by Maybank Investment Bank and rated by FiinRatings, the bond was used to finance a major water treatment project in Long An province. This achievement not only boosted investor confidence but also demonstrated how international guarantee facilities can enhance the creditworthiness of local companies, thereby unlocking access to green non-sovereign financing from global development institutions.

In brief, the cement sector in Viet Nam stands at a pivotal moment. By embracing alternative fuels and leveraging diverse financing mechanisms, particularly green finance and international partnerships, the industry can reduce costs, lower emissions, and protect the environment while contributing to the economy's sustainable development goals.

Mr Ignacio Sánchez, Senior Analyst for Sustainable Energy in Infrastructure and Cities, Ministry of Energy, Chile: The speaker explored the role of smart materials in the energy sector, focusing on opportunities and challenges, in the context of Chile as an economy of 20 million people, with nearly universal access to electricity and a high urban concentration. Chile remains as the world's largest producer of copper and a major source of lithium, being of significance in the global supply chain of critical materials. Chile's energy sector, however, still relies heavily on fossil fuel imports, though renewables—mainly hydro—make up an important share of electricity production. The economy's diverse geography, from the arid north to the humid south, adds layers of complexity and opportunity for tailored energy solutions.

Smart materials are expected to enhance the performance and longevity of renewable energy systems, adapt to regional climates and resource potentials, and guide more efficient energy consumption. By improving durability and efficiency, smart materials can reduce waste and help extend the sustainability of renewable installations. For example, Chile's researchers are experimenting with hydrogen production via photocatalysis using copper oxide and tin dioxide nanomaterials, which split water molecules under sunlight to generate green hydrogen. Similarly, green hydrogen storage is being improved through palladium nanospheres that increase capacity by 40% compared to conventional tanks.

Chile is making efforts to leverage its natural resources, industrial byproducts, and academic expertise to push the boundaries of sustainable energy solutions. However, the adoption of smart materials faces significant hurdles such as fostering public acceptance, integrating smart materials into public policy goals, and ensuring that prices remain competitive for widespread adoption. A crucial task is bridging the gap between academia and industry through active knowledge transfer, while also engaging the public sector to accelerate innovation and connect stakeholders. Policymakers are called upon not only to support research and development but also to redefine what counts as "smart" in materials and techniques, ensuring that established practices evolve alongside emerging technologies.

IV. Discussion, Recommendations and Conclusions

Through the active sharing of information and experiences at the Workshop, speakers and participants exchanged views on how to promote efficient adoption of smart materials for sustainable energy. Recommendations are summarized as below:

1. Recommendations for MSMEs

- MSMEs should be encouraged to access smart and sustainable technologies into their operations, including but not limited to investing in automated systems to enhance production efficiency, exploring the use of phase change materials for energy conservation, considering advanced energy options such as offshore wind and emerging thorium-based nuclear technologies, etc.
- MSMEs should also strengthen their understanding of smart materials and adopt new innovations, including biofuels derived from diverse feedstocks such as cassava, sugarcane, coconut, soybean, plums, and sorghum, etc.

2. Recommendations for APEC member economies/governments

- Promote policies and incentives to accelerate R&D in renewable energy, with a particular focus on smart materials that contribute to sustainability.

- Promote capacity-building initiatives and establish platforms to facilitate technology transfer, ensuring wider access to advanced solutions.
- Develop comprehensive databases and undertake technology and materials mapping to provide valuable insights into adoption pathways and market opportunities.
- Foster collaboration with academia, industry stakeholders, and multinational corporations to enhance knowledge-sharing and the commercialization of innovative technologies.

3. Recommendations for APEC as a whole

- Take the lead in positioning smart materials as a strategic priority for sustainable energy development. This could involve convening dedicated forums and events to exchange insights, best practices, and emerging technologies (e.g.: hydrogen and other advanced materials, etc.,), and so on.
- Develop a regional roadmap for the adoption of smart materials to ensure coordinated progress across economies.
- Create innovative financing mechanisms to support large-scale deployment and promote equitable access for all member economies.

Hereinabove are some recommendations from the workshop's participants and speakers that require further thoughts and discussions at the upcoming EWG meetings to transform into more concrete and practical activities.