Sustainable Biomass Energy Conversion

Background

Expanding bioenergy applications stands as a core pillar of the “Innovative Energy” framework in Taiwan's “Twelve Key Strategies” for achieving a net-zero transition [1]. Reinforcing this commitment, the 2024 National Project of Hope further designates green growth and the 2050 Net-zero Transition as a national objective, catalyzing a “second energy transition” to cultivate a diversified green energy ecosystem [2]. The robust conversion of biomass resources is pivotal to this mandate, driving the acceleration of renewable bioenergy, maximizing green power, and fortifying Taiwan’s domestic energy resilience.

On a global scale, the circular utilization of biomass is widely recognized as a definitive pathway to phasing out fossil fuels. While biomass energy applications are vast, Sustainable Aviation Fuel (SAF), Sustainable Marine Fuel, and Biogas Utilization have emerged as the top strategic priorities. This targeted focus is compelled by their critical alignment with international agreements, surging demand across domestic and international markets, and their unparalleled potential to synchronize resource sustainability with high-yield energy recovery.

Global Outlook and Domestic Progress

The International Energy Agency (IEA) projects that bioenergy will constitute nearly 20% of the global energy mix by 2050[3]. However, Taiwan's 2022 electricity generation statistics indicate that biomass accounted for a mere 0.05% [4], revealing a stark disparity when measured against the nation’s maximum domestic potential of approaching 15% [5-12]. To bridge this critical gap, Taiwan must aggressively diversify its feedstock supply and accelerate the development and integration of advanced bioenergy technologies, thereby maximizing the deployment of bioenergy and reinforcing national energy security.

(1) Sustainable Aviation Fuel

Driven by rapid international progress in aviation carbon reduction agreements, the global Sustainable Aviation Fuel (SAF) supply chain is rapidly expanding to meet the surging demands of the net-zero transition. This development also demonstrates that biofuels are increasingly being deployed in aviation transport as substitutes for conventional fossil fuels. As of May 2024, SAF adoption has reached critical milestones worldwide: 41 countries have launched dedicated SAF programs, 122 airports now offer SAF supply, and more than 50 airlines have integrated it into their operations [13].

In response, Taiwan has elevated the cultivation of a localized SAF supply chain to a national strategic priority, marked by the launch of a cross-ministerial “SAF Working Platform.” Although several leading domestic petrochemical companies have already begun investing in SAF production-line construction, the path to domestic commercialization remains fraught with critical bottlenecks, primarily insufficient feedstock supply, prohibitive product costs, and a lack of robust policy incentives needed to drive economies of scale. To accelerate this transition, Taiwan must leverage the pioneering experiences of regions like the EU and Singapore. By executing a medium- to long-term strategy that fosters cross-ministerial and cross-industry integration, Taiwan can comprehensively synchronize its R&D initiatives, regulatory frameworks, policy support systems, and global strategic positioning.

(2) Sustainable Marine Fuel (SMF)

Global maritime transport accounts for approximately 3% of total greenhouse gas emissions, making it a critical frontier in the pursuit of net-zero pathways. On the regulatory front, the EU Emissions Trading System (EU ETS) expanded its purview in 2024 to encompass maritime transport, mandating that qualifying vessels report emissions and surrender corresponding carbon allowances [14]. Concurrently, the International Maritime Organization (IMO) is formulating a life-cycle greenhouse gas intensity standard for marine fuels. Slated to enter into force in 2027, this standard will be coupled with a global pricing mechanism to aggressively drive the decarbonization of international shipping [15].

To actively respond to this mandate, Taiwan's Ministry of Transportation and Communications and Ministry of Economic Affairs have jointly launched the "Maritime Alternative Fuel Working Platform" to streamline cross-ministerial coordination and oversee policy execution. In the private sector, Taiwan's leading maritime carriers, namely Evergreen Marine, Yang Ming Marine Transport, and Wan Hai Lines, have spearheaded the adoption of biofuels, and are steadily expanding their fleets with methanol and LNG dual-fuel vessels [16–18]. To further accelerate SMF development, Taiwan must leverage international policy experience to formulate a forward-looking, national-level roadmap. Strategically, this requires not only deepening international cooperation but also cultivating domestic autonomous fuel supply chains and reinforcing port bunkering hubs, thereby elevating the long-term sustainability of Taiwan's maritime industry.

(3) Biogas Utilization

On a global scale, biogas production is predominantly fueled by agricultural residues and livestock manure. The IEA projects that the share of global biogas allocated for power and heat generation will climb from the current 70% to 85% by 2040 [19]. A review of Taiwan's current landscape, however, reveals a stark contrast: as of July 2024, only about 17% of national swine population is integrated into biogas power generation [20], and agricultural residues have not yet seen fully scaled bioenergy applications. This disparity underscores a critical bottleneck in the nation's resource circulation and bioresource-to-energy transition.

Historically, domestic biogas facilities have been constrained by their reliance on anaerobic digestion of a single feedstock, namely pig manure, resulting in limited overall gas production. In contrast, the global vanguard has aggressively adopted co-digestion technologies, synchronizing multiple feedstocks to substantially amplify biogas production efficiency. On the domestic technological front, Taiwan has already begun driving industry upgrades through the deployment of intelligent environmental control systems, energy circularity models, and large-scale field validations. Looking ahead, Taiwan must deepen its R&D and implementation of organic resource co-digestion technologies to maximize bioenergy outputs and complete a comprehensive circular economy framework

Strategic Planning Frameworks

To actualize the "Sustainable Biomass Energy Conversion" strategic layout, this framework prioritizes three core development pillars: Sustainable Aviation Fuel, Sustainable Marine Fuel, and Biogas Energy. Supported by six comprehensive implementation strategies (see Figure 1), the initiative establishes clear quantitative targets for 2030, for the aviation sector, achieving a 5% to 10% SAF blending ratio in overall aviation fuel consumption; for international maritime transport, increasing the share of zero- or near-zero carbon fuels and technologies to 5%–10% of total maritime energy consumption; and for biogas energy, elevating the energy conversion rate of methane feedstocks to between 40% and 50%. In parallel, by leveraging international best practices, Taiwan will aggressively scale up its domestic production-line capacities for sustainable marine fuels. By strictly aligning with global emission-reduction mandates, the nation will also establish an authoritative certification, testing, and verification ecosystem for sustainable aviation and marine fuels.

Strategy 1: Critical Technology for Circular Biomass Energy Conversion

Prioritize domestic biomass feedstocks that are supplemented by international sources ,and consolidate and optimize a domestic and international biomass resource database network. Develop emerging biomass materials with the strong potential for generating

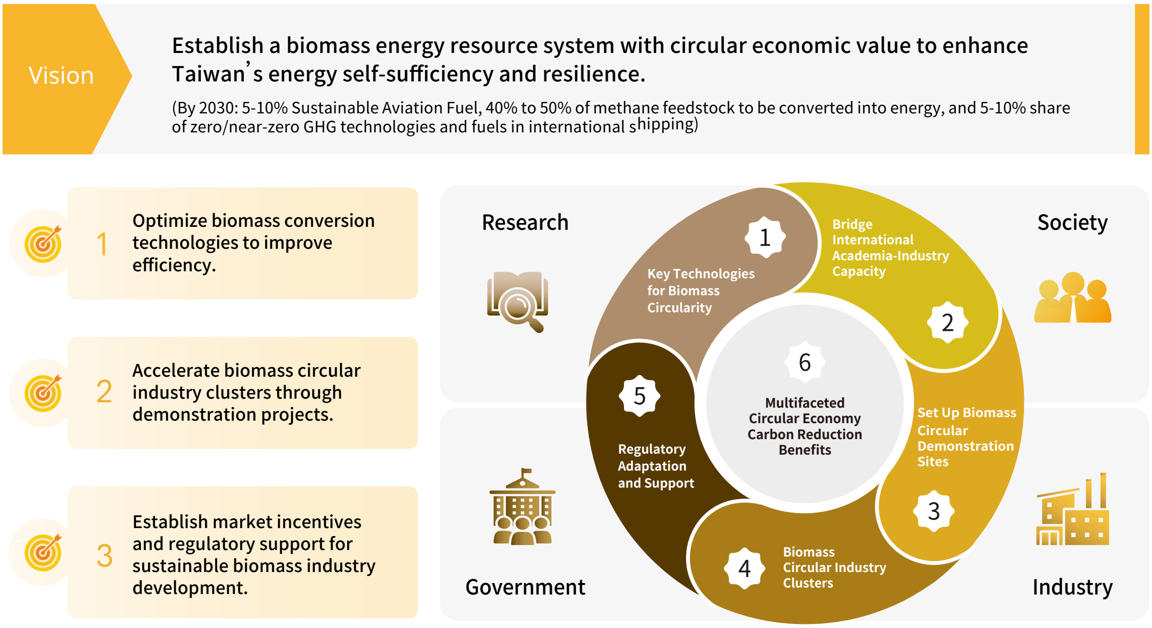

Figure 1 Strategies for the Sustainable Biomass Energy Conversion

Source: Taiwan Science and Technology Office for Net-zero Emission (T-STONE) (2025)

fuel. Advance cost- effective bioenergy conversion technologies, including prioritizing improvements in the efficiency of converting waste cooking oil into hydrogenated esters and fatty acids (HEFA) for sustainable aviation fuel production while conducting R&D on bioenergy conversion technologies for emerging feedstocks. Explore bioenergy applications based on various feedstocks that include advanced co-digestion technologies and biogas production sources from various co-digestion types (livestock manure, agricultural residues, municipal sludge, and food waste) suitable to unique regional characteristics. In addition, expand the use of anaerobic treatment and biogas measures for high-concentration organic wastewater, and integrate bioenergy with carbon capture, utilization, and storage (BECCUS). Promote advanced conversion technologies to produce bio-methanol for use as sustainable maritime fuels.

Strategy 2: Connect International Industry and Academia Capabilities

Strengthen international cooperation on key technologies by promoting feedstocks and forward-looking technologies for next-generation low-carbon sustainable aviation and marine fuels, as well as high-efficiency biogas production technologies and methanation applications based on diversified feedstocks. Establish an international industry–academia alliance to advance biomass-based carbon-negative technologies. At the same time, draw on the experience of overseas demonstration and verification sites to accelerate the development of Taiwan's integrated verification system for biomass energy conversion. Efforts will also be made to align with international process testing and certification systems for diversified feedstocks to support key technology development.

Strategy 3: Establish Demonstration Hubs for Circular Biomass Energy Conversion

Establish dedicated demonstration zones for SAF and SMF, covering feedstocks, conversion technology, fuel blending, and certification. Integrate artificial intelligence (AI), blockchain, and the Internet of Things (IoT) to optimize the management of feedstocks for domestic sustainable fuels, improve collection and transportation efficiency, and enhance production technologies. These efforts aim to develop Taiwan into an Asia-Pacific supply center for sustainable aviation and marine fuels with international export or supply capabilities. Establish circular biogas utilization demonstration zones tailored to local needs (diversified feedstocks/high-value applications), and promote closed-loop and zero-waste sandbox pilot projects to support the testing and deployment of advanced production technologies.

Strategy 4: Circular Bioeconomy Industrial Clusters

Facilitate the development of an international supply chain system for SAF and SMF by developing a sustainable aviation fuel industry ecosystem that incorporates benefit assessments of the whole life-cycle carbon footprints, business models, and economic scale. Furthermore, develop localized circular biomass industrial clusters and establish feedstocks collection and transportation business models for biomass collections. Promote the innovative use of biogas residues and digestate liquids while expanding their circular reuse and carbon sequestration value. Explore international market opportunities by facilitating the export of turnkey biogas energy industry technologies.

Strategy 5: Regulatory Adjustment and Support Measures

Implement regulatory adjustments and relaxations to enhance the flexibility of biomass equipment installations, applications of feedstocks sites, and disposal and utilization channels. Accelerate the development of certification mechanisms and methodologies for carbon offset credits and carbon sequestration. Additionally, continuously refine relevant support measures and incentive mechanisms (e.g., new environmental subsidies for biomass feedstocks, incentives, subsidies, and support mechanisms for SAF/SMF transport fuels). Review Taiwan's carbon offset trading and carbon pricing mechanisms to assess the economic benefits for driving biomass technology development. Establish a green finance system to support the sustainable development of the biomass resource industry.

Strategy 6: Multifaceted Circular Economy Carbon Reduction Benefits

Introduce life-cycle assessment (LCA) to promote carbon offsets for circular biomass resources. Expand the market scale for renewable energy certificates associated with sustainable biomass energy to support the achievement of carbon neutrality goals. Align with the Task-Force on Nature-related Financial Disclosures (TNFD) framework to guide financial investments toward activities that generate carbon-negative contributions.

Potential Benefits

Biomass circularity stands as a foundational pillar in constructing a sustainable, net-zero society. By fully developing and deploying domestic biomass potentials, Taiwan can substantially substitute conventional fossil fuels, thereby fortifying energy resilience and autonomy. Strategically maximizing biomass energy recovery is estimated to drive a massive annual carbon reduction of 65 million metric tons. Furthermore, aligned with 2030 targets, the rollout of SAF is projected to slash annual emission by 1.44 million metric tons, complemented by a 950,000 metric tons annual reduction from biomethane applications. Collectively, these milestones will aggressively accelerate the decarbonization of Taiwan’s energy landscape.

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