

A-138

## ***Plasma-assisted entrained flow gasification as a key technology for Net Zero - a review***

L. Kufferath-Sieberin<sup>1</sup>, S. Fleck<sup>1</sup>, U. Santo<sup>1</sup>, D. Becker<sup>2</sup>, M. Vogelbacher<sup>2</sup>, J. Matthes<sup>2</sup>, F. Scheiff<sup>1,3</sup>

<sup>1</sup>Karlsruhe Institute of Technology (KIT), Institute for Technical Chemistry, Gasification Technology (ITC vgt), Herrmann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany, <sup>2</sup>Karlsruhe Institute of Technology (KIT), Institute for Automation and Applied Informatics (IAI), Herrmann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany, <sup>3</sup>Karlsruhe Institute of Technology (KIT), Engler-Bunte-Institute, Fuel Technology (EBI ceb), Engler-Bunte-Ring 1, 76131 Karlsruhe, Germany

Gasification is a well-known thermochemical process for converting carbon-based feedstocks into high-value syngas. Oxygen-based gasification is a high-temperature, autothermal process based on partial oxidation. Especially at higher H<sub>2</sub>/CO ratios, significant quantities of CO<sub>2</sub> are generated, which limits the overall carbon efficiency (CE). A promising alternative is plasma-assisted gasification, which uses electrical generated heat and steam as the gasification medium, substantially reducing CO<sub>2</sub> production. The plasma flame serves as an independent and flexible heat source that can be powered by renewable electricity. Bastek et al. [1] and Dossow et al. [2] published Aspen-based simulations of biomass-to-liquid processes, demonstrating the potential for upgrading low-quality biogenic feedstocks via plasma-assisted entrained flow gasification (PEFG). Kuznetsov et al. [3] reviewed various reactor designs, covering both existing installations and their future potential.

At ITC, the conversion of biogenic and plastic waste-based pyrolysis oils has been examined in the last years [4], [5], [6]. An Aspen Plus model for entrained flow gasification (EFG) was developed, validated by experimental data derived from the high-pressure EFG operated at Carbon Cycle Lab at KIT. This model is used for scale-up of to a 100 MW gasifier-scale case study.

To quantify the benefits and identify challenges of steam-plasma-assisted entrained flow gasification (PEFG), the Aspen Plus model has been extended to account for plasma integration. The model integrates (i) gas and fuel supply, (ii) plasma-assisted gasifier and (iv) downstream syngas clean-up. In the presented work, plasma-assisted entrained flow gasification is compared against oxygen-based biogenic and plastic waste-based pyrolysis oil gasification simulation.

Parametric studies shed a light on the influence of gasification media (O<sub>2</sub>, steam, CO<sub>2</sub>) and the thermal efficiency of plasma-derived heat. Performance is evaluated applying characteristic parameters, e.g., Carbon Efficiency (CE) and Cold gas efficiency (CGE). An outlook on the flexibilization of chemical processes with the focus on grid stability is given.

The findings suggest, that plasma-assisted gasification is a promising route toward a circular carbon economy for the chemical industry, acting both as a high efficiency syngas producer and as a functional CO<sub>2</sub> sink. Leveraging this potential will require further development in reactor design, stable-to-operate plasma sources, long-term testing and upscaling approaches.

### References:

- [1] Bastek S, Dossow D, Tamošiūnas A, Umeki K, Spliethoff H, Fendt S, (2025), Technical evaluation of plasma-assisted entrained flow gasification for hydrogen-rich syngas production from waste and biomass, Elsevier, International Journal of Hydrogen Energy, 150184, 157, 2025-08-13
- [2] Dossow M, Bastek S, Spliethoff H, Fendt S, (2025), Electrifying biomass-to-liquid processes using

plasma-assisted entrained flow gasification, Elsevier, Energy Conversion and Management, 120049, 341, <https://linkinghub.elsevier.com/retrieve/pii/S0196890425005734>, 2025-09-09

[3] Kuznetsov VA, Gräbner M, Schimpke R, Uhrlandt D, Richter A, (2026), Systematic evaluation of gasifiers driven by the high-enthalpy plasma supply, Elsevier, Fuel, 138538, 417, <https://linkinghub.elsevier.com/retrieve/pii/S0016236126002917>, 2026-03-04

[4] Eberhard M, Santo U, Michelfelder B, Günther A, Weigand P, Matthes J, Waibel P, Hagenmeyer V, Kolb T, (2020), The bioliq® Entrained-Flow Gasifier – A Model for the German Energiewende, Wiley, ChemBioEng Reviews, 106-118, <https://onlinelibrary.wiley.com/doi/abs/10.1002/cben.202000006>, 2025-09-04

[5] Dammann M, (2024), Numerical modelling and simulation of atmospheric entrained flow gasification of surrogate fuels, Karlsruhe, <https://publikationen.bibliothek.kit.edu/1000172116>, 2026-02-20, Karlsruhe Institute of Technology (KIT)

[6] Dammann M, Santo U, Böning D, Knoch H, Eberhard M, Kolb T, (2025), Entrained flow gasification: Pilot-scale experimental, balancing and equilibrium data for model validation, Elsevier, Fuel, 132809, <https://linkinghub.elsevier.com/retrieve/pii/S0016236124019586>, 2025-08-25