Cape Peninsula University of Technology

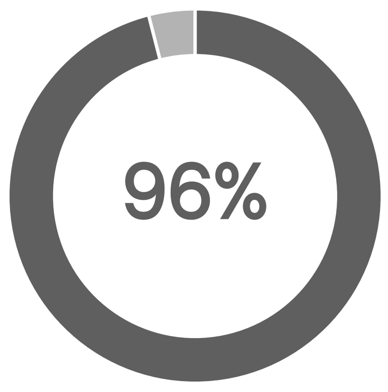
sanedi
South African National Energy Development Institute

Hydrogen Production from Biomass: Thermochemical and Biological Pathways

Masha, M.A., Mpungose, P.P., Nomnqa, M., Mabuda, A.I., Godongwana, B.

1 Introduction

- Hydrogen (H_2) is a clean energy carrier and industrial chemical[1].
- Fossil-based hydrogen (steam reforming) produces CO_2 — unsustainable[2].
- Renewable routes use biomass and organic waste via:
  - Thermochemical conversion[3].
  - Biological (anaerobic) processes[4].



HYDROGEN FROM FOSSIL FUELS

AMMONIA (FERTILIZER)	PETROLEUM REFINING	METHANOL	INDUSTRIAL CHEMICALS	ENERGY & FUEL CELLS
Haber–Bosch process	Hydrocracking, Desulfurization	Syngas Conversion	Hydrogenation, HCl, etc.	Syngas Conversion
~50%	~30-35%	~10%	~5%	GROWING

TOP USES OF HYDROGEN

2 Thermochemical Processes

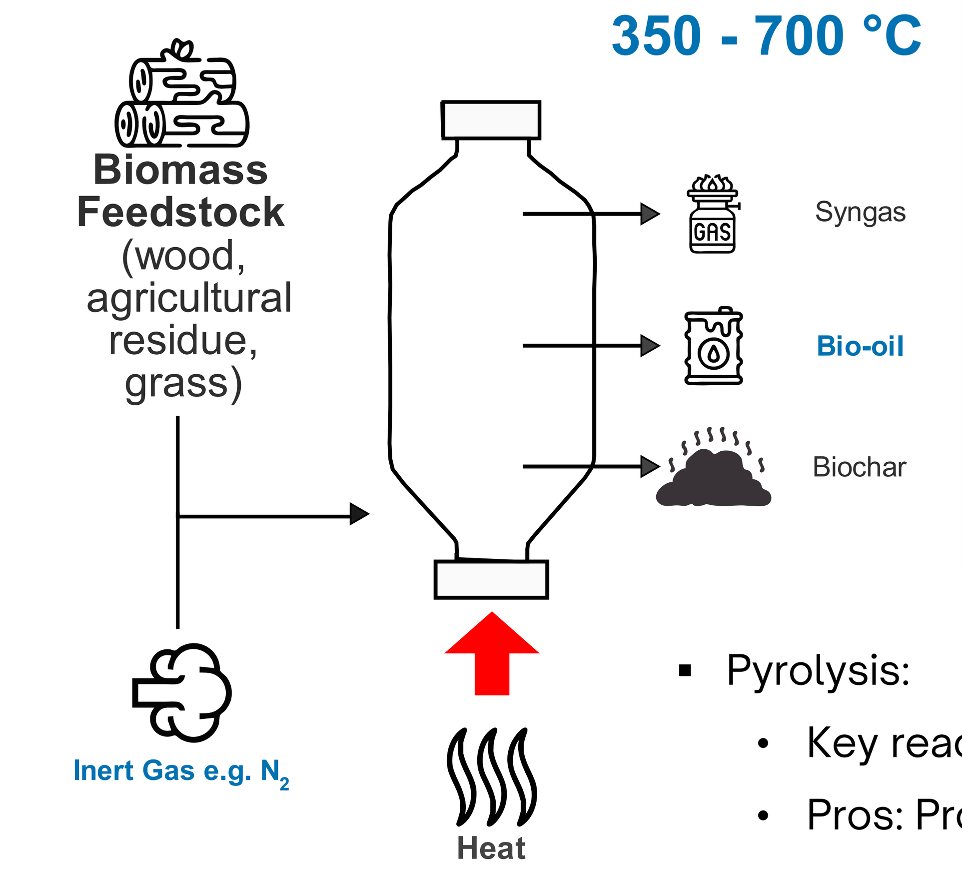


Fig A: Pyrolysis schematic illustration

- Gasification:
  - Key reactions - $C + H_2O \rightarrow CO + H_2$, $CO + H_2O \rightarrow CO_2 + H_2$, $CH_4 + H_2O \rightarrow CO + 3H_2$[6].
  - Pros: Generates higher H_2 yields than pyrolysis[7].
  - Cons: Produces CO and CO_2, Formation of tar (less desirable than bio-oil)[8].

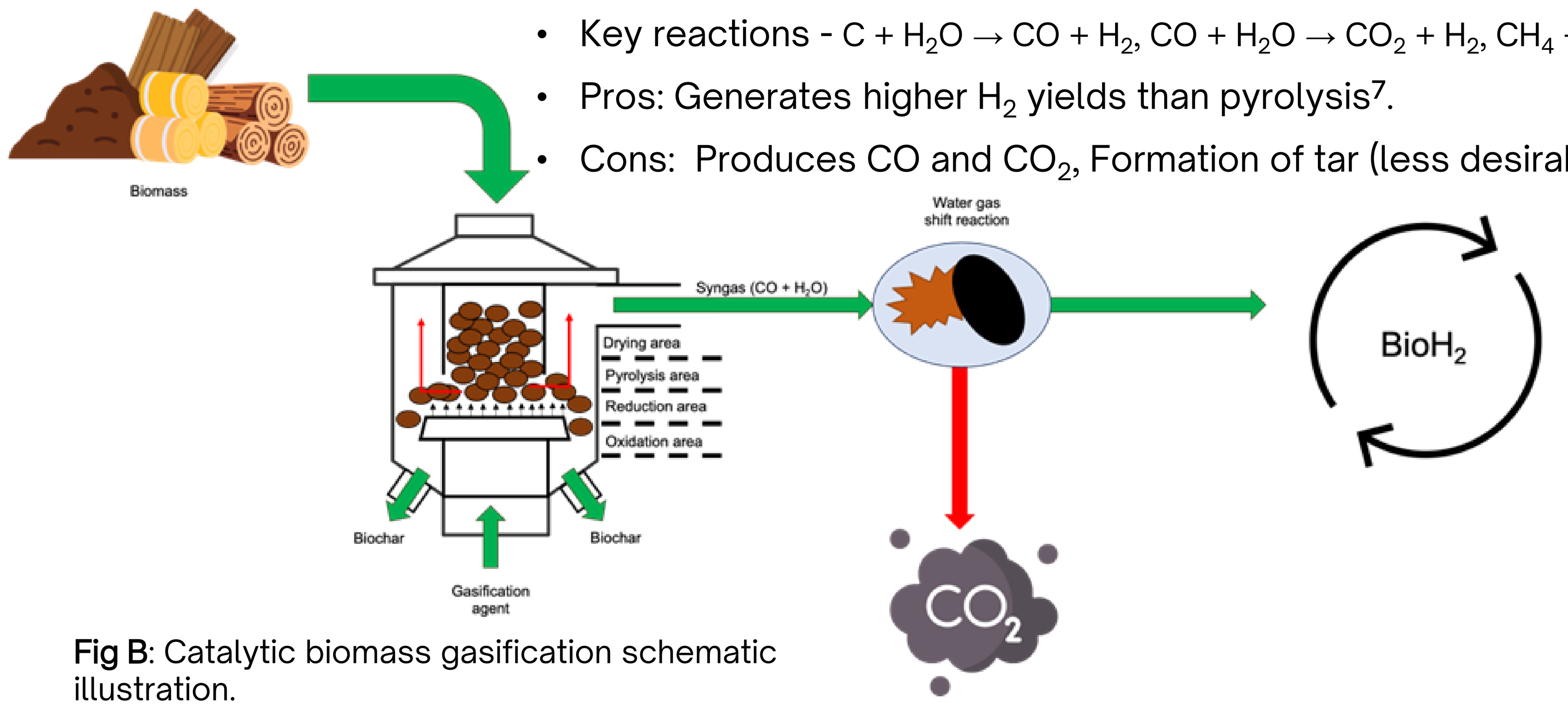


Fig B: Catalytic biomass gasification schematic illustration.

- Pyrolysis:
  - Key reactions - Cleavage of large polymer molecules into smaller hydrocarbons in absence of air/oxygen[5].
  - Pros: Produces lower greenhouse gas emissions compared to gasification and combustion[3].
  - Cons: Lower hydrogen yields than gasification, Liquid product (bio-oil) requires upgrading via gasification to increase hydrogen output[3].

3 Biological Process

- Microbes such as Clostridium and Enterobacter species consume organic waste under anaerobic conditions to produce hydrogen (H_2), carbon dioxide (CO_2), and digestate (a nutrient-rich residue)[4].
- Key reaction – $C_6H_{12}O_6 \rightarrow 2\ CH_3COOH + 2\ CO_2 + 4\ H_2$[9].
- Pros: Utilizes wet organic waste, unlike pyrolysis or gasification which require drying, Low energy input – operates efficiently at 30–60 °C[10].
- Cons: Low hydrogen yield compared to thermochemical methods, Sensitive to pH (5–7) and temperature fluctuations, requiring controlled conditions[11].

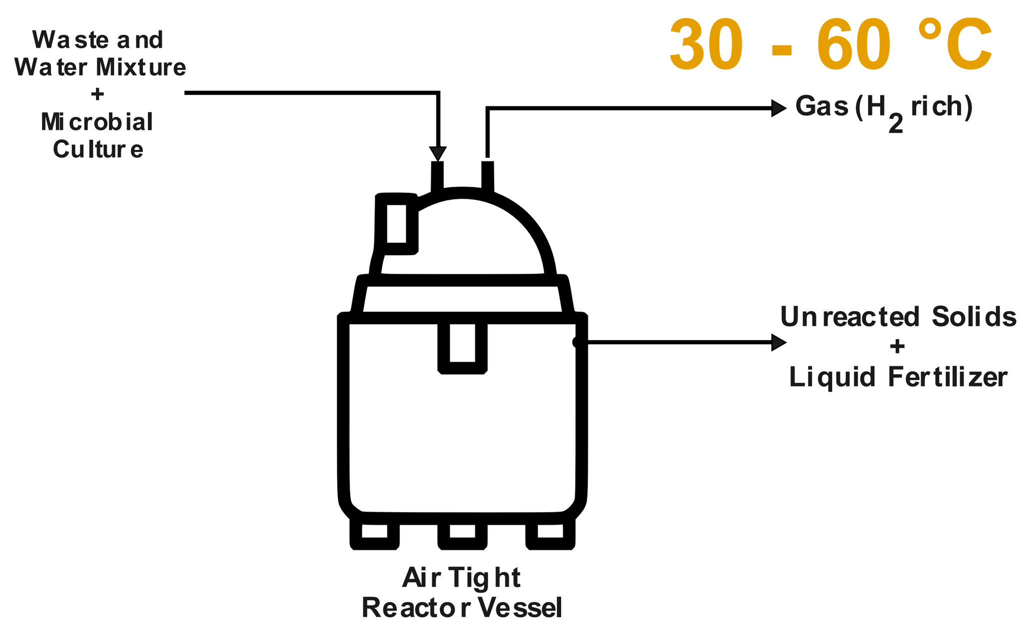


Fig B: Anaerobic digestion of waste to H_2 gas

4 Environmental & Energy Impact

- Both routes enable waste-to-energy conversion, supporting a circular bio-economy[12].
- Integration with carbon capture technologies can further enhance sustainability and reduce net CO_2 emissions[13].
- Hybrid systems can maximize energy recovery e.g. Re-digesting the digestate from hydrogen-producing fermentation to generate methane, Followed by methane steam reforming to produce additional hydrogen, and Pyrolysis or gasification of undigested solids for further energy recovery[14].

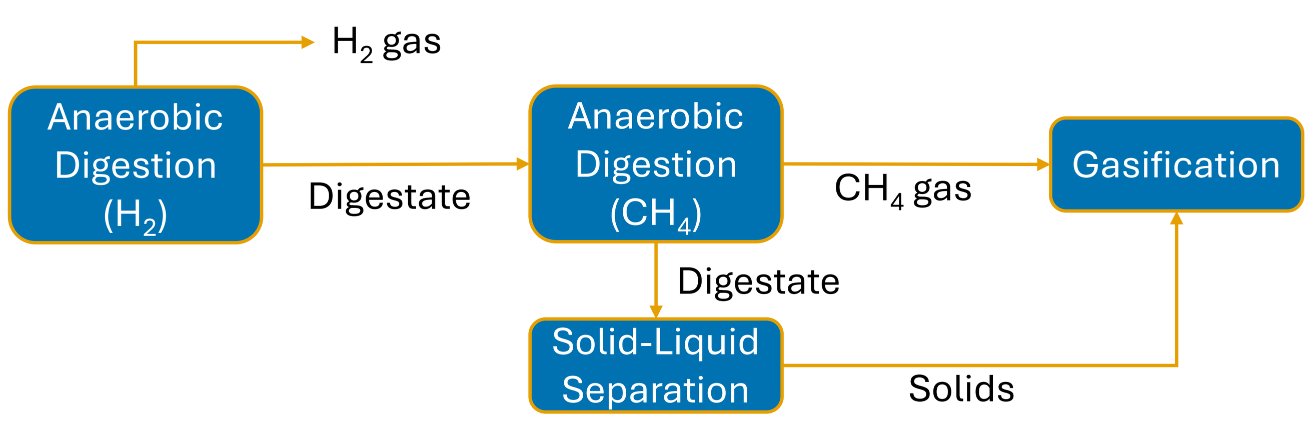


Fig C: Biological-Thermochemical hybrid system

5 Conclusion

- Thermochemical processes: Offer higher hydrogen yields but require high energy input, leading to increased production costs. Best suited for dry waste feedstocks.
- Biological processes: Are eco-friendly and low-energy, though they produce lower hydrogen yields. Ideal for wet organic waste streams.
- Future focus: Emphasis on process optimization, catalyst development, process intensification, and integrated hybrid systems to enhance overall efficiency and sustainability.

6 References

- [1] Brandon, N. P. & Kurban, Z. (2017). Clean energy and the hydrogen economy. Phil. Trans. R. Soc. A, 375, 20160400.
- [2] Guilbert, D. & Vitale, G. (2021). Hydrogen as a clean and sustainable energy vector for global transition from fossil-based to zero-carbon. Clean Technologies, 3(4), 881-909.
- [3] Zhang, Y., Li, X., Wang, H., & Chen, J. (2025). Catalytic pyrolysis of biomass: A review of zeolite, carbonaceous, and metal oxide catalysts. Nanomaterials, 15, 493.
- Full list of references available upon request.