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Supplementary Information N°1 for

Life cycle assessment and techno-economic comparison of methane production routes from sewage sludge: incineration vs. hydrothermal gasification and anaerobic digestion

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Aim of this document

This document compiles all detailed calculations, methodologies, and results related to the analysis of various treatment and valorization pathways for sewage sludge. The first section provides an overview of the methods used, including the main equations of the model. The second section presents the detailed results, with focus on the Life Cycle Assessment (LCA) and the five endpoint indicators from the IMPACT World+ method.

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S1. Methods

S1.1 Complete flowsheet of the routes studied

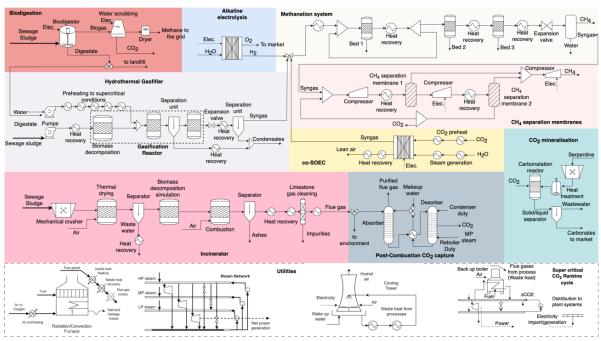


Figure 1: Integrated flowsheet of sewage sludge treatment technologies with upgrading syngas units, and CO₂ management processes, and auxiliary utility systems.

S1.2 Sewage sludge composition

The sewage sludge (Table 1) considered has a composition determined from the mean value of those reported for the proximate and ultimate analysis in the open literature for this specific type of biomass, on a wet basis [10], [13], [14], [15], [16], [17], [18], [19].

Table 1: Proximate and ultimate analysis of sewage sludge.

Proximate Analysis	Value (%)	Ultimate Analysis	Value (%)
Moisture content	79.27	С	34.84
Fixed Carbon	9.51	Н	6.07
Volatile Matters	61.95	О	24.07
Ash	28.54	N	4.76
		S	1.72

S1.3 Set of equations used to model HTG reported in literature.

Table 2: Set of equations used to model HTG reported in literature.

Process	Reaction	References
WGS	$CO + H_2O \rightarrow CO_2 + H_2 (R3)$	[1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]

SMR	$CH_4 + H_2O \rightarrow CO + 3H_2 (R4)$	[1], [2], [12], [10], [5], [7], [3], [8], [11]
Hydrogenation	$CO + 2H_2 \rightarrow CH_4 + \frac{1}{2}O_2$	[2], [6]
Boudouard	$2CO \rightarrow CO_2 + C$	[2], [10], [4], [6], [7]
Biomass decomposition	$CH_xO_y + (1-a)H_2O \rightarrow CO + (1-a+y/2)H_2$	[9], [10], [5], [8], [7]
Methanation	$2H_2 + CO_2 \rightarrow CH_4 + 2H_2O$	[6], [9], [7], [4]
Methane formation	$C + 2H_2 \rightarrow CH_4$	[7], [4]
Carbon oxidation	$C + O_2 \rightarrow CO_2$	[10], [4], [7]
Steam reforming	$C_nH_m + 2nH_2O \rightarrow (2n + m/2)H_2 + nCO_2$	[10]
Carbon monoxide combustion	$C + O \rightarrow CO$	[4]

S1.4 Calculation of Methane Yield and Carbon Conversion

The performance of the model can be established by the calculation of the total syngas yield and carbon conversion yield.

S1.4.1. Methane Yield

The total methane yield ($Yield_{CH4}$) refers to the amount of methane produced per unit of sewage sludge processed in a specific conversion process. It is expressed in percentage, according to Equation (1), where $m_{total,CH4}$ and $m_{sewagesludge}$ are the total methane flow rate and the mass flow rate of the sewage sludge, respectively.

$$Yield_{CH4} = \frac{m_{total, CH4}}{m_{sewagesludge}} (1)$$

S1.4.2. Carbon Conversion Efficiency

The carbon conversion efficiency, expressed in percentage, corresponds to the total carbon (TC) in the methane produced divided by the total carbon in the sewage sludge, according to Equation (2).

Carbon Conversion =
$$\frac{TC_{CH4}}{TC_{sewagesludge}}$$
(2)

S1.5 Methodology for calculating the exergy and LHV of the components

The determination of exergy values for material flows is based on Szargut's reference environment for standard chemical exergy [20]. This environment defines stable and abundant reference substances, along with their concentrations, at a temperature of T = 298.15 K and a pressure P = 101.325 kPa.

The chemical exergy E_{ch} of the material flows is calculated using Equation (3) [21]:

$$E_{\rm ch} = \Delta_f G + \sum_{\rm el} n_{\rm el} E_{\rm ch,el} (3)$$

where $E_{\rm ch}$ and $E_{\rm ch,el}$ are the standard chemical exergies, in kJ/mol, of the compound and constitutive element, respectively. $n_{\rm el}$ represents the molar quantity of each element in the compound, and $\Delta_f G$ is the Gibbs standard free energy of formation of the compound at ambient temperature, in kJ/mol.

Industrial solid and liquid fuels, as well as materials like biomass, are typically composed of multiple chemical compounds. The ratio of chemical exergy to the lower heating value $\phi = \frac{E_{ch}}{LHV}$ remains constant for pure substances with identical mass ratios of chemical constituents (H/C, O/C, N/C). Szargut [21] developed correlations to describe the dependence of ϕ on these atomic ratios. For methane, ϕ is equal to 1.04, whereas for biomass with C/O between 0.5 and 2, ϕ can be calculated at standard conditions (P_0 , T_0) using Equation (4):

$$\phi_{dry} = \frac{1.044 + 0.0160 \left(\frac{H}{C}\right) - 0.3493 \left(\frac{O}{C}\right) \left[1 + 0.0531 \left(\frac{H}{C}\right)\right] + 0.0493 \left(\frac{N}{C}\right)}{1 - 0.4124 \left(\frac{O}{C}\right)} (4)$$

The lower heating value (LHV) and specific chemical exergy (E_{Ch}), both in MJ/kg, of the materials considered in this work can be found in Table 3.

Table 3: Calculated lower heating value (LHV) and specific chemical exergy (E_{ch}) for sewage sludge, digestate from sewage sludge digestion, and methane.

<u> </u>	angestate in this servage stands angestion, and institution				
Materials	LHV [MJ/kg]	E _{ch} [MJ/kg]			
Sewage sludge	14.62	16.52			
Digestate	11.12	13.68			
CH₄	50.00	52.00			

The LHV, in MJ/kg, is estimated based on Channiwala and Parikh correlations (Equation 5) for digestate and sewage sludge, based on the mass fractions of the constitutive elements [22].

LHV =
$$349.1 \cdot C + 1178.3 \cdot H + 100.5 \cdot S - 103.4 \cdot O - 15.1 \cdot N - 21.1 \cdot ASH - 0.0894 \cdot Hh_{lv}$$
 (5)

where carbon (C), hydrogen (H), sulfur (S), oxygen (O), nitrogen (N), and ASH are the respective mass fractions of the components in the dry biomass, and h_{IV} is the enthalpy of evaporation of water at standard conditions (2,442.3 kJ/kg).

S1.6 Methodology used for carbon footprint assessment in the OSMOSE platform

The calculation of the carbon footprint is done in the OSMOSE platform, in which each energetic and material flow and each technology have associated a corresponding impact factor ($\zeta_{\text{CO}_2^+}$). The total equivalent CO_2 emissions, (CO_2^{ei}) (ei is environmental impact), including emissions from technologies construction ($\xi_{\text{C}u}^{\text{CO}_2}$), dismantling ($\xi_{\text{d}u}^{\text{CO}_2}$), and operational emissions ($CO_2^{ei,\text{op}}$), in Equation (5), are coming from the Ecoinvent database version 3.10 and

each emission factor is sized to the technologies, assuming linear equivalence. In Equation (6), (f_u^{mult}) represents the sizing factor of a unit as determined by the optimization process.

 CO_2 -equivalent emissions calculated considering the direct emissions from all material flows, or resources (*re*) in the set (*RE*) ($\varepsilon_{\rm re}^{\rm CO_2}$). Additionally, the export of resources, such as the methane produced, is represented as ($\varepsilon_{\rm se}^{\rm CO_2}$).

$$CO_2^{ei} = CO_2^{ei,op} + \sum_{u=1}^{U} (\xi_{Cu}^{CO_2} + \xi_{du}^{CO_2}) f_u^{\text{mult}}$$
(5)

$$CO_2^{ei,op} = \sum_{t=1}^{T} \left(\sum_{\text{re}=1}^{\text{RE}} m_{\text{re},t}^{\div} \, \varepsilon_{\text{re}}^{\text{CO}_2} + \sum_{\text{se}=1}^{\text{SE}} m_{\text{se},t}^{\div} \, \varepsilon_{\text{se}}^{\text{CO}_2} \right) (6)$$

S1.7. Market costs details

Table 4: Market costs and selling prices for feedstock and products.

Material/Energy	Price	Unit	References	
Electricity	0.200	€/kWh	[23]	
Methane	0.070	€/kWh	[24]	
Water	0.002	€/kg	[25]	
Water disposal	0.002	€/kg	[25]	
Limestone	0.040	€/kg	[26]	
Serpentine	0.024	€/kg	[27]	
Magnetite	0.030	€/kg	[27]	
MgCO₃	0.200	€/kg	[28]	
SiO ₂	0.050	€/kg	[29]	
NaCl	0.120	€/kg	[27]	
NaHCO₃	0.375	€/kg	[27]	

S1.8. Technological costs details

Table 5: Technologies and associated costs.

Technology	Cost	Unit	References
Co-electrolysis	1200	€/kW _(elec)	[30]
Methanator	300	€/kW _(CH₄)	[31]
CH₄ membrane	6.95	€/(kg _(CH₄) /h)	[32]
Alkaline electrolyser	1200	€/kW	[30]
Incineration gas cleaning	1300	€/(Nm³/h)	[33]
Water scrubbing cost	15	€/(Nm³/h)	[34]
Anaerobic digester	220	€/(t/h)	[35], [36]
HTG	1060	€/ (t/h)	[37]
Serpentine-based CO₂ mineralisation reactor	1355	€/ (t/h)	[38]

Flue gas CO₂ capture unit	48.7	€/(t _(CO₂) /h)	[39]
Incineration	38	€/(t _(waste) /h)	[40]

S2. Results

S2.1. Syngas composition and carbon conversion yield

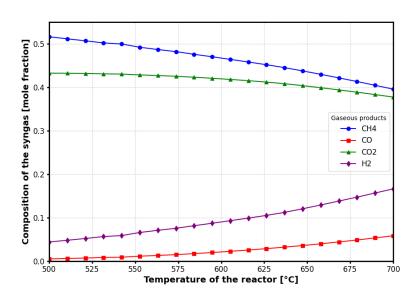


Figure 2: Syngas composition variation as a function of temperature, with a water-to-biomass ratio of 40% and at a pressure of 220 bar.

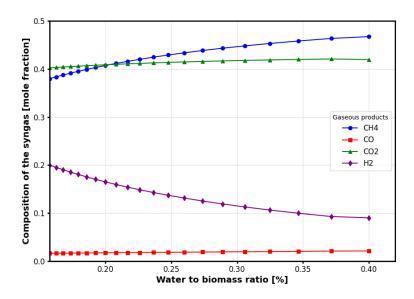


Figure 3: Syngas composition variation according to water-biomass concentration, at a temperature of 550°C and at a pressure of 220 bar.

S2.2 Control volume and exergy efficiency of the sewage sludge treatment considering the HTG

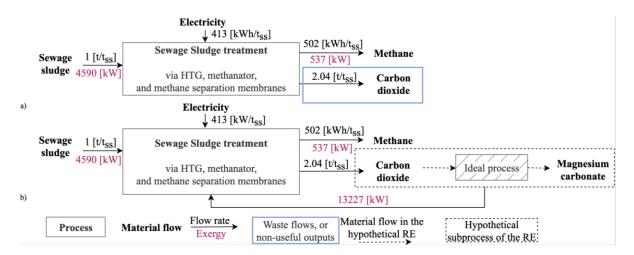


Figure 4: (a): Control volume of the sewage sludge treatment considering route (a) (HTG+methanation+membranes), and Morris and Szargut [20] reference environment (RE). (b): Control volume and exergy flows of the similar route, studied with the proposed reference environment.

S2.3. Impact scores across the five endpoint categories for the 19 routes studied

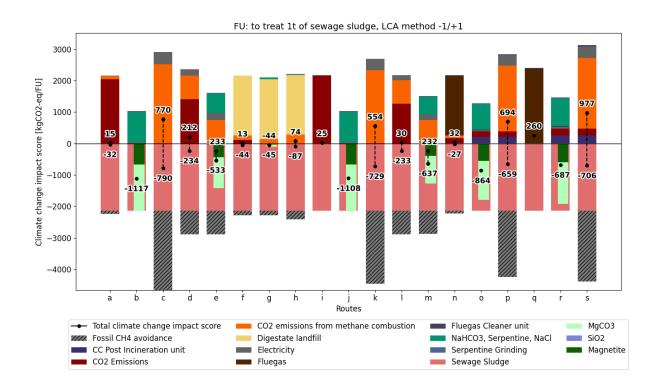


Figure 5: Carbon footprint impact score of the 19 routes studied, considering 0% and 100% methane avoidance. Routes can be found in Table 1.

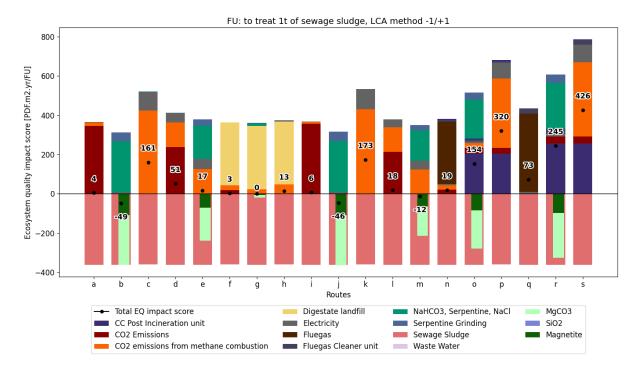


Figure 6: Ecosystem quality (EQ) impact score of the 19 routes studied. Routes can be found in Table 1.

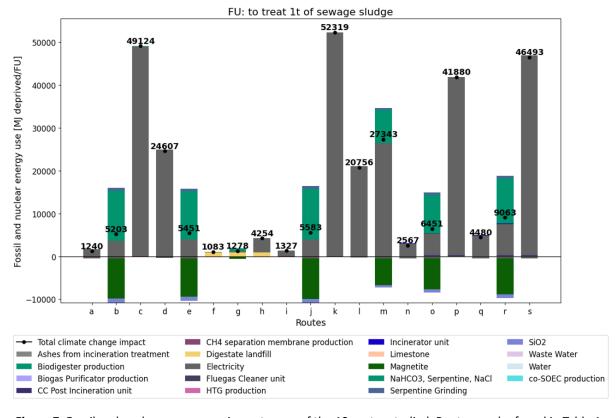


Figure 7: Fossil and nuclear energy use impact score of the 19 routes studied. Routes can be found in Table 1.

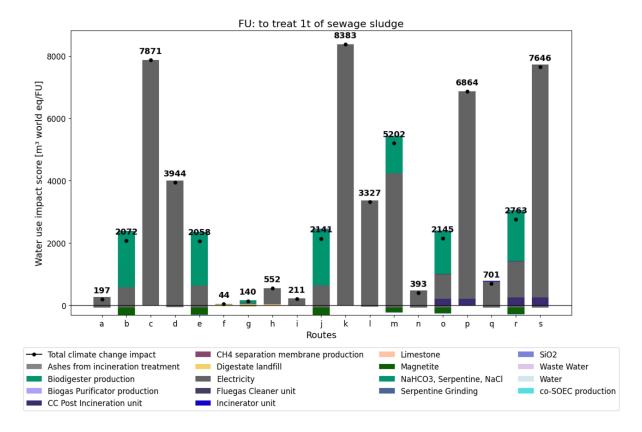


Figure 8: Water use impact score of the 19 routes studied. Routes can be found in Table 1.

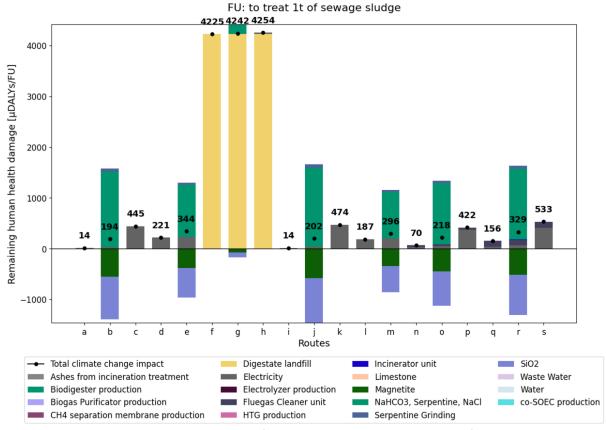


Figure 9: Human health impact score of the 19 routes studied. Routes can be found in Table 1.

References

- [1] J. A. Okolie, S. Nanda, A. K. Dalai, and J. A. Kozinski, "Hydrothermal gasification of soybean straw and flax straw for hydrogen-rich syngas production: Experimental and thermodynamic modeling," *Energy Conversion and Management*, vol. 208, p. 112545, Mar. 2020, doi: 10.1016/j.enconman.2020.112545.
- [2] J. Louw, C. E. Schwarz, and A. J. Burger, "Catalytic supercritical water gasification of primary paper sludge using a homogeneous and heterogeneous catalyst: Experimental vs thermodynamic equilibrium results," *Bioresource Technology*, vol. 201, pp. 111–120, Feb. 2016, doi: 10.1016/j.biortech.2015.11.043.
- [3] W. Cao *et al.*, "Hydrogen production from supercritical water gasification of chicken manure," *International Journal of Hydrogen Energy*, vol. 41, no. 48, pp. 22722–22731, Dec. 2016, doi: 10.1016/j.ijhydene.2016.09.031.
- [4] A. M. Inuwa, I. Jato, and S. O. Giwa, "Aspen Plus Modelling and Simulation of Supercritical Steam and Poultry Litter Gasification for the Production of Hydrogen Fuel and Electricity," in ECP 2023, MDPI, May 2023, p. 102. doi: 10.3390/ECP2023-14723.
- [5] H. Schmieder *et al.*, "Hydrothermal gasification of biomass and organic wastes," *The Journal of Supercritical Fluids*, vol. 17, no. 2, pp. 145–153, Apr. 2000, doi: 10.1016/S0896-8446(99)00051-0.
- [6] J. A. Okolie, E. I. Epelle, S. Nanda, D. Castello, A. K. Dalai, and J. A. Kozinski, "Modeling and process optimization of hydrothermal gasification for hydrogen production: A comprehensive review," *The Journal of Supercritical Fluids*, vol. 173, p. 105199, Jul. 2021, doi: 10.1016/j.supflu.2021.105199.
- [7] S. Letellier, F. Marias, P. Cezac, and J. P. Serin, "Gasification of aqueous biomass in supercritical water: A thermodynamic equilibrium analysis," *The Journal of Supercritical Fluids*, vol. 51, no. 3, pp. 353–361, Jan. 2010, doi: 10.1016/j.supflu.2009.10.014.
- [8] D. Castello and L. Fiori, "Supercritical water gasification of biomass: Thermodynamic constraints," *Bioresource Technology*, vol. 102, no. 16, pp. 7574–7582, Aug. 2011, doi: 10.1016/j.biortech.2011.05.017.
- [9] H. Feng *et al.*, "Sewage sludge treatment via hydrothermal carbonization combined with supercritical water gasification: Fuel production and pollution degradation," *Renewable Energy*, vol. 210, pp. 822–831, Jul. 2023, doi: 10.1016/j.renene.2023.04.071.
- [10] D. Hantoko *et al.*, "Thermodynamic study on the integrated supercritical water gasification with reforming process for hydrogen production: Effects of operating parameters," *International Journal of Hydrogen Energy*, vol. 43, no. 37, pp. 17620–17632, Sep. 2018, doi: 10.1016/j.ijhydene.2018.07.198.
- [11] F. N. Rahma, K.-Q. Tran, and R. Khalil, "Process Modelling and Pinch Analysis for an Integrated System of Anaerobic Digestion with Digestate Recycling via Hydrothermal Gasification," in *Computer Aided Chemical Engineering*, vol. 52, A. C. Kokossis, M. C. Georgiadis, and E. Pistikopoulos, Eds., in 33 European Symposium on Computer Aided Process Engineering, vol. 52., Elsevier, 2023, pp. 3227–3232. doi: 10.1016/B978-0-443-15274-0.50514-X.
- [12] M. J. Antal, S. G. Allen, D. Schulman, X. Xu, and R. J. Divilio, "Biomass Gasification in Supercritical Water," *Ind. Eng. Chem. Res.*, vol. 39, no. 11, pp. 4040–4053, Nov. 2000, doi: 10.1021/ie0003436.

- [13] M. Urciuolo, R. Solimene, R. Chirone, and P. Salatino, "Fluidized bed combustion and fragmentation of wet sewage sludge," *Experimental Thermal and Fluid Science*, vol. 43, pp. 97–104, Nov. 2012, doi: 10.1016/j.expthermflusci.2012.03.019.
- [14] N. Gao, K. Kamran, C. Quan, and P. T. Williams, "Thermochemical conversion of sewage sludge: A critical review," *Progress in Energy and Combustion Science*, vol. 79, p. 100843, Jul. 2020, doi: 10.1016/j.pecs.2020.100843.
- [15] S. Karki, J. Poudel, and S. Oh, "Thermal Pre-Treatment of Sewage Sludge in a Lab-Scale Fluidized Bed for Enhancing Its Solid Fuel Properties," *Applied Sciences*, vol. 8, no. 2, p. 183, Jan. 2018, doi: 10.3390/app8020183.
- [16] İ. Özbay, B. Özbay, and U. Akdemir, "Biodrying for fuel recovery from sewage sludge: An integrated evaluation by ultimate and proximate analyses," *Env Prog and Sustain Energy*, vol. 41, no. 1, p. e13723, Jan. 2022, doi: 10.1002/ep.13723.
- [17] E. Díaz, L. Pintado, L. Faba, S. Ordóñez, and J. M. González-LaFuente, "Effect of sewage sludge composition on the susceptibility to spontaneous combustion," *Journal of Hazardous Materials*, vol. 361, pp. 267–272, Jan. 2019, doi: 10.1016/j.jhazmat.2018.08.094.
- [18] W. P. Chan and J.-Y. Wang, "Comprehensive characterisation of sewage sludge for thermochemical conversion processes Based on Singapore survey," Waste Management, vol. 54, pp. 131–142, Aug. 2016, doi: 10.1016/j.wasman.2016.04.038.
- [19] Q. Xu, S. Tang, J. Wang, and J. H. Ko, "Pyrolysis kinetics of sewage sludge and its biochar characteristics," *Process Safety and Environmental Protection*, vol. 115, pp. 49–56, Apr. 2018, doi: 10.1016/j.psep.2017.10.014.
- [20] D. R. Morris and J. Szargut, "Standard chemical exergy of some elements and compounds on the planet earth," *Energy*, vol. 11, no. 8, pp. 733–755, Aug. 1986, doi: 10.1016/0360-5442(86)90013-7.
- [21] J. Szargut, Exergy Method: Technical and Ecological Applications. WIT Press, 2005.
- [22] S. A. Channiwala and P. P. Parikh, "A unified correlation for estimating HHV of solid, liquid and gaseous fuels," *Fuel*, vol. 81, no. 8, pp. 1051–1063, May 2002, doi: 10.1016/S0016-2361(01)00131-4.
- [23] S. F. O. of E. SFOE and Confédération Suisse, "Energie-Dashboard Bundesamt für Energie." Accessed: Apr. 16, 2025. [Online]. Available: https://energiedashboard.admin.ch/dashboard
- [24] Energie 360, "Prix du gaz: toutes les informations sur nos prix et la fluctuation des prix du gaz," Energie 360°. Accessed: Apr. 16, 2025. [Online]. Available: https://www.energie360.ch/fr/nos-services/gaz/prix-du-gaz/
- [25] "WASSER FÜR WASSER (WfW) | WATER FACTS," WASSER FÜR WASSER (WfW). Accessed: Apr. 16, 2025. [Online]. Available: https://wfw.ch/en/water-facts/nachhaltigkeit-von-leitungswasser
- [26] "Nordonia Landscape Supplies Landscape supplies offering pickup and delivery in Nordonia, Ohio." Accessed: Apr. 16, 2025. [Online]. Available: https://nordonialandscapesupplies.com/
- [27] R. Castro-Amoedo, J. Granacher, M. A. Daher, and F. Maréchal, "On the role of system integration of carbon capture and mineralization in achieving net-negative emissions in industrial sectors," *Energy Environ. Sci.*, vol. 16, no. 10, pp. 4356–4372, 2023, doi: 10.1039/D3EE01803B.
- [28] L.-C. Pasquier, G. Mercier, J.-F. Blais, E. Cecchi, and S. Kentish, "Technical & economic evaluation of a mineral carbonation process using southern Québec mining wastes for

- CO2 sequestration of raw flue gas with by-product recovery," *International Journal of Greenhouse Gas Control*, vol. 50, pp. 147–157, Jul. 2016, doi: 10.1016/j.ijggc.2016.04.030.
- [29] G. Wernet, C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz, and B. Weidema, "The ecoinvent database version 3 (part I): overview and methodology," *Int J Life Cycle Assess*, vol. 21, no. 9, pp. 1218–1230, Sep. 2016, doi: 10.1007/s11367-016-1087-8.
- [30] I. International Energy Agency, "The Future of Hydrogen," 2019, Accessed: Feb. 01, 2025. [Online]. Available: https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf
- [31] D. Flórez-Orrego, S. Sharma, S. de Oliveira Junior, and F. Maréchal, "Combined exergy analysis, energy integration and optimization of syngas and ammonia production plants: A cogeneration and syngas purification perspective," *Journal of Cleaner Production*, vol. 244, p. 118647, Jan. 2020, doi: 10.1016/j.jclepro.2019.118647.
- [32] F. Ahmad, K. K. Lau, A. M. Shariff, and G. Murshid, "Process simulation and optimal design of membrane separation system for CO2 capture from natural gas," *Computers & Chemical Engineering*, vol. 36, pp. 119–128, Jan. 2012, doi: 10.1016/j.compchemeng.2011.08.002.
- [33] G. Lourinho, O. Alves, B. Garcia, B. Rijo, P. Brito, and C. Nobre, "Costs of Gasification Technologies for Energy and Fuel Production: Overview, Analysis, and Numerical Estimation," *Recycling*, vol. 8, no. 3, p. 49, May 2023, doi: 10.3390/recycling8030049.
- [34] N. Lawson, M. Alvarado-Morales, P. Tsapekos, and I. Angelidaki, "Techno-Economic Assessment of Biological Biogas Upgrading Based on Danish Biogas Plants," *Energies*, vol. 14, no. 24, p. 8252, Dec. 2021, doi: 10.3390/en14248252.
- [35] A. Milbrandt, "Comparison of Select Food Waste Utilization Options," *National Renewable Energy Laboratory*, vol. NREL/BR-6A20-81024., 2021, [Online]. Available: https://www.nrel.gov/docs/fy22osti/81024.pdf
- [36] F. Remy, "Potential for the anaerobic digestion of municipal solid waste (MSW) in the city of Curitiba, Brazil." 2018. Accessed: Dec. 12, 2024. [Online]. Available: https://www.divaportal.org/smash/get/diva2:1198207/fulltext01.pdf
- [37] E. Gasafi, M.-Y. Reinecke, A. Kruse, and L. Schebek, "Economic Analysis of Sewage Sludge Gasification in Supercritical Water for Hydrogen Production," *Biomass and Bioenergy*, vol. 32, no. 12, pp. 1085–1096, Dec. 2008, doi: 10.1016/j.biombioe.2008.02.021.
- [38] W. J. J. Huijgen, R. N. J. Comans, and G.-J. Witkamp, "Cost evaluation of CO2 sequestration by aqueous mineral carbonation," *Energy Conversion and Management*, vol. 48, no. 7, pp. 1923–1935, Jul. 2007, doi: 10.1016/j.enconman.2007.01.035.
- [39] M.-B. Hägg, A. Lindbråthen, X. He, S. G. Nodeland, and T. Cantero, "Pilot Demonstration-reporting on CO2 Capture from a Cement Plant Using Hollow Fiber Process," *Energy Procedia*, vol. 114, pp. 6150–6165, Jul. 2017, doi: 10.1016/j.egypro.2017.03.1752.
- [40] D. Panepinto and G. Genon, *Wastewater sewage sludge: the thermal treatment solution.*, vol. WIT Trans Ecol Environ 180. 2024.