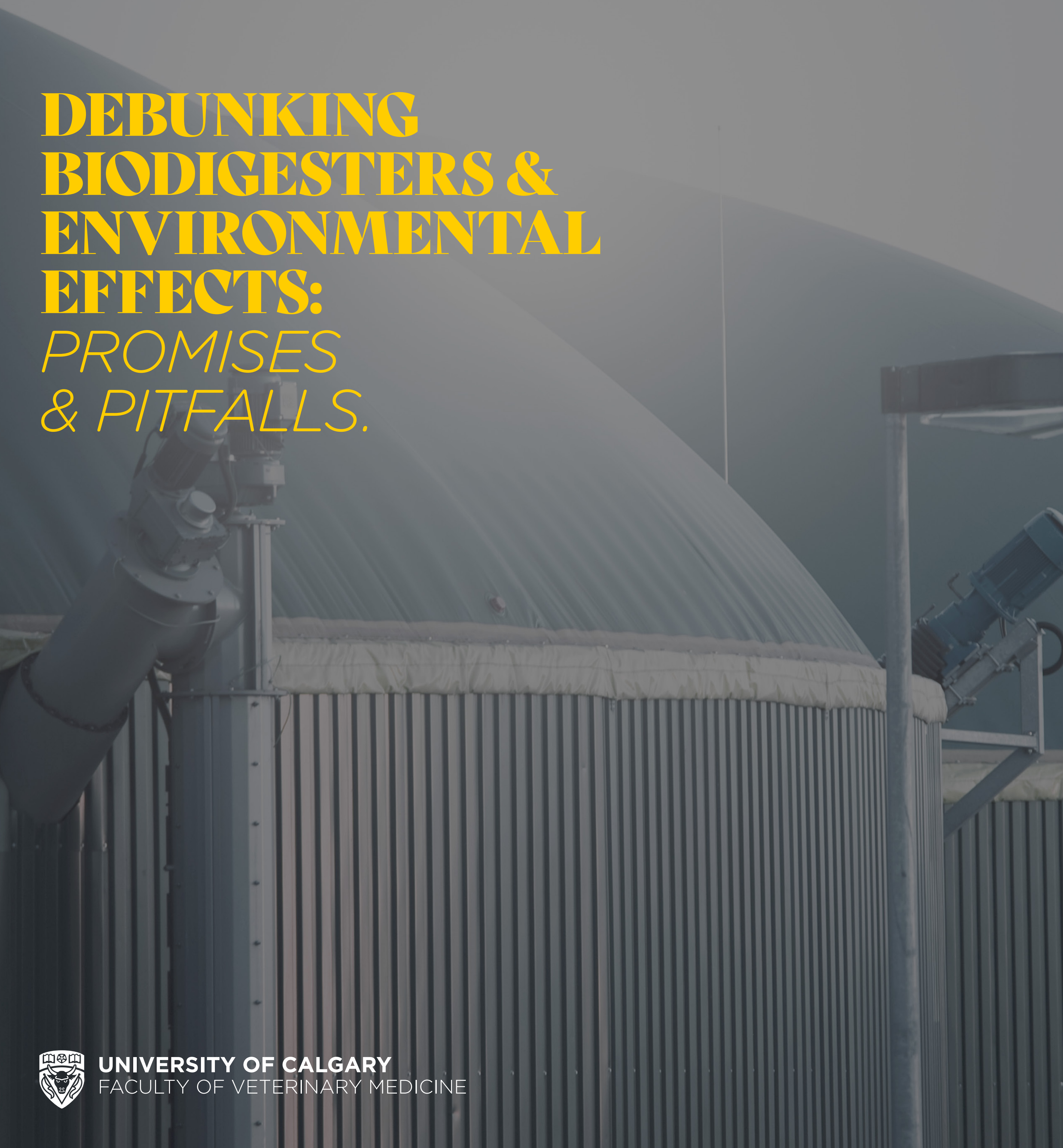
DEBUNKING BIODIGESTERS & ENVIRONMENTAL EFFECTS: *PROMISES & PITFALLS.*



UNIVERSITY OF CALGARY
FACULTY OF VETERINARY MEDICINE

BIODIGESTERS & ENVIRONMENTAL EFFECTS.

Biodigesters, also known as anaerobic digesters, are systems that biologically break down organic material in the absence of oxygen, producing biogas (primarily methane and carbon dioxide) and digestate, a nutrient-rich slurry (Chen and Neibling, n.d.). These systems are increasingly being promoted as a sustainable solution to organic waste management, particularly in agriculture, municipalities, and food production sectors (Orzi et al., 2010; Piadeh et al., 2024). By offering both energy generation and waste treatment, biodigesters align with circular economy goals and climate mitigation strategies (Mancini and Raggi, 2021; Wiśniewska et al., 2021). However, their environmental impact is not uniformly positive and depends greatly on factors such as scale, feedstock composition, design, and operational management. This paper explores the environmental benefits and challenges of biodigesters, aiming to present a balanced view of their role in sustainable development.

POSITIVE ENVIRONMENTAL IMPACTS.

GREENHOUSE GAS EMISSIONS REDUCTION

A primary environmental advantage of biodigesters is their ability to reduce greenhouse gas (GHG) emissions. Organic waste, particularly manure and food residues, emits methane—a potent GHG—when left to decompose in open air or landfills. Anaerobic digestion captures this methane, allowing it to be used as a renewable energy source instead of being released into the atmosphere (Piadeh et al., 2024). Studies suggest that using biogas for electricity and heat can significantly reduce lifecycle emissions compared to fossil fuels (Lantz et al., 2007).

IMPROVED ORGANIC WASTE MANAGEMENT

Biodigesters contribute to waste minimization by diverting biodegradable materials from landfills. This reduces land use pressure and decreases leachate and odour emissions associated with uncontrolled decomposition (Manyi-Loh et al., 2013) (Mönch-Tegeder et al., 2013). The controlled digestion process also stabilizes organic material, reducing pathogen levels and odor potential (Chen and Neibling, n.d.).

DIGESTATE AS FERTILIZER SUBSTITUTE

The solid and liquid by-products of anaerobic digestion—collectively known as digestate—contain valuable nutrients like nitrogen, phosphorus, and potassium. When properly managed, digestate can replace synthetic fertilizers, reducing the need for energy-intensive chemical inputs and closing nutrient loops (Mancini and Raggi, 2021; Piadeh et al., 2024). Additionally, digestate application can improve soil organic matter and water retention (Alburquerque et al., 2012).

RENEWABLE ENERGY GENERATION

Biodigesters offer decentralized renewable energy production, beneficial particularly in rural or off-grid communities. They support local energy autonomy and reduce reliance on non-renewable sources (Meegoda et al., 2025; Piadeh et al., 2024). In some regions, surplus biogas can be upgraded to biomethane and injected into the natural gas grid or used as a vehicle fuel, further diversifying low-carbon energy options (Meegoda et al., 2025).

POTENTIAL ENVIRONMENTAL RISKS & CHALLENGES.

ODOUR AND AIR POLLUTION

While biodigesters can reduce odours compared to unmanaged waste, improper handling—especially during feedstock loading or digestate spreading—can cause offensive smells and air pollution (Nkoa, 2014; Wiśniewska et al., 2021). Leaks in gas collection systems may also result in fugitive methane emissions, which compromise environmental gains (Chen and Neibling, n.d.; Selormey et al., 2021).

DIGESTATE MISMANAGEMENT

Digestate must be carefully stored and applied to land to avoid environmental damage. Over-application or inappropriate timing can lead to nutrient runoff, eutrophication of water bodies, and nitrate leaching into groundwater (Meegoda et al., 2025; Nkoa, 2014). Regulations and guidelines for digestate quality and application rates vary by region and are often inconsistently enforced.

WATER USE AND CONTAMINATION RISK

Water is often added to the feedstock to maintain the slurry consistency required for digestion. In water-scarce areas, this can stress local supplies. Furthermore, leachate from digestate or slurry tanks can pose a risk to surface and groundwater if containment systems are inadequate (Jesus et al., 2021; Selormey et al., 2021; Yue et al., 2010).

SYSTEM INEFFICIENCIES AND CARBON COSTS

If not optimized, biodigesters may consume more energy than they produce, especially if feedstock is transported long distances or if the digestion process is inefficient. Fossil fuel use in collection and processing can reduce or negate climate benefits (Evangelisti et al., 2014). Proper life cycle assessments are crucial to determine the net environmental impact of each installation (Wang et al., 2014).

CONTEXTUAL CONSIDERATIONS.

The environmental outcomes of biodigesters vary significantly depending on local conditions. In countries with high agricultural waste production and poor waste management infrastructure, biodigesters can offer substantial environmental gains. However, in regions with robust composting systems or clean energy grids, the relative benefits may be reduced (Fusi et al., 2016).

Moreover, scale matters. Industrial-scale biodigesters are often more efficient and better regulated than small-scale systems, which may suffer from operational inconsistencies. Nonetheless, small-scale digesters remain vital in developing countries, where they can provide clean cooking fuel and improved sanitation when combined with proper training and maintenance support (Massaro et al., 2015; Piadeh et al., 2024; Wang et al., 2014).

Effective policy frameworks and stakeholder engagement are critical to ensure that biodigesters are integrated sustainably. This includes permitting processes, incentives for biogas use, digestate standards, and support for community-level capacity building.

CONCLUSION.

Biodigesters present a compelling environmental opportunity, particularly in reducing greenhouse gas emissions, improving organic waste management, and supporting renewable energy production. However, their effectiveness depends heavily on appropriate feedstock management, infrastructure investment, and regulatory oversight. Poorly managed systems can lead to odour issues, nutrient runoff, and water contamination, undermining their environmental credentials. As part of a broader strategy for sustainable development, biodigesters must be implemented alongside sound agricultural practices, environmental safeguards, and context-specific design. With careful planning and oversight, they can play a key role in a circular, low-carbon economy.

This work was supported by BMO in an agreement that encourages research, research dissemination, and public outreach. The donors will not be involved in the study design, collection, analysis, interpretation of data, the writing of the documents, or the decision to submit it for publication.

REFERENCES.

Alburquerque, J.A., de la Fuente, C., Bernal, M.P., 2012. Chemical properties of anaerobic digestates affecting C and N dynamics in amended soils. Agriculture, Ecosystems & Environment, Recycling of organic resudues to agriculture 160, 15–22. https://doi.org/10.1016/j.agee.2011.03.007

Chen, L., Neibling, H., n.d. Anaerobic Digestion Basics.

Evangelisti, S., Lettieri, P., Borello, D., Clift, R., 2014. Life cycle assessment of energy from waste via anaerobic digestion: A UK case study. Waste Management 34, 226–237. https://doi.org/10.1016/j.wasman.2013.09.013

Fusi, A., Bacenetti, J., Fiala, M., Azapagic, A., 2016. Life Cycle Environmental Impacts of Electricity from Biogas Produced by Anaerobic Digestion. Front Bioeng Biotechnol 4, 26. https://doi.org/10.3389/fbioe.2016.00026

Jesus, R.H.G. de, Souza, J.T. de, Puglieri, F.N., Piekarski, C.M., Francisco, A.C. de, 2021. Biodigester location problems, its economic–environmental–social aspects and techniques: Areas yet to be explored. Energy Reports 7, 3998–4008. https://doi.org/10.1016/j.egyr.2021.06.090

Lantz, M., Svensson, M., Björnsson, L., Börjesson, P., 2007. The prospects for an expansion of biogas systems in Sweden—Incentives, barriers and potentials. Energy Policy 35, 1830–1843. https://doi.org/10.1016/j.enpol.2006.05.017

Mancini, E., Raggi, A., 2021. A review of circularity and sustainability in anaerobic digestion processes. Journal of Environmental Management 291, 112695. https://doi.org/10.1016/j.jenvman.2021.112695

Manyi-Loh, C.E., Mamphweli, S.N., Meyer, E.L., Okoh, A.I., Makaka, G., Simon, M., 2013. Microbial Anaerobic Digestion (Bio-Digesters) as an Approach to the Decontamination of Animal Wastes in Pollution Control and the Generation of Renewable Energy. International Journal of Environmental Research and Public Health 10, 4390–4417. https://doi.org/10.3390/ijerph10094390

Massaro, V., Digiesi, S., Mossa, G., Ranieri, L., 2015. The sustainability of anaerobic digestion plants: a win–win strategy for public and private bodies. Journal of Cleaner Production 104, 445–459. https://doi.org/10.1016/j.jclepro.2015.05.021

Meegoda, J.N., Chande, C., Bakshi, I., 2025. Biodigesters for Sustainable Food Waste Management. International Journal of Environmental Research and Public Health 22, 382. https://doi.org/10.3390/ijerph22030382

Nkoa, R., 2014. Agricultural benefits and environmental risks of soil fertilization with anaerobic digestates: a review. Agron. Sustain. Dev. 34, 473–492. https://doi.org/10.1007/s13593-013-0196-z

Orzi, V., Cadena, E., D'Imporzano, G., Artola, A., Davoli, E., Crivelli, M., Adani, F., 2010. Potential odour emission measurement in organic fraction of municipal solid waste during anaerobic digestion: Relationship with process and biological stability parameters. Bioresource Technology 101, 7330–7337. https://doi.org/10.1016/j.biortech.2010.04.098

Piadeh, F., Offie, I., Behzadian, K., Rizzuto, J.P., Bywater, A., Córdoba-Pachón, J.-R., Walker, M., 2024. A critical review for the impact of anaerobic digestion on the sustainable development goals. Journal of Environmental Management 349, 119458. https://doi.org/10.1016/j.jenvman.2023.119458

Selormey, G.K., Barnes, B., Kemausuor, F., Darkwah, L., 2021. A review of anaerobic digestion of slaughterhouse waste: effect of selected operational and environmental parameters on anaerobic biodegradability. Rev Environ Sci Biotechnol 20, 1073–1086. https://doi.org/10.1007/s11157-021-09596-8

Wang, X., Chen, Y., Sui, P., Gao, W., Qin, F., Wu, X., Xiong, J., 2014. Efficiency and sustainability analysis of biogas and electricity production from a large-scale biogas project in China: an emergy evaluation based on LCA. Journal of Cleaner Production 65, 234–245. https://doi.org/10.1016/j.jclepro.2013.09.001

Wiśniewska, M., Kulig, A., Lelicińska-Serafin, K., 2021. Odour Nuisance at Municipal Waste Biogas Plants and the Effect of Feedstock Modification on the Circular Economy—A Review. Energies 14, 6470. https://doi.org/10.3390/en14206470

Yue, Z., Teater, C., Liu, Y., MacLellan, J., Liao, W., 2010. A sustainable pathway of cellulosic ethanol production integrating anaerobic digestion with biorefining. Biotechnology and Bioengineering 105, 1031–1039. https://doi.org/10.1002/bit.22627