Industry note: Innovative waste-to-energy pyrolysis technology for sustainable biowaste utilisation

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1 Introduction: the global imperative for sustainable waste management and climate action

The global imperative for sustainable waste management is escalating, driven by environmental concerns, resource scarcity, and climate change mitigation targets (Wilson et al., 2015; IPCC, 2022). Biowaste, a diverse category encompassing agricultural, food industry, and forestry residues, presents significant challenges in terms of disposal, often leading to greenhouse gas (GHG) emissions from decomposition or open burning, and land scarcity for landfills (Kaza et al., 2018). In the face of ambitious targets set by international agreements like the Paris Agreement (United Nations, 2021; UNFCCC,

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2023), reinforced at successive Conferences of the Parties (COP), innovative, sustainable waste valorisation technologies are more pressing than ever (IPCC, 2022).

This industry note showcases a pioneering technological solution that not only mitigates these environmental burdens but also transforms biowaste into valuable resources, thereby exemplifying advanced circular economy principles and contributing significantly to the global carbon neutrality agenda. While applicable to various biowaste streams, the technology finds an ideal target in palm kernel cake (PKC), a substantial byproduct of the palm oil industry (PASPI, 2021). The large concentration of PKC at palm oil mills significantly mitigates the logistical challenges and costs associated with biowaste collection, making it a highly attractive feedstock for this decentralised waste-to-energy solution (WIPO, 2021). Malaysia, as one of the world's largest producers of palm oil, operating a vast network of mills (MPOB, 2024), stands as a prime use case for the successful and widespread deployment of this technology.

2 The innovative FiF's integrated PMET and GGAC systems

The 'factory in factory (FiF)' concept is a testament to its commitment to 'fuelling the future with waste' and maximising the value of 'industrial residual re-valuable (IRR)'. The core of this innovative system lies in the seamless integration of two advanced thermochemical conversion processes (Kao, 2025). The system offers an agricultural renewable energy (ARE) total solution service for agricultural residual producers by applying patent technology equipment pyrolysis molecularisation extraction technology (PMET) and gas generator assemble cabinet (GGAC). The whole procedure is without secondary pollutants, making it a net-zero achievement accelerator.

2.1 PMET pyrolysis extraction system

Pyrolysis, a thermochemical decomposition of organic materials at elevated temperatures in the absence of oxygen, is central to the PMET system. This process is particularly well-suited for biomass like PKC due to its high organic content and favourable energy balance. PMET is a biomass gasification system that contains high-efficiency biomass gasification, extraction, and separation functions, allowing it to stably produce high-purity combustible gas, high-concentration biomass extract, and high-carbon content biochar.

- *Feedstock and throughput:* The existing system is designed for an input of 300 kg/hour, which is equivalent to 200 tonnes/month of input material. This capacity indicates its suitability for industrial-scale application within or adjacent to facilities generating concentrated biowaste, such as palm oil mills.
- *Energy efficiency:* The existing PMET system operates with an energy use of 20 kWh, demonstrating remarkable efficiency. This low energy footprint is crucial for the overall sustainability of the operation.
- *Product streams and value creation:* The pyrolysis process yields three primary product streams, each with distinct applications and economic value:

a *Biogas:* Generated from the biomass, this biogas serves as an energy source. This critical internal energy source drives the subsequent gasification process and makes the entire system largely self-sufficient. The combustible gas can be connected to the GGAC biomass gas generator system, which has high energy utilisation.

b *Biochar:* A stable, carbon-rich solid residue, produced at a rate of 360 tonnes/year. This translates to 30 tonnes/month. Biochar from biowaste, including PKC, is a highly valuable co-product, ideal for carbon sequestration and soil quality improvement. It can also be used for environmental remediation and potentially as an additive in construction materials. The production of biochar can be sequestered underground to restore the earth.

c *Extract (green tar/bio-oil):* A liquid fraction produced at 120 tonnes/year. This 'green tar' or bio-oil (approximately 10 tonnes/month and 150 litres/month green tar) holds potential as a biofuel or a chemical feedstock. This technology also enables natural compounds extraction and separation, applicable to the development of natural antibacterial and anti-insect agents, health promoters, cosmetic raw materials, biomedical materials, and fragrance raw materials.

2.2 GGAC gas generation system

The GGAC system represents the crucial link in the waste-to-energy chain, utilising the biogas generated from the PMET pyrolysis for electricity generation.

- *Green power generation (PG):* The existing system can generate 200 kWh of green power, translating to 130,000 kW/month. This consistent and substantial energy output can offset energy consumption at the mill or factory or be fed into the national grid. PMET generates syngas from biomass, and GGAC converts it into stable green electricity, which is ideal for off-grid farms, rural processors, or private power systems.
- *Minimal energy consumption:* The existing GGAC system has an energy use of 10 kWh, underscoring its efficiency and self-sustaining nature.
- *Grid integration and energy security:* By converting waste biomass into consistent electrical power, the system enhances energy security for industrial operations and contributes to the diversification of a nation's energy mix, reducing reliance on fossil fuels.

3 Direct contributions to COP objectives and global climate action

The FiF initiative, through its PMET and GGAC systems, is a tangible demonstration of how advanced technological solutions can directly address the multifaceted challenges of climate change, aligning with and amplifying the objectives articulated at various COP summits (CISL, 2022):

- *Decarbonisation of industrial processes (COP28 and beyond):* COP28 in Dubai emphasised the 'beginning of the end' for the fossil fuel era and a call to transition away from fossil fuels. This technology directly contributes by generating renewable

electricity from biomass, reducing the need for grid power often sourced from fossil fuels. It promotes 'achieving carbon neutrality in manufacturing', a critical step towards industrial decarbonisation. This also contributes to national carbon neutrality/net-zero targets.

- *Methane emission reduction (global methane pledge, COP29):* The declaration on reducing methane from organic waste, highlighted at COP29, underscores the urgency of cutting methane emissions, particularly from the waste and agricultural sectors. By processing biowaste through pyrolysis and gasification, this technology prevents the anaerobic decomposition of organic waste in landfills or wastewater, which is a major source of methane, a potent GHG. The capture and utilisation of biogas further ensure that any generated methane is converted into useful energy rather than escaping to the atmosphere. This reduces methane emissions and burning pollution, protecting air and water.
- *Renewable energy targets (Paris Agreement, COP commitments):* Countries are committed to tripling renewable energy capacity by 2030. The 130,000 kW/month of green power generated from biowaste contributes directly to a nation's renewable energy goals. This also boosts green energy in rural areas and creates local jobs.
- *Malaysia's feed-in tariffs (FiT) for biomass energy:* This scheme was established under the Renewable Energy Act 2011 by Malaysia Sustainable Energy Development Authority (SEDA, 2011) and aims to promote renewable energy generation by requiring utility companies to purchase electricity generated from eligible renewable energy sources at a fixed premium price for a specific duration. For biomass energy, including that derived from agricultural residues like those from the palm oil industry, SEDA Malaysia sets specific FiT rates. These rates vary based on factors such as type of biomass, capacity of the plant, location, and commissioning year. The existence of this FiT mechanism in Malaysia provides a strong financial incentive for projects like the FiF concept, ensuring a stable and predictable revenue stream for electricity generated from palm oil biomass waste. This directly supports the economic viability and deployment of waste-to-energy solutions.
- *Circular economy and resource efficiency (cross-cutting COP themes):* The FIF model exemplifies circular economy principles by 'turning industrial waste into resources'. This minimises waste, conserves natural resources, and reduces environmental impact. Malaysia has significantly advanced its commitment to these principles, aiming to promote sustainable production and consumption while contributing to a net-zero GHG emissions target by 2050. Furthermore, the circular economy opportunities in Malaysia (Holland Circular Hotspot, 2021) provides a comprehensive guide for transitioning towards a circular economy by emphasising reducing, reusing, and recycling. The New Industrial Master Plan 2030 (MITI, 2023) reinforces this by pushing for net-zero industrial decarbonisation and actively encouraging industrial symbiosis and green procurement through its focus on resource efficiency. These plans, along with the Green Technology Master Plan 2017–2030 (KeTTHA, 2017), establish a robust framework supporting the adoption of green technology, sustainable resource utilisation, and governmental leadership in

green procurement. This also helps in processing organic solid waste, avoiding open burning or landfilling, and solves landfill overflow and incinerator capacity issues. This enhances waste treatment capacity, reducing illegal burning and pollution.

- *Carbon sequestration via biochar (nature-based solutions):* The substantial production of biochar (360 tonnes/year/unit) offers a tangible pathway for carbon removal. When incorporated into soil, biochar remains stable for extended periods, effectively sequestering atmospheric carbon. This aligns with COP's growing recognition of nature-based solutions and engineered carbon dioxide removal (CDR) strategies as vital components of climate action. Studies on palm biomass biochar highlight its high carbon content and stability, making it an effective sequestration agent. Biochar production contributes to carbon credit creation and environmental value. This also improves soil quality and land regeneration by biochar amendment.
- *Sustainable supply chains and ESG integration:* The initiative's focus on 'driving corporate sustainability with ESG' reflects a proactive approach to environmental stewardship and social responsibility within the palm oil value chain. This resonates with COP's emphasis on private sector engagement and the integration of sustainability criteria across global supply chains. Clients can earn a low-cost green energy and carbon neutrality image and contribute to ESG and earth sustainability, benefiting exports and brand value. This also builds carbon credit revenue and global collaboration potential.

4 Malaysia's leadership in green technology and policy support

Malaysia has strategically positioned itself as a leader in green technology and circular economy development. This specific biowaste valorisation technology is a prime example of how such an innovation ecosystem can thrive within its borders. The Malaysian government's commitment is articulated in key national plans, such as the Twelfth Malaysia Plan 2021–2025 (MEA, 2021), which explicitly includes 'embracing the circular economy' as a core strategy and sets a target to achieve net-zero GHG emissions by 2050. Further underpinning this is the Circular Economy Blueprint for Solid Waste in Malaysia 2025–2035 (KPKT, 2025), providing a comprehensive roadmap for resource efficiency and waste minimisation. The New Industrial Master Plan 2030 (MITI, 2023) reinforces this national agenda by emphasising sustainability, industrial decarbonisation, and the adoption of green technologies. The regulatory framework, notably the FiT scheme administered by SEDA Malaysia under the Renewable Energy Act 2011 (Malaysia, 2011), provides clear incentives for biomass energy projects, ensuring their economic viability and fostering the deployment of waste-to-energy solutions. Furthermore, Malaysia's established research institutions and engineering expertise serve as critical enablers for developing and optimising complex integrated systems like the FiF model, in line with objectives outlined in the Green Technology Master Plan Malaysia 2017–2030 (KeTTHA, 2017) and the foundational National Green Technology Policy 2009 (KeTTHA, 2017). These policies and frameworks demonstrate a strong governmental commitment to decarbonisation, waste reduction, and local green economy development, and reduce dependence on imported energy, improving national energy resilience.

Table 1 Estimated annual financial projections for a FIF project at a small Malaysian palm oil mill (5 FiF units)

Financial metric	*Unit*	*Value (annual)*	*Calculation basis/assumptions*	*Source/comments*
Project inputs and outputs (total for 5 FiF units)				
Total PKC processed	Tonnes/year	12,000	5 units * 200 tonnes/month/unit * 12 months/year	Key feedstock volume
Total green power generated	kW/month	650,000	5 units * 130,000 kW/month/unit	Total renewable electricity production
Total biochar production	Tonnes/year	1,800	5 units * 360 tonnes/year/unit	Carbon sequestration and soil amendment product
Total bio-oil (green tar) production	Tonnes/year	600	5 units * 120 tonnes/year/unit	Potential biofuel/chemical feedstock
Revenue streams				
Energy sales	RM	2,730,000	(650,000 kW/month * 12 months) * RM 0.35/kWh	Malaysian FiT (conservative average)
Biochar sales	RM	3,240,000	1,800 tonnes/year * RM 1,800/tonne	RM 4.5/USD; USD 400/tonne (conservative market price)
Bio-oil (green tar) sales	RM	1,350,000	600 tonnes/year * RM 2,250/tonne	RM 4.5/USD; USD 0.50/liter (conservative, assuming 1 kg/L)
Total annual revenue	RM	7,320,000	Sum of energy, biochar, and bio-oil sales	Indicates strong income potential
Cost considerations				
Capital expenditure (CAPEX)	RM	15,000,000	Illustrative: based on typical costs for similar biomass-to-energy plants (~0.9 MW equivalent)	Actual require detailed project quotes
Annual operating expenditure (OPEX)	RM	1,750,000	Illustrative: includes labour, maintenance, consumables. Low energy consumption of FiF is advantageous.	Estimated, subject to detailed operational
Financial performance indicators				
Annual net revenue	RM	5,570,000	Total annual revenue – annual OPEX	Key profitability metric
Simple payback period	Years	2.7	CAPEX/annual net revenue	Highly attractive for investors
Energy self-consumption	%	Low	FIF units require minimal internal energy (20 kWh PMET, 10 kWh GGAC per unit)	Ensures high proportion of generated energy is available for sale

5 Applicability in Malaysian oil palm mills

Malaysia is one of the world's largest producers of palm oil, operating a vast network of palm oil mills. As of December 2024, there are 453 fresh fruit bunch (FFB) mills in operation across Malaysia. These mills have a combined processing capacity of 125,397,570 tonnes/year (MPOB, 2024). These mills process FFB and generate substantial volumes of biomass waste, including PKC, empty fruit bunches (EFB), palm oil mill effluent (POME), and palm kernel shells (PKS). PKC, specifically, is a rich lignocellulosic material, making it an excellent feedstock for thermochemical conversion processes like pyrolysis and gasification due to its consistent composition and relatively high energy content. The concentration of this waste at a single point, the palm oil mill, makes it an ideal target for this technology, as it significantly mitigates the logistical challenges and costs associated with collecting dispersed biowaste.

5.1 Volume of PKC and energy generation potential

An average small palm oil mill in Malaysia processes between 30 to 60 tonnes of FFB per hour. From this, PKC constitutes approximately 5–6% of the FFB processed. Therefore, a mill processing 30 tonnes of FFB per hour would generate approximately:

$$30 \text{ tonnes FFB / hour} \times 0.05 \text{ (PKC yield)} = 1.5 \text{ tonnes PKC / hour.}$$

The FIF PMET system is designed to process 0.3 tonnes/hour of PKC, which generates 130,000 kW/month of green power. Scaling this to the PKC generation of a small Malaysian mill:

A mill generating 1.5 tonnes PKC/hour is equivalent to:

$$1.5 \text{ tonnes PKC / hour} \div 0.3 \text{ tonnes PKC / hour (FIF capacity)} = 5 \text{ FIF units.}$$

Therefore, theoretically, one smallest palm oil mill (processing 30 tonnes FFB/hour) could potentially accommodate five existing integrated FIF units. The total PG from these five units would be:

$$5 \text{ units} \times 130,000 \text{ kW / month / unit} = 650,000 \text{ kW / month.}$$

Assuming continuous operation for 24 hours/day, 30 days/month:

$$650,000 \text{ kW / month} \div (30 \text{ days / month} \times 24 \text{ hours / day})$$
$$\approx 902.78 \text{ kW (average continuous power output).}$$

This substantial energy output highlights the significant potential for decentralised renewable energy generation within the Malaysian palm oil industry.

5.2 Bankability of the FIF concept in Malaysian oil palm mills

The bankability of this FiF concept hinges on a robust revenue model, operational efficiency, and supportive regulatory frameworks. For investor due diligence, a clear financial projection is essential.

5.2.1 Assumptions for financial projections

- *PKC yield from FFB:* Assumed 5% of FFB processed, in line with industry averages.
- *Operating days/month:* Assumed 30 days of continuous operation for calculation simplicity. Actual mill operation may vary due to maintenance or FFB availability.
- *FiT rate (Malaysia):* RM 0.35/kWh is a conservative average for biomass. Actual rates vary based on plant capacity, location, and contract terms with SEDA Malaysia.
- *Biochar price:* USD 400/tonne is a conservative estimate. Prices are subject to market demand, quality specifications (e.g., carbon content, volatile matter), and certification for carbon markets (exchange rate: 1 USD = 4.5 RM, as of June 2025).
- *Bio-oil price:* USD 0.50/liter is a conservative estimate. Bio-oil market is nascent, and prices depend on end-use applications and further refining needs (density assumed 1 g/mL).
- *CAPEX:* Illustrative and based on broad industry estimates for similar-scale biomass plants. Actual costs would require detailed engineering and procurement quotes.
- *OPEX:* Illustrative and based on a percentage of revenue, reflecting the inherent efficiency of the FiF system's low energy consumption. Detailed OPEX would include specific labour costs, maintenance schedules, and consumables.
- *Exclusions:* This simplified model does not include detailed depreciation, financing costs (e.g., interest on loans), corporate taxes, or specific incentives like green investment tax allowance (GITA) offered by the Malaysian government, which would further enhance project economics. Carbon credit sales, while a significant potential revenue stream, are also not explicitly quantified here due to their variable nature.

5.2.2 Interpretation for investor due diligence

The estimated simple payback period of approximately 2.7 years suggests a highly attractive investment proposition. This rapid return on investment is a critical indicator for investors, especially in the renewable energy and waste valorisation sectors. The key drivers of this strong financial performance are:

- *Abundant, low-cost feedstock:* Biowaste, particularly PKC in palm oil-producing regions like Malaysia, is a readily available waste product, reducing feedstock acquisition costs.
- *Multiple revenue streams:* The diversified revenue from electricity, biochar, and bio-oil provides resilience against market fluctuations in any single product.
- *Supportive policy environment:* Malaysia's FiT mechanism and broader commitment to renewable energy and circular economy principles significantly de-risk the investment and ensure a stable market for the generated outputs.
- *Environmental and ESG benefits:* Beyond financial returns, the project offers strong environmental, social, and governance (ESG) credentials, appealing to impact investors and those seeking to meet sustainability mandates. Reducing waste,

generating clean energy, and sequestering carbon are significant non-financial benefits. Clients can also earn the low-cost green energy and carbon neutrality image.

5.2.3 Risks and mitigation for due diligence

- *Technology scaling:* While the technology has demonstrated capacity, scaling to multiple units for a large mill or other industrial facilities requires careful planning and execution. However, the modular design allows flexible deployment across farms and factories of various scales.
- *Marketvolatility:* Prices for biochar and bio-oil can fluctuate. Diversified revenue streams help mitigate this.
- *Operational reliability:* Ensuring consistent uptime and efficient operation of pyrolysis and gasification units is crucial. The system provides a stable power supply by waste renewal application.
- *Regulatory changes:* Changes in FiT rates or carbon pricing mechanisms could impact profitability.

Overall, for due diligence, this preliminary analysis indicates that the FiF concept presents a compelling opportunity for investors interested in sustainable industrial solutions within the Malaysian palm oil sector and other biowaste-generating industries. Further detailed feasibility studies, including pilot projects, would be recommended to validate these projections and optimise implementation strategies.

6 Conclusions and future outlook

The FiF initiative, powered by the PMET Pyrolysis Extraction and GGAC Gas Generation System, stands as a beacon of sustainable innovation. It offers a comprehensive and economically viable solution for transforming various biowaste streams, exemplified by PKC, into valuable renewable energy, a stable carbon sink (biochar), and a potential bio-oil feedstock. This technology directly supports multiple pillars of the global climate agenda, as championed at COP meetings: mitigating GHG emissions, expanding renewable energy infrastructure, fostering circular economy practices, and enabling tangible carbon sequestration. The entire procedure is without secondary pollutants, making it a net-zero achievement accelerator.

The analysis of its applicability in Malaysian oil palm mills reveals a compelling business case. With average mills generating ample PKC and a supportive regulatory environment for renewable energy and biomass utilisation, the FiF concept demonstrates strong bankability with a potentially rapid payback period. As the world intensifies its efforts to achieve net-zero emissions and build a truly circular economy, the FiF model provides a robust example of how integrated waste-to-energy solutions can contribute significantly to these overarching goals. Continued research and development, particularly in optimising bio-oil upgrading and exploring novel applications for biochar, will further amplify the impact of this technology. Its successful implementation in Taiwan offers valuable lessons and a replicable blueprint for other nations, especially those in Southeast Asia with significant palm oil industries, seeking to harmonise

industrial development with environmental stewardship and climate resilience. The system also provides benefits for agricultural residual producers by enabling them to resource their residues to generate revenue, avoid waste pollution problems, and lower treatment costs. For countries, it contributes to decarbonisation, waste reduction, and local green economy development, reduces dependence on imported energy, and improves national energy resilience. For the Earth, it creates sustainable energy and reduces environmental damage, and converts waste into energy, reducing planetary burden, promoting renewable energy usage expansion to mitigate climate change.

References

Cambridge Institute for Sustainability Leadership (CISL) (2022) *What is COP?* [online] https://www.cisl.cam.ac.uk/cop-climate-change-conference (accessed 1 July 2025).

Holland Circular Hotspot (2021) *Circular Economy Opportunities in Malaysia: Dutch Solutions to Malaysian Challenges* [online] https://www.rvo.nl/files/file/2022/03/Malaysia%20Booster%20Programme.pdf (accessed 1 July 2025).

IPCC (2022) 'Climate change 2022: mitigation of climate change', Shukla et al. (Eds.): *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, https://doi.org/10.1017/9781009157926.

Kao, M-W. (2025) *Biomass Gasification System and Electricity Generation System Including the Same*, Taiwan Patent No. M667986.

Kaza, S., Yao, L., Bhada-Tata, P. and Van Woerden, F. (2018) *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, Urban Development Series*, World Bank, Washington, DC, https://doi.org/10.1596/978-1-4648-1329-0.

KeTTHA (Ministry of Energy, Green Technology and Water) (2017) *Green Technology Master Plan Malaysia 2017–2030* [online] https//www.prno.gov.my/wp-content/uploads/2019/07/Green-Technology-Master-Plan-Malaysia-2017-2030.pdf (accessed 1 July 2025).

KPKT (Ministry of Housing and Local Government of Malaysia) (2025) *Circular Economy Blueprint for Solid Waste in Malaysia 2025–2030* [online] https://www.kpkt.gov.my/kpkt/resources/user_1/GALERI/PDF_PENERBITAN/BLUEPRINT/BLUEPRINT_EKONOMI_KITARAN_SIS_PEPEJAL_DI_MALAYSIA_2025_2035.pdf (accessed 1 July 2025).

Malaysia (2011) *Renewable Energy Act 2011 (Act No. 725)*, Percetakan Nasional Malaysia Berhad, Kuala Lumpur [online] https://policy.asiapacificenergy.org/node/1213 (accessed 1 July 2025).

Malaysian Palm Oil Board (MPOB) (2024) *Number & Capacities of Palm Oil Sectors December 2024 (Tonnes/Year)* [online] https://bepi.mpob.gov.my/index.php/import/1177-number-capacities-of-palm-oil-sectors-2024 (accessed 1 July 2025).

Ministry of Economic Affairs, Malaysia (MEA) (2021) *Twelfth Malaysia Plan 2021–2025: A Prosperous, Inclusive, Sustainable Malaysia* [online] https://pulse.icdm.com.my/wp-content/uploads/2021/09/Twelfth-Plan-Document_compressed-1.pdf (accessed 1 July 2025).

Ministry of Investment, Trade and Industry, Malaysia (MITI) (2023) *New Industrial Master Plan 2030* [online] https://www.mdbc.com.my/wp-content/uploads/2023/09/NIMP_2030.pdf (accessed 1 July 2025).

Palm Oil Agribusiness Strategic Policy Institute (PASPI) (2021) *Potential for Utilization of Palm Wastes*, PASPI Monitor Report [online] https://gapki.id/en/news/2025/03/05/palm-biomass-hugely-potential-to-support-energy-resilience/ (accessed 1 July 2025).

Sustainable Energy Development Authority, Malaysia (SEDA) (2011) *Feed-in-Tariff (FIT)* [online] https://www.seda.gov.my/reportal/fit/ (accessed 1 July 2025).

UNFCCC (2023) *The Paris Agreement* [online] https://unfccc.int/process-and-meetings/the-paris-agreement (accessed 1 July 2025).

United Nations (2021) *The Paris Agreement* [online] https://www.un.org/en/climatechange/paris-agreement (accessed 1 July 2025).

Wilson, D.C., Rodic, L., Modak, P. et al. (2015) *Global Waste Management Outlook*, United Nations Environment Programme (UNEP), Nairobi, ISN: 978-92-807-3479-9, https://eprints.whiterose.ac.uk/id/eprint/99773/.

WIPO (2021) *Technological Options for the Treatment and Valorisation of Palm Oil Mill Effluent in Indonesia* [online] https://www3.wipo.int/wipogreen/en/docs/wipogreen-pome-technology-catalog-winrock-Dec-17-2021.pdf (accessed 1 July 2025).