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Can WWTPs become biorefinery centers for producing green hydrogen? A simulation case integrating sludge gasification and water electrolyzers

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INTRODUCTION & AIM

Background

Wastewater Treatment Plants (WWTPs) face the dual challenge of managing sewage sludge and meeting their own energy demands. Gasification can valorize sludge into energy-rich syngas. Water electrolysis, powered by surplus renewable electricity, produces green hydrogen (H_2) and pure oxygen (O_2) as a co-product.

Aim

This study aims to assess the techno-energy feasibility of an integrated biorefinery by simulating a conventional WWTP (150,000 p.e.) through:

- Valorizing biogas in a Combined Heat and Power (CHP) unit.
- Integrating sludge gasification.
- Using electrolyzer-derived O_2 as gasifying agent.

METHOD

Simulation Tool : SuperPro Designer V13 was used to model all processes

System Configuration & Scenarios:

Model Assumptions :

- WW Treatment capacity: 150,000 equivalent inhabitants
- The Electric and Thermal efficiency of the combined heat and power engine (CHP) : 39.7% and 52% respectively.

Scenarios:

- Air gasification (Equivalence Ratios ER: 0.15, 0.20, 0.25)
- O_2-enriched gasification using electrolyzer O_2
- O_2-enriched gasification under an O_2/CO_2 atmosphere with in situ CO_2 capture (CaO)

- The model includes

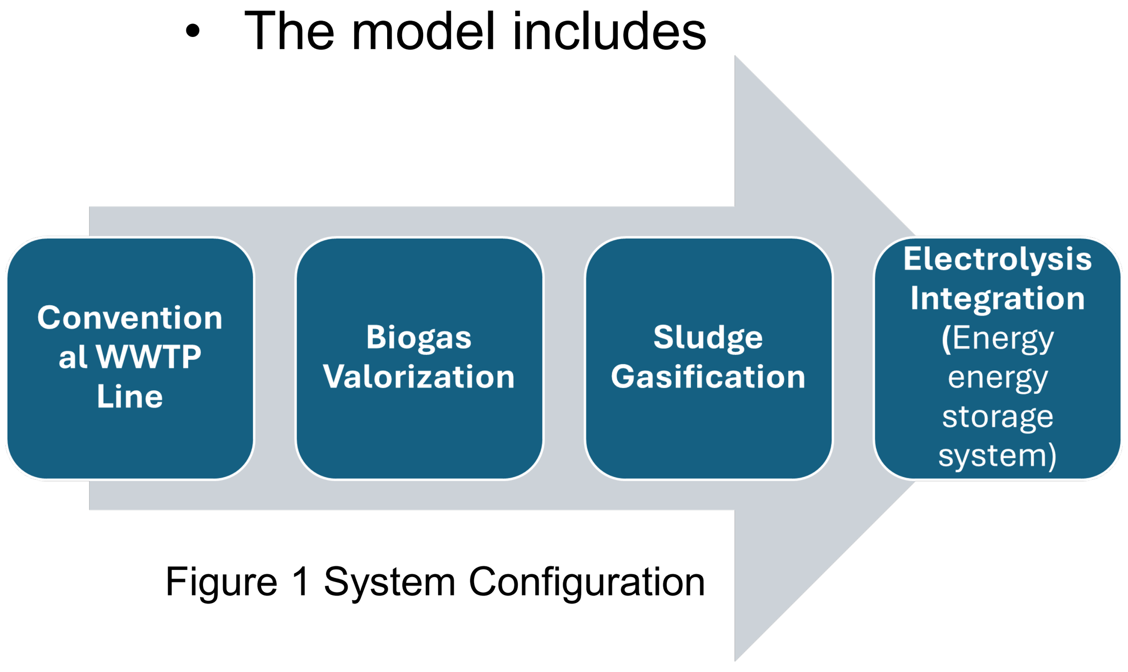

Figure 1 System Configuration

Table 1 Sludge Characteristic Assumptions

Parameter	Value
Volatile (%)	61.6 ± 6.6
Ash (%)	33.9 ± 3.1
LHV (MJ/kg)	12.4 ± 0.8
Elemental composition	
C	34.0 ± 1.2
H	5.2 ± 0.4
N	4.7 ± 0.6
S	0.7 ± 0.1

RESULTS & DISCUSSION

1. **Energy Bottleneck: Sludge Drying**

Assuming **all biogas** is sent to the CHP unit:

- Electricity produced: 430 kW
- biogas must be diverted to a burner: Electricity production drops from 430 kW → 233 kW Auxiliary fuel required (418 m³/d of natural gas (173 kW)

Table 2 Energy demand for Sludge Drying : Energy bottleneck

Item	Value
Drying unit demand	**616 kW**
Heat available from engine (high temp)	Only **45.7%** of demand

RESULTS & DISCUSSION

2. Effect of Equivalence Ratio (ER) on Syngas Composition

Increasing ER dilutes syngas with N_2 and reduces methane fraction. Higher temperatures increase CO (Boudouard reaction) but lower overall LHV

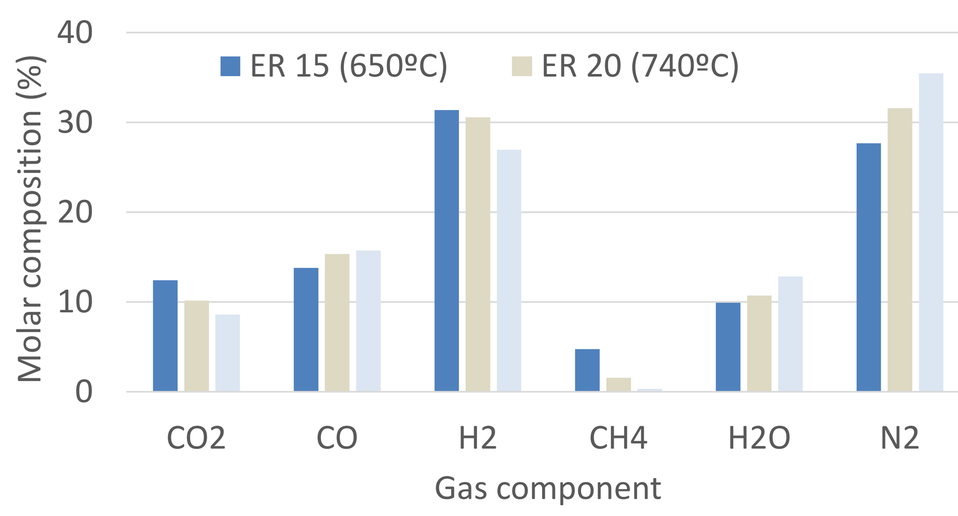

Figure 2.The operating temperature and gas composition under different ER applied to the gasifier

Table 3. The effect of ER on Syngas Composition and Heating Value

ER	T (°C)	Syngas LHV (MJ/m³)	Key Observation
0.15	648	**7.65**	Higher CH_4 & H_2 production
0.20	740	**6.5**	Baseline case
0.25	881	**5.8**	N_2 dilution, less CH_4 & H_2

3. Sludge Gasification Performance

- O_2 enrichment eliminates N_2 dilution, raising LHV slightly.

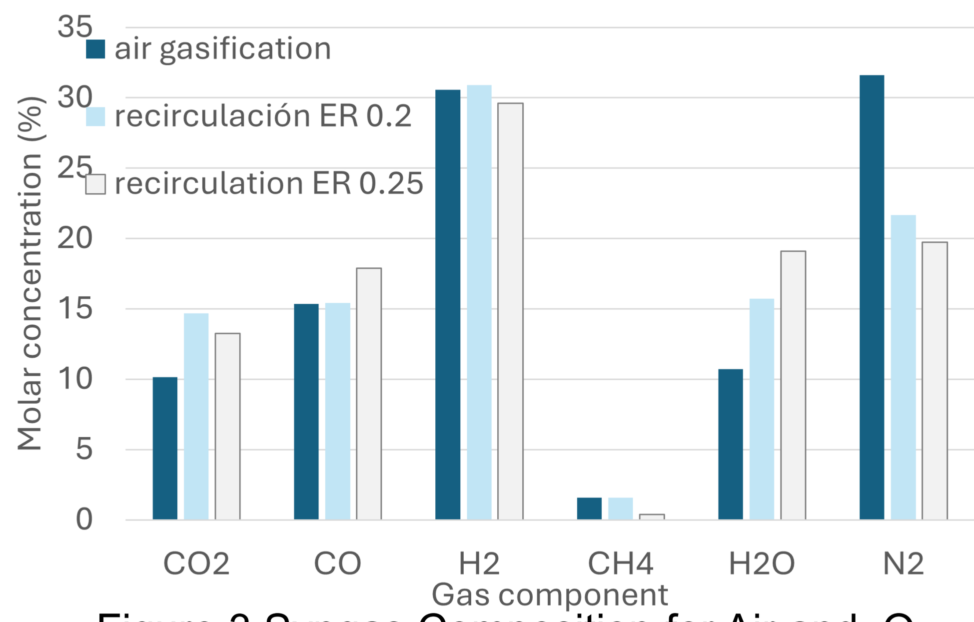

Figure 3 Syngas Composition for Air and. O_2-Enriched Gasification

Table 4 Oxygen-Enriched Gasification performance

Scenario	Syngas LHV (MJ/m³)	Total Energy (kW)	Elect. Demand (kW)
Air (ER 0.20)	**6.5**	1841	–
O_2-enriched (ER 0.20)	**7.0**	1841	**206.7**
O_2-enriched (ER 0.25)	**7.0**	**897 (↓6%)**	**261.8**

- CaO captures CO_2 in-situ, shifting equilibrium to produce more CO, H_2, and CH_4. It acts as catalyst for tar cracking and H_2 enhancement, CO_2 is removed, increasing energy density

Table 5 O_2/CO_2 atmosphere CaO captures scenario

ER	Syngas LHV (MJ/m³)	Energy Improvement
0.20	**8.03**	**+2.4%**
0.15	**8.36**	**+5.5%**

CONCLUSION

- Due to the high energy demand of electrolysis, Oxygen-enriched gasification alone offers limited net energy gain,
- Oxygen-enriched gasification under an O_2/CO_2 atmosphere combined with in-situ CO_2 capture offers the most promising configuration (by enhancing syngas quality, and increasing its energy content)
- Under the simulated conditions and assumptions, green hydrogen production from reclaimed water is currently not economically viable, highlighting the need for further process optimization

FUTURE WORK / REFERENCES

Future work should focus on process optimization to improve the economic viability of green hydrogen production from reclaimed water

References: Aznar et al. (2006); Ellacurriaga et al. (2024); González et al. (2025a,b); Migliaccio et al. (2021); Mun et al. (2013); Sarker et al. (2015); Wei et al. (2008); Xu et al. (2005)