THAILAND BIOMASS INVENTORY PROJECT

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Chapter 1 – Climate & Policy Context: Why Thailand Needs Low-Carbon Resources

Thailand is under pressure to accelerate its climate action. In the Climate Change Performance Index (CCPI), the country ranks 32nd and is rated only medium overall, with particularly low performance in renewable energy and climate policy. Thailand's updated Nationally Determined Contribution (NDC) targets carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065, with a planned 33.3% reduction in GHG emissions by 2030 relative to a business-as-usual pathway. A forthcoming NDC 3.0 aims to shift from BAU-based targets to absolute reductions relative to 2019 emissions, aligning Thailand more closely with the 1.5 °C goal (CCPI, 2025). Despite these ambitious long-term targets, experts highlight slow implementation, continued dependence on coal and natural gas, and outdated energy policies. This gap between ambition and action underscores the need to unlock domestic, low-carbon energy sources and to create clear pathways for a just transition and greater renewable-energy deployment.

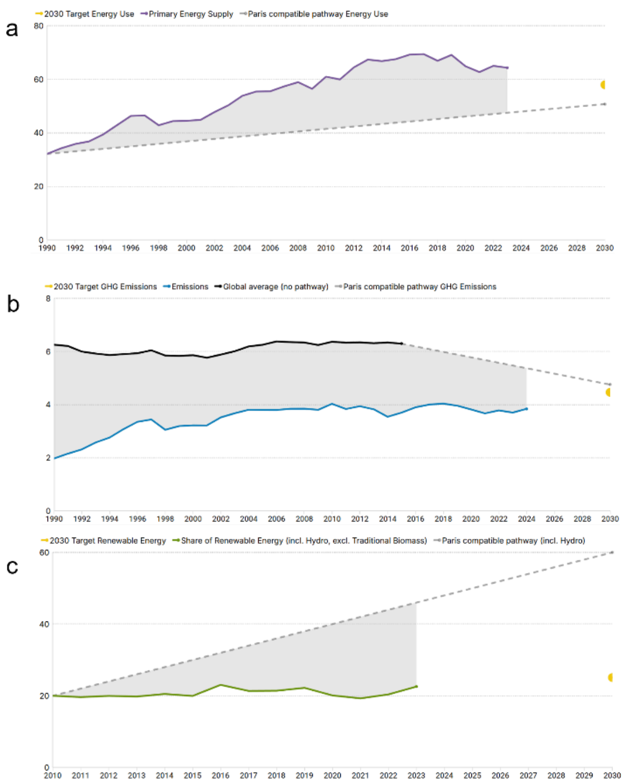

Figure 1. Biomass potential and energy targets for Thailand's Sustainable Future (left side) and Comparison of Current Trends with Paris-aligned Energy and Emissions Goals for 2030 (right side); (a) Energy use per Capita (GJ), (b) GHG emissions per capita (t CO_2 eq., incl. LULUCF), (c) Share of renewable energy (in % of TPES) (CCPI, 2025).

Chapter II – Agricultural biomass: a large but underused domestic resource

One promising route to strengthen energy security and reduce energy imports is the utilization of agricultural residues. In Thailand, residues such as bagasse, rice husk, rice straw, sugarcane residue, and other by-products from rice mills, sugar factories, rubber plantations, and palm-oil mills form a substantial but underutilized energy resource. According to the Energy Policy and Planning Office (EPPO), these residues could generate around 3070 MW of power, with bagasse alone contributing approximately 900 MW as it can be seen in Table 1 (EPPO, 2009).

Table 1. Power generation potential of agricultural residues in Thailand

Fuel type	Power potential (MW)
Bagasse	900
Rice husk	700
Rice straw	650
Sugarcane residue	570
Oil palm residues	70
Corncob	70
Cassava residue	70
Wood waste	40
Total	3070

Source: Energy Policy and Planning Office (EPPO), Ministry of Energy, 2009.

To harness this potential, Thailand is promoting biomass through policies such as the BCG Economy Model, Thailand 4.0, and the Energy Efficiency Plan (EEP 2015–2036), which encourage green and circular economic practices. Private-sector engagement from companies such as SCG, PTT Global Chemical, and the Federation of Thai Industries further supports the deployment of biomass technologies, linking national climate targets with industrial innovation.

Chapter III – From "waste" to functional materials: lignocellulosic structure

In practice, these residues are more than just fuel. They are lignocellulosic materials composed mainly of cellulose, hemicellulose and lignin, together with volatile matter and fixed carbon that are important for carbonization. Composition data (Table 2–3) for rice husk, bagasse, corn cobs, coconut shell, palm shell and rubber latex confirm high fractions of cellulose and hemicellulose and variable lignin contents. This natural polymer network can be upgraded not only into heat and power, but also into fuels, chemicals, porous carbons, hydrochars, polymers and carbon materials for energy storage.

Table 2. Type of biomass with different resources

Type of biomass	Feedstock	Amount/year	Province	Current applications	References
Agriculture	Rice husk	51.4 Mt/tons	Northeastern (Nakhon Sawan)	Porous carbon, silica composites	Krungsri, 2023
	Sugarcane (Bagasse)	30.8 Mt/year	Northeast (Kamphaeng Phet, Nakhon Sawan, so on)	Feedstock	Krungsri, 2023
	Molasses	0.2 Mt/year	Northeastern, central, and eastern regions	Feedstock, solvent	Krungsri, 2023
	Palm kernel shell	3.6 Mt/year	Surat Thani, Chumphon, and Krabi	Activated carbon, hydrochar	Krungsri, 2024
	Rubber (Latex)	4.7 Mt/year	Surat Thani (Southern)	Polymer	European Forest Institute, 2024
	Coconut shells			Supercap, carbon	

Table 3. Potential for hybrid electrolyte: Agriculture

Feedstock	Organic content (%)									Ref.
	CE	Bond type	HC	Bond type	LIG	Bond type	Volatile matter	Fixed carbon	Ash	
Rice husk	35-40	β-1-4	15-20	β>α	20-25	Ether & C-C	60-70	10-15	15-20	Kumar et al., 2009
Bagasse	40-50	β-1-4	20-30	β=α	18-24	Ether & C-C	15-20	10-15	1-4	Rao et al., 2024
Corn cobs	45-55	β-1-4	23-25	-	20-30	-	65-75	10-15	3-6	Purnomo et al., 2025
Coconut shells	54-65	β-1-4	4-5	-	30-42	-	70-80	15-25	0.5-1.5	Araujo et al., 2015
Palm shell	30-45	β-1-4	20-35	β=α	15-30	Ether & C-C	60-80	10-20	5-20	Abdullah and Sulaiman, 2013
Rubber (Latex)	35-45	β-1-4	20-25	β=α	20-30	Ether & C-C	65-75	15-20	1-5	Tanaka et al., 2016

Noted: CE: Celullose, LIG: Lignin

However, converting raw residues into high-value products is not automatic. It requires appropriate pretreatment, process development, and technology scale-up, as well as investment in infrastructure and skilled personnel. These opportunities and challenges define the research space for developing biomass-derived hybrid electrolytes.

Chapter IV – Why target hemicellulose?

Among the primary constituents of lignocellulosic biomass are cellulose, hemicellulose, and lignin. Hemicellulose is particularly attractive for selective extraction and chemical valorization. Unlike cellulose, which exhibits a highly crystalline and hydrogen-bonded structure, or lignin, which is extensively cross-linked through aromatic networks, hemicellulose possesses a random, amorphous architecture composed of heterogeneous sugar units. This structural irregularity results in weaker intermolecular interactions and renders hemicellulose more susceptible to chemical and enzymatic depolymerization (Nkosi *et al*., 2018). Consequently, hemicellulose can be selectively hydrolyzed under relatively mild conditions using dilute acids, alkalis, or tailored enzyme systems, positioning it as a strategic precursor for functional polymers, sugar-derived chemicals, and hybrid electrolyte materials. Effective valorization of hemicellulose requires a comprehensive understanding of its bonding characteristics and its deconstruction behavior relative to cellulose and lignin. In integrated biorefinery schemes, selective hemicellulose removal not only yields soluble sugar-rich streams but also preserves the structural integrity of cellulose, enabling downstream processing routes to be optimized independently. Such hierarchical utilization maximizes carbon efficiency while minimizing excessive degradation of valuable biomass fractions.

Among the lignocellulosic components, hemicellulose is particularly attractive. Because of its random, amorphous structure and diverse sugar units, hemicellulose is easier to extract and depolymerize than crystalline cellulose and highly cross-linked lignin (Nkosi *et al*., 2018). It can be selectively broken down by dilute acids, alkalis or enzymes, making it a suitable precursor for functional polymers and hybrid electrolytes. Designing efficient extraction and conversion routes, therefore, requires a clear understanding of the relative roles, bonding and deconstruction behaviour of hemicellulose, cellulose, and lignin.

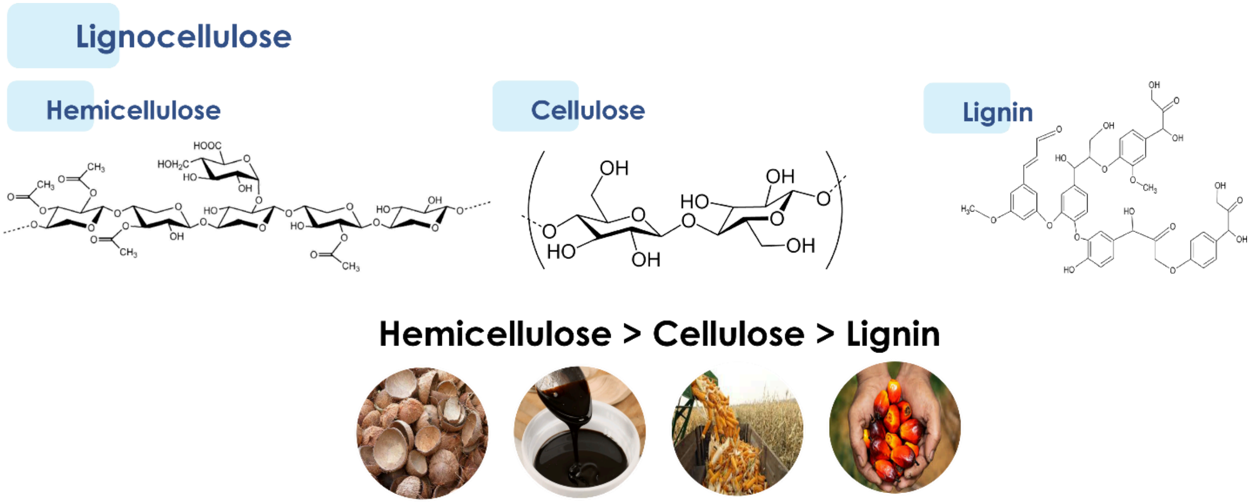

Figure 2. Structural Overview of Lignocellulose Components in Agricultural Biomass.

Chapter V – Case study: Extracting hemicellulose from palm shells and corn cobs

To demonstrate this concept, palm shells and corn cobs were selected as representative Thai agricultural residues due to their relatively high hemicellulose and lignin contents, as summarized in Table 3. These residues are abundantly available, underutilized, and aligned with Thailand's biomass utilization and climate mitigation strategies. Prior to chemical extraction, raw materials were washed thoroughly to remove soil particles and water-soluble impurities, followed by oven drying to constant weight. The dried biomass was then ground and sieved to particle sizes below 60 mesh. Particle size reduction plays a critical role in biomass processing by enhancing mass transfer, increasing accessible surface area, and ensuring reproducible reaction kinetics during chemical treatments. Uniform particle size distribution minimizes diffusion limitations and improves the consistency of hemicellulose solubilization under hydrothermal or acidic conditions.

For palm shell biomass, hemicellulose extraction was conducted following the methodology reported by Manaf *et al*., (2018), with minor modifications. Palm shell powder was treated with 1.5 wt% aqueous nitric acid (HNO_3) at a solid-to-liquid ratio of 1g:8 mL and reacted at 121 °C for 30 min. Under these conditions, the amorphous hemicellulose fraction is preferentially hydrolyzed and solubilized, while the crystalline cellulose matrix remains largely intact and lignin undergoes only partial cleavage. Following treatment, the reaction slurry separated into a hemicellulose-rich liquid phase and a solid residue enriched in cellulose and residual lignin. This phase separation highlights the feasibility of selectively isolating hemicellulose-derived sugars without extensive degradation of cellulose, thereby preserving its potential as a secondary glucose source. A similar strategy was applied to corn cob biomass, albeit under modified conditions to accommodate its denser anatomical structure. Corn cob powder was treated with 1.5 wt% aqueous sulfuric acid (H_2SO_4) at a solid-to-liquid ratio of 1 g:10 mL and reacted at 120 °C for 5 h. These conditions favor extensive cleavage of hemi-cellulosic glycosidic bonds while limiting cellulose depolymerization. As with palm shell processing, digestion resulted in a hemicellulose-rich liquor and a cellulose-dominant solid fraction (Cao *et al*., 2023; Hu *et al*., 2010; Shinners *et al*., 2007). The hemicellulose solutions recovered from both feedstocks thus represent renewable, Thailand-sourced precursors rich in monosaccharides and oligosaccharides. These streams serve as critical molecular entry points for the synthesis of advanced materials, including hybrid electrolytes, while simultaneously linking national biomass policies with molecular-scale materials design.

Beyond their role as polymeric precursors, hemicellulose-derived liquors serve as gateways to sugar-platform chemistry. Controlled hydrolysis of hemicellulose yields monosaccharides, predominantly glucose, xylose, and arabinose, which act as universal intermediates in modern biorefinery frameworks. In parallel, cellulose-rich residues preserved during selective hemicellulose extraction can be further depolymerized to generate additional glucose streams. Among these sugars, glucose occupies a central position due to its chemical versatility, global availability, and compatibility with diverse conversion pathways as it can be seen in Figure 3. Glucose can be transformed into alcohols (e.g., ethanol and glycerol), organic acids, and furanic derivatives, each of which plays a critical role in chemical manufacturing, energy storage technologies, and polymer electrolyte systems. Consequently, sugar-platform integration provides a unifying framework that connects biomass deconstruction with downstream synthesis of value-added chemicals and energy materials.

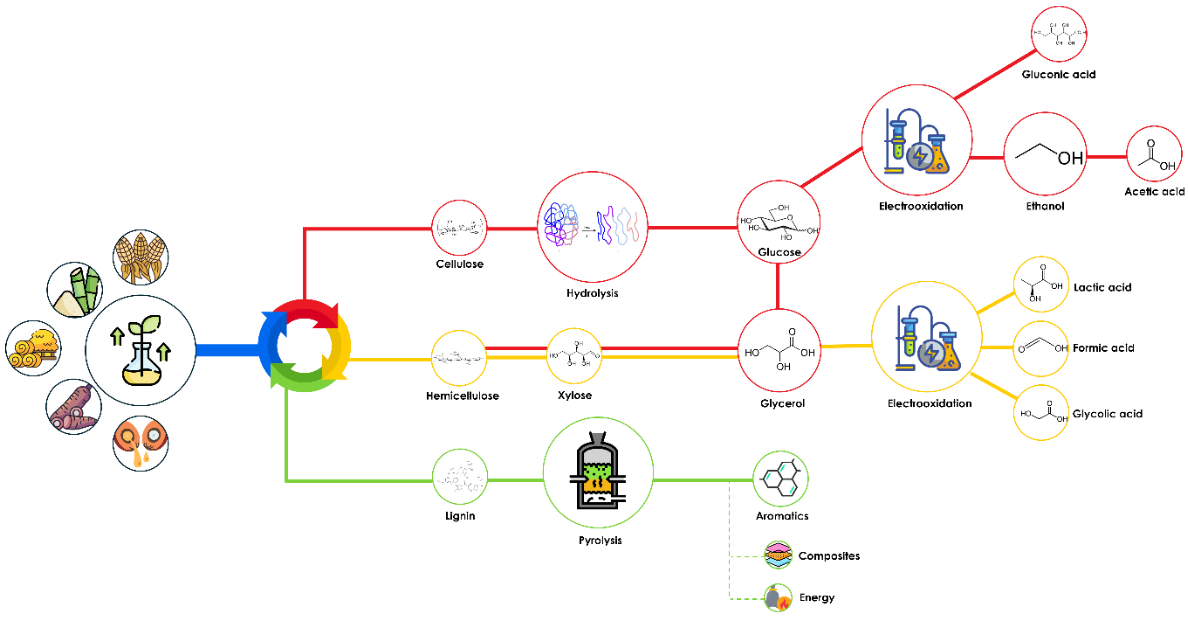

Figure 3. Schematic background of biomass valorization

While lignocellulosic residues require multistep depolymerization to access sugar platforms, sugar-rich biomass streams offer a direct and efficient alternative. Compared to sugarcane, sweet sorghum juice contains higher concentrations of reducing sugars, particularly glucose and fructose (Murray *et al.*, 2009). Sweet sorghum (*Sorghum bicolor* (L.)) has emerged as an attractive bio-refinery crop due to its high biomass yield, sugar-rich juice, adaptability to marginal land, and relatively low cultivation costs (Ahmad Dar *et al.*; Appiah-Nkansah *et al.*, 2019). In contrast to solid lignocellulosic systems, sweet sorghum juice enables immediate access to fermentable and chemically convertible sugars, significantly reducing pretreatment severity and energy input (**Figure 4**). Acid-catalyzed conversion studies have demonstrated that fructose in sweet sorghum juice can be fully converted into 5-hydroxymethylfurfural (HMF), achieving yields exceeding 90% in an 80/20 (v/v) acetone/water solvent system, while more than 85% of glucose remains unreacted and available for recycling (**Figure 5**). This selective conversion underscores glucose's strategic role as a recyclable platform molecule rather than a consumable reactant. Alternatively, Lewis acid catalysts such as $AlCl_3$ enable broader conversion of mixed sugar systems, including fructose, glucose, and sucrose, yielding over 70% HMF. However, the presence of multiple sugar species increases process complexity, operating costs, and capital investment due to separation and purification requirements. Techno-economic analyses indicate that HMF production from sweet sorghum juice results in a minimum selling price of approximately USD 1,909 per ton, reflecting the trade-offs inherent in mixed-sugar processing.

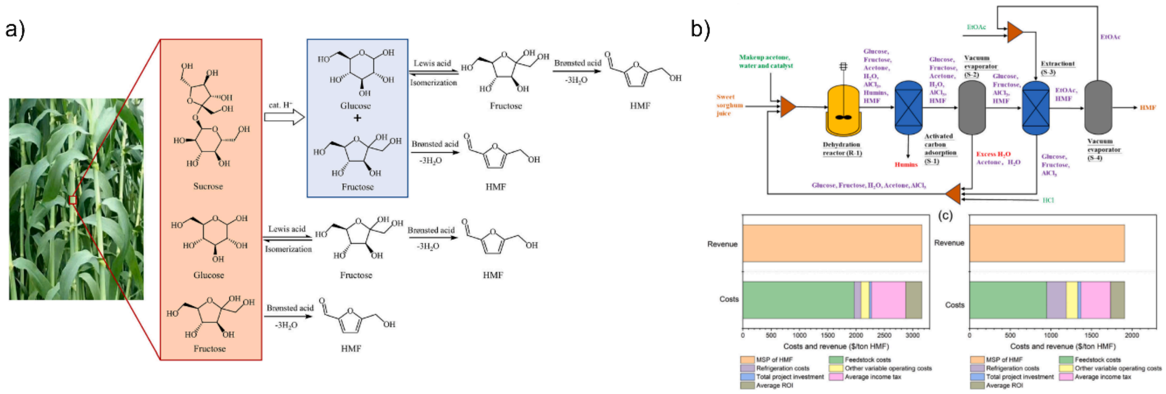

Figure 4. (a) Reaction pathway to produce HMF from a sucrose-glucose-fructose mixture; (b) Overall process flow diagram for the production of HMF and summary of costs and revenues for the proposed process (Zhou *et al*., 2025).

Taken together, lignocellulosic residues (palm shell and corn cob) and sugar-rich biomass (sweet sorghum) converge at a common molecular junction defined by glucose and fructose platforms. These sugars serve as versatile intermediates that can be selectively routed toward alcohols such as ethanol and glycerol, furanic compounds such as HMF, or polymerizable species for hybrid electrolyte systems. By integrating solid biomass deconstruction with liquid sugar feedstocks, this strategy maximizes feedstock flexibility, enhances carbon utilization efficiency, and supports scalable production of sustainable energy materials. Importantly, this integrated approach aligns molecular-level design with national biomass utilization policies and global climate objectives, positioning sugar-platform chemistry as a cornerstone for next-generation bio-derived electrolytes and functional materials.

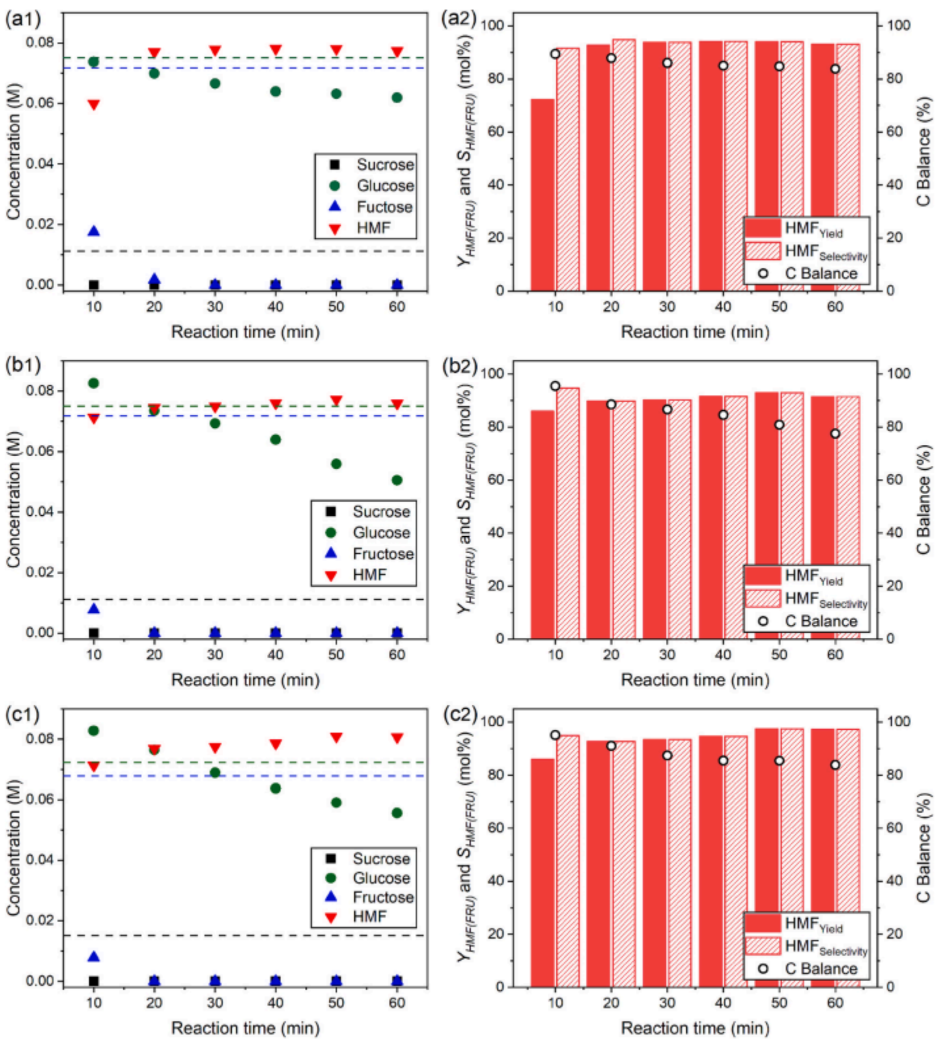

Figure 5. Concentration-time profile (left) and yield, and carbon balance (right) of HCl-catalyzed mixed sugar hydrolysis is an 80 vol% acetone concentration system: (a) Simulated sweet sorghum juice catalyzed by HCl (5 mM); (b) Hydrolyzed sweet sorghum juice catalyzed by HCl (40 mM); (c) Clarified-hydrolyzed sweet sorghum juice catalyzed by HCl (40 mM). Other reaction conditions: T = 150 ℃, acetone/water ratio = 8:2 (v/v) (Zhou *et al.*, 2025).

Chapter VI – Economic Analysis: CAPEX, OPEX. And Revenue from Biomass Utilization

Having outlined the potential of biomass from agricultural residues and the technical processes required to extract value-added products like hybrid electrolytes, it's crucial to assess the economic viability of scaling these technologies. Biomass conversion presents a promising economic opportunity for Thailand, with an estimated annual revenue of approximately USD 2.16 million from the sale of high-value by-products such as glyceric acid, acetic acid, and lactic acid. The capital expenditure (CAPEX) required to establish biomass conversion facilities is projected at USD 2.39 million, while the annual operating expenses (OPEX) amount to around USD 5.91 million. While the upfront investment and operating costs are substantial, the profitability of the biomass sector depends on its ability to scale and increase production efficiency. By optimizing biomass conversion processes and integrating renewable energy generation, Thailand can create a sustainable business model that not only aligns with its climate goals but also drives economic growth, job creation, and a reduction in fossil fuel dependency.

Chapter VII - Environmental & Economic Benefits of Biomass Utilization

As highlighted in the previous panels, biomass from agricultural residues offers a dual benefit: substantial economic potential and significant environmental advantages. By transitioning to biomass-based energy solutions, Thailand can reduce its dependence on fossil fuels, contributing to lower greenhouse gas emissions and supporting the country's goal of carbon neutrality by 2050 and net-zero emissions by 2065. Additionally, biomass utilization can generate sustainable, renewable energy, create high-value products like glyceric acid, and stimulate job creation in the green tech sector, driving economic growth. This synergy between economic and environmental goals makes biomass an ideal candidate for Thailand's energy future, helping to achieve both climate targets and economic development. Ultimately, scaling up biomass infrastructure and investing in process technologies will unlock the full potential of this resource, enhancing energy security, reducing carbon emissions, and providing economic returns while fostering a greener, more sustainable Thailand.

REFERENCES

[1] Climate Change Performance Index (CCPI). (2025). CCPI Rank: Thailand. Retrieved from https://ccpi.org/country/tha/.

[2] Energy Policy and Planning Office (EPPO), Ministry of Energy, Thailand. (2009). Biomass. Retrieved from http://www.eppo.go.th/engy/Load/ET08.pdf.

[3] Nkosi, S. P., & Kanny, K. (2018). Extraction of hemicellulose and lignin from sugarcane bagasse for biopolymer films: Green process. *Journal of Advanced Materials and Processing*, *6*(3), 57-65.

[4] Nigam, P. S. N., Marchant, R., Banat, I. M., & Singh, D. (1999, August). Ethanol production from sugarcane molasses at 45oC using thermotolerant yeast at industrial scale. In *Energy & Environment Africa Development Conference,*. Energy & Environment Africa Development Conference.

[5] Abdullah, N., & Sulaiman, F. (2013). The oil palm wastes in Malaysia. In *Biomass now-sustainable growth and use*. IntechOpen.

[6] Hidayu, A. R., Sukor, M. Z., Mohammad, N. F., Elham, O. S. J., Azri, N. I., Azhar, M. A. I., & Jalil, M. J. (2019, November). Preparation of activated carbon from palm kernel shell by chemical activation and its application for β-carotene adsorption in crude palm oil. In *Journal of Physics: Conference Series* (Vol. 1349, No. 1, p. 012103). IOP Publishing.

[7] Salema, A. A., & Ani, F. N. (2012). Pyrolysis of oil palm empty fruit bunch biomass pellets using multimode microwave irradiation. *Bioresource technology*, *125*, 102-107.

[8] Kengchuwong, M., Ketwong, C., Nuasri, C., Wanich, S., Trisupakitti, S., & Morris, J. (2023). Rubber wood sawdust waste converted to activated carbon for heavy metal removal from wastewater. *Journal of Food Health and Bioenvironmental Science*, *16*(1), 26-36.

[9] Mazlan, M. A. F., Uemura, Y., Yusup, S., Elhassan, F., Uddin, A., Hiwada, A., & Demiya, M. (2016). Activated carbon from rubber wood sawdust by carbon dioxide activation. *Procedia engineering*, *148*, 530-537.

[10] Peerapong, P., Wongtong, P., Khamdech, S., & Boonraksa, P. (2025). Energy Development Assessment of Biomass Power Plant with Rice Husk Fuel Source in Thailand: Analysis of the Performance, LCOE and Carbon Emissions Reduction. *Journal of Renewable Energy and Smart Grid Technology*, *20*(1), 13-18.

[11] Shinners, K. J., & Binversie, B. N. (2007). Fractional yield and moisture of corn stover biomass produced in the Northern US Corn Belt. *Biomass and Bioenergy*, *31*(8), 576-584.

[12] Bank of Ayudhya. (2023). *Sugar Industry Outlook 2023–2025*. Krungsri Research. https://www.krungsri.com/en/research/industry/industry-outlook/agriculture/sugar/io/sugar-2023-2025.

[13] Cao, M., Lu, M., Yin, H., Zhu, Q., Xing, K., & Ji, J. (2023). Effect of hemicellulose extraction pretreatment on sulfonated corncob biochar for catalytic biodiesel production. *Journal of Environmental Chemical Engineering*, *11*(1), 109058.

[14] Hu, X., Xue, Y., Long, L., & Zhang, K. (2018). Characteristics and batch experiments of acid-and alkali-modified corncob biomass for nitrate removal from aqueous solution. *Environmental Science and Pollution Research*, *25*(20), 19932-19940.

[15] Bank of Ayudhya. (2023). *Sugar Industry Outlook 2023–2025*. Krungsri Research. https://www.krungsri.com/en/research/industry/industry-outlook/agriculture/sugar/io/sugar-2023-2025.

[16] Silalertruksa, T., Wirodcharuskul, C., & Gheewala, S. H. (2022). *Environmental sustainability of waste circulation models for sugarcane biorefinery system in Thailand. Energies 15 (24), 9515*.

[17] Zhou, F., Xiang, Z., Zhang, H., Bu, Q., Zhu, W., Hu, W., & Wang, H. (2025). Economical production of 5-hydroxymethylfurfural from sorghum juice as inexpensive feedstock in an acetone/water solvent system. *Bioresource Technology*, 132592.

[18] Dar, M. R., Dar, A.E., Kaur, A., Phutela, G. U. (2018). Sweet sorghum-a promising alternative feedstock for biofuel production. *Renewable and Sustainable Energy Reviews*, 82, 4070-4090.

[19] Appiah-Nkansah, B. N., Li, J., Rooney, W., Wang, D. (2019). A review of sweet sorghum as a viable renewable bioenergy crop and its techno-economic analysis. *Renewable Energy*, 143, 1121-1132.

[20] Murray, S. C., Rooney, W. L., Hamblin, M. T., Mitchell, S. E., & Kresovich, S. (2009). Sweet sorghum genetic diversity and association mapping for brix and height. *The plant genome*, *2*(1).