



Process-Level Sustainability and Resource-Efficiency Assessment of Corncob-Based Lactic-Acid Production using gPROMS

Adoga D. O., Alabi S. B., Oboh I. O.

Department of Chemical Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa Ibom State, Nigeria

ABSTRACT

This study evaluated the process-level sustainability and resource efficiency of an integrated corncob-to-lactic-acid process simulated in gPROMS. The steady-state pathway comprised dilute-acid pretreatment, enzymatic hydrolysis, fermentation, membrane filtration, acidification, purification and product storage. At a reference corncob throughput of $2,500 \text{ kg h}^{-1}$, the process produced $1,984 \text{ kg h}^{-1}$ lactic acid in approximately $2,002 \text{ kg h}^{-1}$ purified product. The process achieved 87.6% overall efficiency, 78.4% carbon-conversion efficiency, 96.8% lactic-acid recovery and 99.1 wt% product purity. Total heating demand was 2,678 kW, equivalent to 4.86 MJ kg^{-1} lactic acid; the purification reboiler accounted for 43.5% of this demand. Direct process-water intensity was 6.05 L kg^{-1} lactic acid. Filtration cake and gypsum were generated at 842 and 684 kg h^{-1} , giving a combined solid-residue intensity of 0.769 kg kg^{-1} lactic acid. The estimated greenhouse-gas indicator was $1.42 \text{ kg CO}_2\text{-eq kg}^{-1}$ lactic acid within the adopted boundary. Purification heat, water use and solid-residue management were the principal hotspots. The results provide a process-development baseline for heat integration, water recycling, residue valorisation and subsequent cradle-to-gate assessment.

ARTICLE INFO

Article History

Received: May, 2026

Received in revised form: July, 2026

Accepted: August, 2026

Published online: September, 2026

KEYWORDS

Corncob; Lactic Acid; gPROMS; Resource Efficiency; Sustainability

INTRODUCTION

Lactic acid is an important platform chemical used in food, pharmaceutical, cosmetic and chemical manufacture and as a precursor for polylactic acid. Fermentative production can provide optically pure lactic acid, but conventional processes commonly depend on refined sugars or starch. The use of lignocellulosic residues can reduce competition with food resources and support the conversion of agricultural wastes into higher-value products (Abdel-Rahman et al., 2011; John et al., 2007). Corncob is a potentially useful feedstock because it contains cellulose and hemicellulose that can be converted into fermentable sugars after suitable pretreatment and hydrolysis.

The environmental advantage of a lignocellulosic route is not automatic. Dilute-acid pretreatment requires heat and chemicals; enzymatic hydrolysis can require long residence

times and substantial enzyme input; fermentation performance determines the amount of feedstock and utilities required per unit product; and downstream recovery can dominate energy demand. Calcium-based neutralisation and subsequent acidification can additionally generate large quantities of gypsum. Consequently, high conversion at an individual process stage does not by itself establish the sustainability of the full production pathway (Daful and Görgens, 2017; Li, Y. et al., 2021).

Process modelling is useful at the early design stage because it links unit-operation performance to material flows, utility requirements and residue generation. Vance et al. (2024) showed that process configuration, scale and energy source can materially change the environmental and economic performance of a lactic-acid biorefinery. Similarly, integrated assessments have identified fermentation yield,

Corresponding author: Adoga D. O.

adogadavid@unical.edu.ng

Department of Chemical Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



chemical consumption, separation efficiency and energy source as major drivers of lignocellulosic lactic-acid performance (Brobbe et al., 2024; Manandhar & Shah, 2023).

Previous work by Adoga et al. (2026a) established experimental fermentation-kinetic and optimisation information for lactic-acid production from corncob, while Adoga et al. (2026b) reported the statistical optimisation of dilute-acid corncob hydrolysis for fermentable-sugar production. The present study addresses a different question: how the complete simulated conversion pathway performs in terms of material utilisation, energy demand, direct water use, greenhouse-gas indication and residue generation. The objective was therefore to develop a process-level sustainability profile from the gPROMS material and energy inventory, identify the dominant hotspots, and define practical priorities for process integration and subsequent pilot-scale investigation.

MATERIALS AND METHODS

Process description and simulation basis

The production pathway comprised seven principal operations: dilute-acid

pretreatment, enzymatic hydrolysis, fermentation, membrane filtration, acidification, purification and product storage. Corncob and process water entered the pretreatment stage, where structural disruption and hemicellulose conversion increased carbohydrate accessibility. The pretreated solids underwent enzymatic hydrolysis to release glucose and xylose. The resulting sugar stream was fermented to lactic acid, after which suspended solids were removed by membrane filtration. Calcium lactate in the clarified broth was converted to lactic acid using sulfuric acid, generating gypsum. The lactic-acid stream was purified to the required product concentration and transferred to storage.

The process was implemented as a steady-state model in gPROMS. Unit models were linked by component mass balances and energy relationships so that the output of each stage formed the input to the next. The reference simulation processed $2,500 \text{ kg h}^{-1}$ corncob with $12,000 \text{ kg h}^{-1}$ process water. The resulting production basis was $1,984 \text{ kg h}^{-1}$ lactic acid in approximately $2,002 \text{ kg h}^{-1}$ purified product. At 8,000 operating hours per year, this corresponds to $15,872 \text{ t year}^{-1}$ lactic acid.

Table 1. Principal Operating and Performance Basis of the Simulated Process

Process stage	Operating basis	Performance output
Pretreatment	168 °C; 8.60 bar; 1.80 wt% H_2SO_4 ; 34 min	91.3% hemicellulose conversion; 63.8% lignin removal
Hydrolysis	49 °C; pH 4.9; 24 FPU g^{-1} cellulose; 61 h	93.6% cellulose conversion; 186.7 g L^{-1} fermentable sugars
Fermentation	42 °C; 1.15 bar	118.6 g L^{-1} LA; 0.91 g g^{-1} yield; 3.04 $\text{g L}^{-1} \text{h}^{-1}$ productivity
Filtration	91 $\text{L m}^{-2} \text{h}^{-1}$ membrane flux	97.2% solids removal; 842 kg h^{-1} cake
Acidification	71 °C; 412 kg h^{-1} H_2SO_4	96.4% calcium-lactate conversion; 684 kg h^{-1} gypsum
Purification	18 stages; reflux ratio 3.4; 1.30 bar	96.8% LA recovery; 99.1 wt% product purity

Assessment boundary and functional basis

The assessment boundary extended from corncob and direct process-water inputs to purified lactic acid, filtration cake, gypsum and fermentation off-gas at the plant gate. The functional basis was 1 kg of lactic acid produced.

The assessment used the simulated steady-state inventory and therefore represents process-level engineering indicators. Agricultural production, corncob collection, long-distance transport, construction, enzyme manufacture, capital equipment, product use and end-of-life treatment

Corresponding author: Adoga D. O.

adogadavid@unical.edu.ng

Department of Chemical Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



were not comprehensively inventoried. No environmental credits were assigned to filtration cake, gypsum or recovered heat.

This boundary permits internally consistent comparison of process streams and identification of engineering hotspots. It does not permit direct environmental superiority claims over alternative lactic-acid routes because comparative life-cycle assessment requires harmonised system boundaries, allocation rules and background datasets in accordance with ISO 14040 and ISO 14044.

Sustainability indicators

Material, energy, water, residue and emissions indicators were derived from the gPROMS inventory. Overall process efficiency and carbon-conversion efficiency were retained from the reconciled process model. Product recovery was defined as lactic acid in the final product divided by lactic acid entering purification.

The following normalised indicators were used:

$$\text{SEC} = 3.6 \Sigma Q_{\text{heat}} / \text{mLA} \quad (1)$$

$$\text{Wl}_{\text{direct}} = m_{\text{water}} / \text{mLA} \quad (2)$$

$$\text{SG}_i = m_i / \text{mLA} \quad (3)$$

$$\text{IGHG} = \Sigma (E_j \text{EF}_j) / \text{mLA} \quad (4)$$

where SEC is specific heating-energy consumption in MJ kg^{-1} lactic acid, ΣQ_{heat} is the sum of process heating duties in kW, mLA is the lactic-acid production rate in kg h^{-1} , $\text{Wl}_{\text{direct}}$ is direct process-water intensity, SG_i is the specific generation of residue i , E_j is the relevant material or energy activity, EF_j is its adopted emission factor, and IGHG is the estimated greenhouse-gas indicator. The factor 3.6 converts kWh to MJ. Condenser duty was reported separately as cooling demand and was not added to heating duty.

Interpretation and verification

The process inventory was checked against the reconciled unit-operation mass and

energy balances. In addition, the fermentation submodel had previously been evaluated against 30 independent experimental operating conditions. The predictive coefficient of determination was 0.9654 and the root mean square error was 0.598 percentage points, with negligible mean bias. These statistics support use of the fermentation predictions within the investigated domain, but they do not constitute experimental validation of every upstream and downstream unit operation.

The calculations were checked by reconciling unit-operation flows with the overall production basis. The five positive heating duties were summed to obtain 2,678 kW. Dividing this value by $1,984 \text{ kg h}^{-1}$ and multiplying by 3.6 gave 4.86 MJ kg^{-1} lactic acid. The $12,000 \text{ kg h}^{-1}$ direct water input divided by $1,984 \text{ kg h}^{-1}$ lactic acid gave 6.05 kg kg^{-1} , which was expressed as 6.05 L kg^{-1} using a water density of approximately 1 kg L^{-1} . Specific residue generation was verified independently from the reported cake and gypsum flow rates.

RESULTS AND DISCUSSION

Model credibility and consolidated sustainability performance

The close agreement between experimental and predicted fermentation yields supports the internal credibility of the process inventory used for the present assessment. The integrated process combined high conversion and recovery with material, energy and residue burdens that were concentrated in a small number of operations. The overall process efficiency was 87.6%, carbon-conversion efficiency was 78.4%, lactic-acid recovery was 96.8%, and final product purity was 99.1 wt%. These figures show that the simulated pathway retained most of the produced lactic acid through downstream processing. However, the lower carbon-conversion efficiency reflects carbon remaining in unconverted material, biomass, residual sugars, off-gas and other non-product streams.

Corresponding author: Adoga D. O.

adogadavid@unical.edu.ng

Department of Chemical Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



Table 2: Consolidated Sustainability Indicators for the Reference Process

Category	Indicator	Value
Material	Overall process efficiency	87.6%
Material	Carbon-conversion efficiency	78.4%
Product	Lactic-acid recovery	96.8%
Product	Final product purity	99.1 wt%
Energy	Total heating demand	2,678 kW
Energy	Specific heating energy	4.86 MJ kg ⁻¹ LA
Cooling	Condenser duty	932 kW
Water	Direct process-water intensity	6.05 L kg ⁻¹ LA
Residue	Combined identified solids	0.769 kg kg ⁻¹ LA
Emission	Estimated GHG indicator	1.42 kg CO ₂ -eq kg ⁻¹ LA
Production	Annual lactic-acid capacity	15,872 t year ⁻¹

Material and carbon conversion performance

Pretreatment converted 91.3% of hemicellulose and removed 63.8% of lignin, while hydrolysis converted 93.6% of cellulose and produced 186.7 g L⁻¹ total fermentable sugars. Fermentation yielded 0.91 g lactic acid per gram of substrate, and purification recovered 96.8% of the lactic acid at 99.1 wt% purity. The sequential performance indicates that the principal product losses did not occur in final purification; rather, remaining losses were distributed across incomplete structural conversion, unconsumed sugar, biomass formation and side streams.

The 78.4% carbon-conversion efficiency is therefore an important complement to the higher unit-operation conversion values. It evaluates the complete carbon pathway rather than a single reaction. Sustainable lactic-acid production from lignocellulosic biomass depends on recovering both C₆ and C₅ sugars and

minimising carbon diversion to inhibitors, biomass and unrecovered residues (Abdel-Rahman et al., 2011; Li, Y. et al., 2021). Further experimental characterisation of filtration cake, residual sugars and off-gas would permit a more detailed carbon balance and identify whether additional product or energy recovery is practical.

Energy performance and thermal hotspot

The process required 2,678 kW of heating duty. Purification was the largest individual heating load: the reboiler required 1,164 kW, equivalent to 43.5% of total process heating. Pretreatment required 742 kW or 27.7%, while hydrolysis, fermentation and acidification contributed 318, 226 and 228 kW, respectively. The condenser imposed an additional cooling duty of 932 kW. The resulting specific heating-energy consumption was 4.86 MJ kg⁻¹ lactic acid.

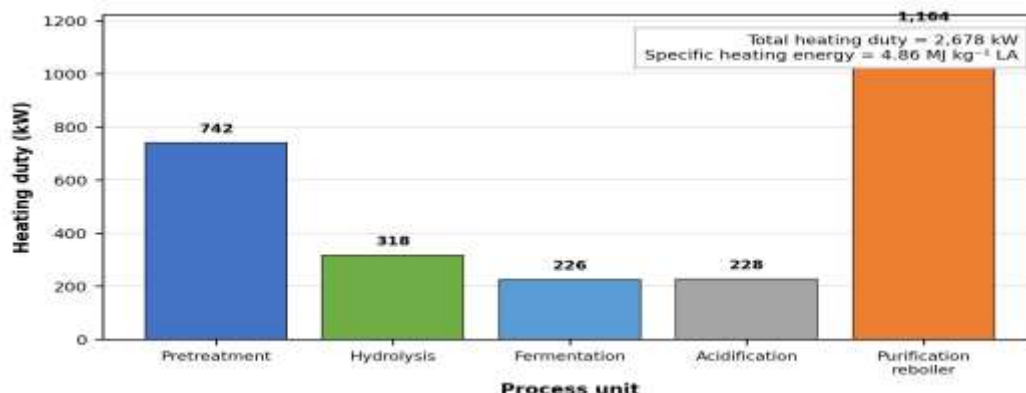


Figure 1. Distribution of heating duty across the simulated process

Corresponding author: Adoga D. O.

adogadavid@unical.edu.ng

Department of Chemical Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

The energy profile identifies purification and pretreatment as the main targets for thermal integration. The high pretreatment duty results from heating a water-rich slurry to 168 °C, whereas the purification duty reflects the thermal requirement of concentrating and recovering lactic acid from an aqueous stream. Reviews of lactic-acid recovery similarly identify downstream separation as a major energy and cost burden (Komesu et al., 2017; Li, C. et al., 2021). Process modelling studies also show that the energy source and heat-integration strategy can alter the overall sustainability ranking of a lactic-acid pathway (Vance et al., 2024).

Potential improvements include feed-effluent heat exchange around pretreatment, recovery of sensible heat from hot acidification and purification streams, reuse of condenser heat where temperature levels permit, and staged evaporation or lower-energy recovery technologies. The reported 91.6% heat-exchanger efficiency indicates effective transfer in the assumed exchanger model, but it should not be interpreted as proof that the full heat-recovery network has been optimised. A pinch-analysis study using stream supply and target temperatures is required to establish the practically recoverable heat.

Direct process-water performance

The direct process-water input was 12,000 kg h⁻¹, corresponding to 6.05 L kg⁻¹ lactic

acid. This indicator covers the principal water feed represented in the process model. It is lower in scope than a water footprint because it excludes upstream water embodied in electricity, steam, chemicals, enzyme manufacture and feedstock production, as well as regional water-scarcity weighting. Accordingly, the result should be described as direct process-water intensity rather than total water footprint.

Water demand is linked to slurry handling, pretreatment, hydrolysis, fermentation medium preparation, washing and downstream separation. Reducing dilution can lower water use and downstream heating demand, but higher solids loading increases viscosity, mixing resistance and mass-transfer limitations. Water reduction should therefore be evaluated jointly with hydrolysis conversion, pumpability, inhibitor concentration and cleaning requirements. Candidate recycling streams must also be assessed for salts, inhibitors and microbial contamination before reuse.

Residue and by-product generation

Filtration produced 842 kg h⁻¹ cake and acidification generated 684 kg h⁻¹ gypsum. These values correspond to 0.424 and 0.345 kg kg⁻¹ lactic acid, respectively. The combined identified solid-residue flow was 1,526 kg h⁻¹, equivalent to 0.769 kg kg⁻¹ lactic acid. Fermentation off-gas was 18.4 Nm³ h⁻¹ or 0.0093 Nm³ kg⁻¹ lactic acid.

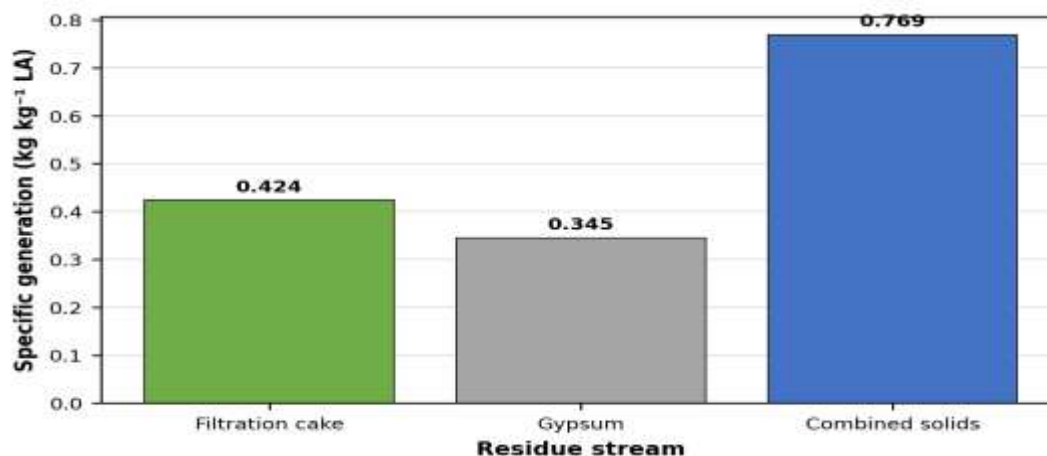


Figure 2. Specific generation of principal solid residues

Corresponding author: Adoga D. O.

adogadavid@unical.edu.ng

Department of Chemical Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



The filtration cake is expected to contain lignin, unconverted carbohydrate, microbial solids and entrained liquid. Its suitability for combustion, anaerobic conversion, soil application or recovery of lignin-derived products cannot be established from mass flow alone; compositional analysis, moisture content, ash, sulfur and contaminant levels are required. Gypsum generation is associated with the conventional calcium-lactate and sulfuric-acid recovery route. Although gypsum may have beneficial uses, market acceptance depends on purity, moisture and local demand. Otherwise, transport and disposal become important environmental and economic burdens.

The residue profile supports investigation of lower-gypsum recovery routes, including low-pH fermentation, solvent extraction, electrodialysis, membrane-assisted separation or alternative neutralising agents. These alternatives can reduce one burden while increasing another, such as electricity consumption, solvent use, membrane replacement or product loss. They should therefore be evaluated on a consistent process and life-cycle basis rather than selected solely on gypsum avoidance.

Greenhouse-gas indicator and boundary limitations

The estimated greenhouse-gas indicator was 1.42 kg CO₂-eq kg⁻¹ lactic acid. At 1,984 kg h⁻¹ lactic acid, this corresponds to approximately 2,817 kg CO₂-eq h⁻¹ and 22,539 t CO₂-eq year⁻¹ at 8,000 operating hours. The

estimate reflects the material and energy activities and emission factors included in the adopted process boundary. It is useful for internal hotspot identification and scenario development but is not directly comparable with published cradle-to-gate values unless boundaries, energy mixes, allocation methods and functional units are harmonised.

Daful and Görgens (2017) demonstrated that integration with existing sugar-mill infrastructure can change both economic and environmental outcomes. More recent modelling confirms that production scale and energy source strongly influence the life-cycle performance of lactic acid (Brobbe et al., 2024; Vance et al., 2024).

For the present process, the dominance of thermal duties indicates that steam-generation technology and fuel source are likely to control a substantial share of greenhouse-gas emissions. Renewable electricity, biomass-derived heat and improved heat recovery should therefore be tested as explicit scenarios in a subsequent life-cycle assessment.

Comparison with relevant studies

Direct numerical comparison with published studies is constrained by differences in feedstock, organism, product concentration, recovery route, energy supply, allocation method and system boundary. Table 3 therefore compares the principal engineering lessons rather than treating unharmonised environmental values as equivalent.

Table 3. Comparison of the Present Process-Level findings with Relevant Studies

Study	Process basis	Principal insight	reported	Relationship to the present study
Daful and Görgens (2017)	Lignocellulosic lactic-acid process with economic and environmental assessment	Process integration and infrastructure choice strongly affected performance	choice affected	Supports combined evaluation of conversion, recovery and utilities
Liu et al. (2015)	Corn-stover lactic acid with minimum-wastewater design	High titre and water management reduced downstream burden	water reduced	Supports water recycling and concentrated processing as improvement priorities

Corresponding author: Adoga D. O.

adogadavid@unical.edu.ng

Department of Chemical Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



Study	Process basis	Principal insight	reported	Relationship to the present study
Li, Y. et al. (2021)	Lignocellulosic lactic-acid sustainability assessment	Fermentation yield and recovery influenced environmental performance	yield and influenced	Supports the emphasis on carbon conversion and product recovery
Vance et al. (2024)	Process-model-based biorefinery scenarios	Scale, process improvements and energy source changed sustainability outcomes	process energy changed	Supports scenario analysis of heat integration and Nigerian energy supply
Present study	Corn cob pathway simulated in gPROMS at 2,500 kg h ⁻¹	Purification heat, direct water use, cake and gypsum were dominant process-level hotspots	heat, direct water use, cake and gypsum were dominant	Provides an internally reconciled Nigerian process-development baseline

The comparison indicates that the present work is most useful as a transparent screening baseline. Its distinctive contribution is the simultaneous quantification of material conversion, heating demand, direct water use, product recovery and identified residues from one reconciled gPROMS flowsheet.

Improvement priorities

The process-level results identify four immediate priorities. First, heat integration should focus on pretreatment and purification because

they jointly account for 71.2% of heating demand. Second, suitable process-water streams should be characterised for recycling without accumulating salts or fermentation inhibitors. Third, the calcium-based recovery route should be compared with lower-gypsum alternatives using product recovery, energy demand and cost as simultaneous criteria. Fourth, filtration cake should be chemically characterised before assigning an environmental credit or selecting a valorisation route.

Table 4. Sustainability Hotspots and Recommended next Investigations

Hotspot	Evidence	Priority investigation
Purification heat	1,164 kW; 43.5% of heating	Pinch analysis; alternative concentration and recovery routes
Pretreatment heat	742 kW; 27.7% of heating	Feed-effluent heat recovery; solids-loading optimisation
Direct water use	6.05 L kg ⁻¹ LA	Water-quality mapping and recycle trials
Gypsum	684 kg h ⁻¹ ; 0.345 kg kg ⁻¹ LA	Purity testing; reuse market; low-gypsum recovery options
Filtration cake	842 kg h ⁻¹ ; 0.424 kg kg ⁻¹ LA	Composition, heating value, biodegradability and safety
GHG estimate	1.42 kg CO ₂ -eq kg ⁻¹ LA	Full cradle-to-gate LCA with Nigerian energy and logistics data

Study limitations

The analysis is based on steady-state simulation and adopted engineering factors. It does not represent seasonal feedstock variation, start-up and shutdown, membrane fouling, cleaning chemicals, water quality, slurry rheology,

equipment manufacture or detailed wastewater treatment. The results therefore establish a process-development baseline and identify priorities.

Corresponding author: Adoga D. O.

adogadavid@unical.edu.ng

Department of Chemical Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



CONCLUSION

The gPROMS-derived process inventory provided an integrated basis for evaluating the resource efficiency of corncob-based lactic-acid production. At a reference corncob throughput of $2,500 \text{ kg h}^{-1}$, the process produced $1,984 \text{ kg h}^{-1}$ lactic acid with 87.6% overall efficiency, 78.4% carbon-conversion efficiency, 96.8% product recovery and 99.1 wt% purity. The specific heating-energy requirement was 4.86 MJ kg^{-1} lactic acid, and direct process-water intensity was 6.05 L kg^{-1} . Purification was the principal thermal hotspot, while filtration cake and gypsum produced a combined solid-residue intensity of 0.769 kg kg^{-1} lactic acid. The estimated greenhouse-gas indicator was $1.42 \text{ kg CO}_2\text{-eq kg}^{-1}$ within the defined process boundary.

The most important opportunities for improvement are heat recovery around pretreatment and purification, controlled water recycling, reduction or beneficial use of gypsum, and valorisation of lignin-rich filtration cake. These measures should be assessed through pilot experiments and scenario-based process simulation before commercial design. A complete cradle-to-gate life-cycle assessment using site-specific Nigerian electricity, fuel, transport, chemical and waste-treatment inventories is recommended as the next environmental evaluation step.

ACKNOWLEDGEMENTS

The authors acknowledge the Departments of Chemical Engineering at the University of Calabar and the University of Uyo for their academic support.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY

The data supporting the findings are contained in the article and the underlying doctoral research records. Additional calculation details may be made available by the corresponding author upon reasonable request.

REFERENCES

- Abdel-Rahman, M. A., Tashiro, Y., & Sonomoto, K. (2011). Lactic acid production from lignocellulose-derived sugars using lactic acid bacteria: Overview and limits. *Journal of Biotechnology*, 156(4), 286–301.
- Abdel-Rahman, M. A., Tashiro, Y., & Sonomoto, K. (2013). Recent advances in lactic acid production by microbial fermentation processes. *Biotechnology Advances*, 31(6), 877–902.
- Adoga, D. O., Samuel, S. S., Egemba, K. C., & Ojong, O. E. (2026a). Kinetic study and optimization of lactic acid production from corncob. *ATBU Journal of Science, Technology and Education*, 14(1), 452–473.
- Adoga, D. O., Samuel, S. S., Okon, F. E., Bassey, O. E., Ojong, O. E., & Esang, J. (2026b). Statistical optimization of dilute acid hydrolysis of corncob biomass for fermentable sugar production in lactic acid bioprocessing. *ATBU Journal of Science, Technology and Education*, 14(1.2), 317–325.
- Brobbey, M. S., Louw, J., & Görgens, J. F. (2024). Effect of production scale on the techno-economic viability and environmental life cycle analysis of lactic acid production in a sugarcane biorefinery. *Food and Bioproducts Processing*, 148, 269–284.
- Cherubini, F. (2010). The biorefinery concept: Using biomass instead of oil for producing energy and chemicals. *Energy Conversion and Management*, 51(7), 1412–1421.
- Daful, A. G., & Görgens, J. F. (2017). Techno-economic analysis and environmental impact assessment of lignocellulosic lactic acid production. *Chemical Engineering Science*, 162, 53–65.
- Hofvendahl, K., & Hahn-Hägerdal, B. (2000). Factors affecting the fermentative lactic acid production from renewable resources. *Enzyme and Microbial Technology*, 26(2–4), 87–107.

Corresponding author: Adoga D. O.

✉ adogadavid@unical.edu.ng

Department of Chemical Engineering, Faculty of Engineering, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



- International Organization for Standardization. (2006a). *Environmental management—Life cycle assessment—Principles and framework (ISO Standard No. 14040:2006)*.
- International Organization for Standardization. (2006b). *Environmental management—Life cycle assessment—Requirements and guidelines (ISO Standard No. 14044:2006)*.
- John, R. P., Nampoothiri, K. M., & Pandey, A. (2007). Fermentative production of lactic acid from biomass: An overview on process developments and future perspectives. *Applied Microbiology and Biotechnology*, 74, 524–534.
- Komesu, A., de Oliveira, J. A. R., Martins, L. H. S., Maciel, M. R. W., & Maciel Filho, R. (2017). Lactic acid production to purification: A review. *BioResources*, 12(2), 4364–4383.
- Li, C., Gao, M., Zhu, W., Wang, N., Ma, X., Wu, C., & Wang, Q. (2021). Recent advances in the separation and purification of lactic acid from fermentation broth. *Process Biochemistry*, 104, 142–151.
- Li, Y., Bhagwat, S. S., Cortés-Peña, Y. R., Ki, D., Rao, C. V., Jin, Y.-S., & Guest, J. S. (2021). Sustainable lactic acid production from lignocellulosic biomass. *ACS Sustainable Chemistry & Engineering*, 9(3), 1341–1351.
- Liu, G., Sun, J., Zhang, J., Tu, Y., & Bao, J. (2015). High-titer L-lactic acid production from corn stover with minimum wastewater generation and techno-economic evaluation based on Aspen Plus modeling. *Bioresource Technology*, 198, 803–810.
- Manandhar, A., & Shah, A. (2023). Techno-economic analysis of the production of lactic acid from lignocellulosic biomass. *Fermentation*, 9(7), 641.
- Menon, V., & Rao, M. (2012). Trends in bioconversion of lignocellulose: Biofuels, platform chemicals and biorefinery concept. *Progress in Energy and Combustion Science*, 38(4), 522–550.
- Vance, C., Mediboyina, M. K., Papadopoulou, E., Cabrera-González, M., Reif, D., Sweeney, J., Harasek, M., & Murphy, F. (2024). Using process modeling and simulation to determine the sustainability of a novel lactic acid biorefinery in Europe: Influence of process improvements, scale, energy source, and market conditions. *Journal of Cleaner Production*, 484, 144347.