Energy and Environmental Performance of a Biogas-Powered Solid Oxide Fuel Cell (SOFC): A Numerical Modeling Approach

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Abstract:

The transition toward sustainable energy systems requires efficient technologies to exploit renewable and distributed resources such as biogas. Conventional Combined Heat and Power (CHP) technologies, including Internal Combustion Engines (ICEs) and Micro Gas Turbines (MGTs), are widely used but suffer from relatively low efficiencies and higher environmental impacts. In this context, Solid Oxide Fuel Cells (SOFCs) represent a promising alternative. However, their integration with real biogas streams remains challenging due to the fuel's low calorific value and system-level design complexities that are not fully addressed in the scientific literature. To address this gap, this work proposes a detailed Aspen Plus® numerical model of a biogas-fed SOFC system, including internal reforming, anodic recirculation, and heat recovery units. The analysis considers a biogas flow from a plant utilizing a patented technology for the pretreatment of organic feedstock. Results show that the system, modeled under thermodynamic equilibrium assumptions and a constant operating voltage, and constant pressure drop, can effectively operate in CHP mode, delivering approximately $438\ kW_{\text{e}}$ of electrical power and $345\ kW_{\text{th}}$ of thermal output, achieving an electrical efficiency of about 51.6% and an overall CHP efficiency of 80.1%. Furthermore, increasing the methane fraction in the biogas significantly enhances both electrical and thermal performance. This constitutes an additional key finding of the study, providing further support for the suitability of SOFC technology in biogas plant applications. The results demonstrate that SOFC systems can significantly outperform conventional onsite generation technologies such as Internal Combustion Engines (ICEs), particularly with respect to local emissions. Moreover, the effect of the Steam/Carbon (S/C) ratio on methane conversion in the pre-reformer was also studied, and it was found that an over (S/C) ratio of 2 is the optimal point not only for methane conversion but also for hydrogen production. The model predictions are consistent with the scientific literature, confirming the potential of SOFC-based systems to improve energy efficiency and reduce greenhouse gas emissions when coupled with upgraded biogas streams.

Keywords:

Aspen Plus ® Numerical Model, Biogas, Energy Systems, Renewable energy, Solid Oxide Fuel Cell.

1. Introduction

Biogas is a promising Renewable Energy Source (RES) for decentralized power generation because it converts organic waste streams into useful energy while supporting decarbonization targets and circular-economy strategies [1,2]. Produced through the anaerobic digestion of sewage sludge, agro-industrial residues, and animal waste, biogas typically contains 50-70 vol% of CH_4 and 30-50 vol% of CO_2 [2]. Its widespread availability and compatibility with distributed energy systems make it particularly attractive for small- and medium-scale Combined Heat and Power (CHP) applications. However, the effective conversion of biogas into electricity and heat strongly depends on the performance of the prime mover and on the fuel quality delivered to the conversion unit.

At present, biogas is mainly exploited through Internal Combustion Engines (ICEs) and Micro Gas Turbines (MGTs), but these technologies are penalized by relatively low electrical efficiencies and by a strong sensitivity to fuel composition. ICEs typically achieve electrical efficiencies of 28-37% in the 10-100 kW_e range and 37-43% in the 100-1000 kW_e range, while MGTs generally operate at 20-30% for 10-100 kW_e units and 25-33% for 100-1000 kW_e systems [3]. In addition, both technologies suffer from mechanical wear, maintenance requirements, and lower performance when biogas quality fluctuates.

In this context, the use of Solid Oxide Fuel Cells (SOFCs) can be a more efficient alternative because of their higher electrical efficiency compared to conventional fluid machines previously mentioned, limited moving parts, low noise, and low pollutant emissions [4]. Their high operating temperature (typically in the range 700-1000 °C) also makes them especially suitable for CHP applications, since high-grade heat can be recovered for process or plant needs.

The potential of SOFCs for biogas conversion has already been recognized in the scientific literature. Saadabadi et al. [5] reviewed the state of the art of biogas-fueled SOFC systems and highlighted that SOFCs can reach electrical efficiencies of 50-60%, while also providing high-temperature residual heat and low emissions. At the same time, the authors identified major constraints related to biogas impurities, carbon formation, and the strong influence of gas composition on system design and durability. From an experimental perspective, Papurello et al. [6] investigated the exploitation of biogas from organic waste in a 500 W_e SOFC stack, demonstrating that SOFC systems can achieve electrical efficiencies above 50% even at part load, thereby confirming the technical potential of biogas-to-electricity conversion in small-scale waste-to-energy applications. At a larger scale, the DEMOSOFC project [7] demonstrated the industrial feasibility of biogas-fed SOFC technology in a wastewater treatment plant through a 174 kW_e installation (3×58 kW_e modules). Results showed a SOFC electrical efficiency from compressed biogas to AC power consistently above 50-52%, with peaks of 56%, and an average overall efficiency of about 82% together with very low emissions. More recently, Wang et al. [8] developed a multi-scale hierarchical model of a biogas-fed SOFC CHP system and reported, at base-case conditions, a system electrical efficiency of 55.6% and a CHP efficiency of 85%. Their analysis also showed that electrical efficiency remained above 50% and CHP efficiency above 80% over typical biogas compositions, confirming the robustness of SOFC-based CHP layouts under variable fuel conditions.

The scientific literature is increasingly moving toward integrated analyses; however, a clear gap remains in the systematic quantification of how upstream biogas upgrading influences SOFC performance, durability, and overall system economics. In particular, most available studies focus either on prototype-scale demonstrations or on SOFC operation under conventional biogas compositions, without explicitly addressing the impact of improved biogas quality achieved upstream of the fuel cell. To address this gap, the present work provides a steady-state Aspen Plus® numerical model of a biogas-fed SOFC system including fuel and air compression, pre-heating, anodic recirculation, internal reforming, electrochemical conversion, afterburning, and heat recovery.

The paper is structured as follows: Section 2. compares upgraded biogas with higher methane content and lower impurities from the patented technology (D1) to conventional biogas without pretreatment (D2), to quantify the effect of fuel quality on the electrical, thermal, and overall efficiency of an SOFC-based CHP system. Section 3. describes the Aspen SOFC model, Section 4. shows the results obtained, and Section 5. reports the conclusions of the work and its future developments.

2. Biogas output characterization and comparative analysis

The biogas feed analysed in this case comes from a patented technology that upgrades the biogas quality by increasing the methane percentage of the methane concentration within the biogas stream. This section provides a comparative assessment of two biogas production pathways, namely D1 and D2, derived from the same feedstock but subjected to different process configurations. In particular, configuration D1 integrates the patented pre-treatment technology, which introduces a thermo-chemical pre-treatment stage and ammonia nitrogen removal upstream of anaerobic digestion. In contrast, configuration D2 represents a conventional digestion process without pre-treatment (see Fig. 1). This approach allows the isolation of the effect of fuel quality on SOFC-based CHP performance under consistent boundary conditions. The model is therefore used to quantify the electrical and thermal outputs of the system based on the gas composition obtained from the D1 configuration, and to evaluate overall system efficiency. Additionally, some impurities are typically present in raw biogas, such as hydrogen sulphide (H_2S) and siloxanes, but they are not included in the analysis as the patented pre-treatment technology is able to reduce these contaminants to negligible levels prior to feeding the gas into the SOFC system, thereby assessing the potential benefits of integrating higher-quality biogas into advanced fuel-cell-based energy conversion systems [9].

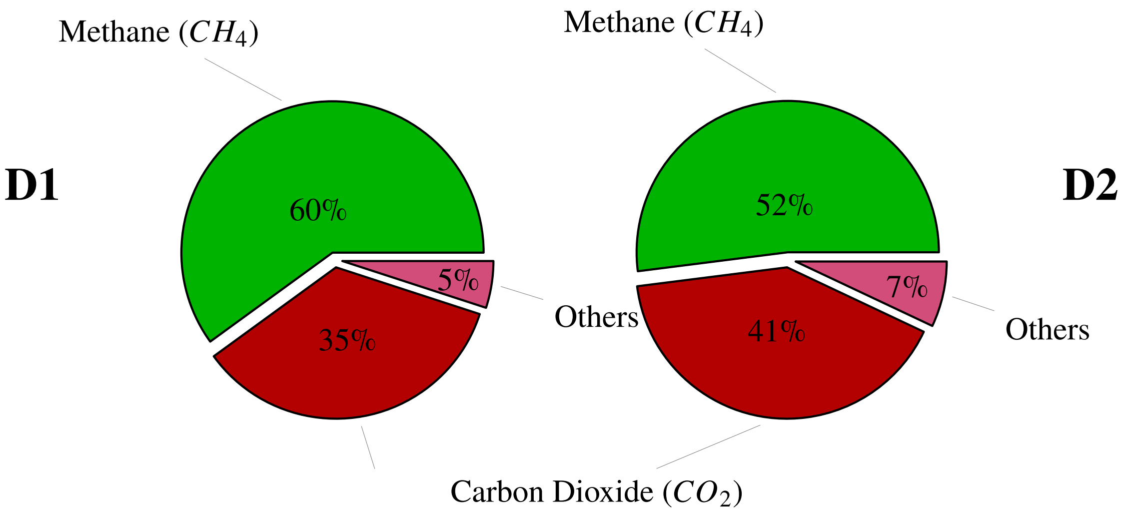

Figure 1: Biogas composition analysis for D1 and D2.

3. Materials and methods

3.1. Aspen Plus® SOFC model

A steady-state Aspen Plus® model of a biogas-fed SOFC system was developed using standard built-in unit operation blocks and calculation routines. The simulated system layout includes the main components required for system operation, namely biogas and air blowers, dedicated preheaters for both streams, a mixer, a pre-reformer, and the SOFC stack, which is modeled through separate modules representing the anode and cathode sides. Downstream of the stack, an afterburner is implemented to oxidize the remaining fuel species, ensuring complete combustion and minimizing the release of unburned hydrocarbons or other pollutants into the environment. This equipment is essential for achieving both regulatory compliance and optimal energy recovery from the exhausts. Meanwhile, a cathode heater is included to ensure thermal balance within the fuel cell, as maintaining an appropriate cathode temperature is critical for electrochemical performance and for avoiding thermal gradients that could lead to cell degradation. In addition, one heat recovery unit is integrated into the system to exploit the high-temperature exhaust gases and enhance overall efficiency. To accurately capture the thermodynamic and electrochemical behaviour of the system, several calculator blocks are embedded within the model, enabling the evaluation of key variables such as fuel utilization, current generation, and energy balances. The calculator blocks in Aspen Plus® are essentially a FORTRAN code with features of exporting data to and importing data from other unit processes of the simulation environment. The complete Aspen Plus® flow sheet of the biogas-fed SOFC system is shown in Fig. 2.

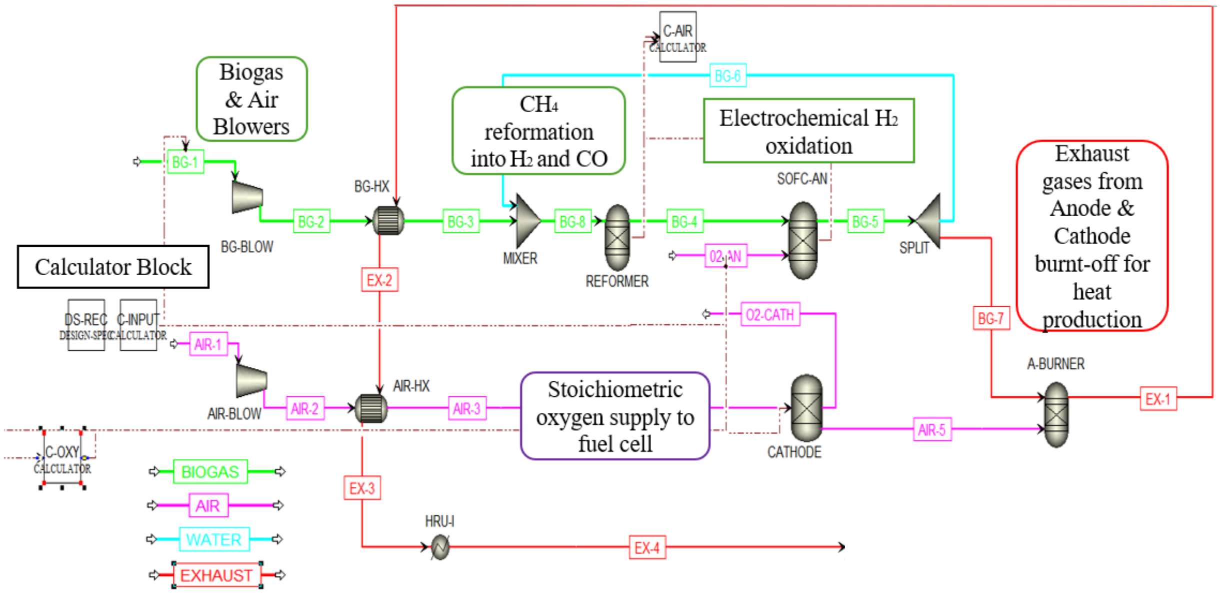

Figure 2: Aspen Plus$^{®}$ model of the biogas-powered SOFC.

The biogas stream “BG-1” is initially at atmospheric pressure and ambient temperature (25 °C). It is compressed by a blower (BG-BLOW) to a pressure slightly above atmospheric conditions, typically around 1.2 bar, and then directed to the waste heat recovery unit, where it is preheated and exits as stream “BG-2” at an elevated temperature of 700 °C. Similarly, the air stream “AIR-1”, required for the electrochemical reactions in the SOFC, starts at atmospheric pressure and ambient temperature (25 °C), is compressed by the blower (AIR-BLOW) to about 1.2 bar, and delivered as stream “AIR-2”, which is also preheated in a subsequent step. The fuel stream “BG-2” and the air stream “AIR-2” are subsequently fed into two separate pre-heaters, denoted as BG-HX and AIR-HX, respectively. These units are modeled in Aspen Plus$^{®}$ as shell-and-tube heat exchangers and are designed to recover thermal energy from the high-temperature exhaust gases. In practical applications, such devices operate as a recuperator, enabling efficient heat exchange between hot exhaust streams and incoming reactants. Specifically, the high-temperature exhaust stream “EX-1” leaving the afterburner is first directed to the BG-HX heat exchanger, where its thermal energy is recovered to pre-heat the incoming biogas up to the reforming temperature. The partially cooled exhaust stream “EX-2” is subsequently routed to the AIR-HX unit, where it is further utilized to increase the temperature of the incoming air stream to the required SOFC operating conditions. This cascade heat recovery configuration allows for an efficient utilization of the exhaust thermal energy, thereby improving the overall system efficiency.

Desulfurized biogas “BG-3” is fed into the MIXER block, where it is combined with a recycled stream “BG-6”. This recycled stream originates from the SOFC anode exhaust and contains water vapour generated during the electrochemical reactions, which is required to sustain the steam methane reforming process. The recirculation loop is modeled using a SPLIT block, which divides the anode exhaust stream “BG-5” into two fractions: a recycled stream “BG-6”, sent back to the mixer, and a purge stream “BG-7”, directed to the downstream afterburner. The resulting mixed stream “BG-8” is then fed to the reformer unit, where methane is converted into syngas, mainly composed of hydrogen (H$_2$) and carbon monoxide (CO), through steam reforming reactions. Steam methane reforming is simulated in Aspen Plus$^{®}$ using an RGibbs reactor block (REFORMER), which represents the internal reforming of methane contained in the biogas under adiabatic conditions. However, the use of an RGibbs reactor involves certain simplifications, as reaction kinetics and electrochemical phenomena are not fully captured. In particular, charge transport, mass diffusion, and overpotential losses are not explicitly modelled, since Aspen Plus$^{®}$ does not provide a dedicated built-in unit capable of fully representing SOFC electrochemical behaviour. Therefore, these limitations should be taken into account when interpreting the simulation results. The reforming reactions are strongly endothermic and require substantial heat input, which is supplied by the exothermic electrochemical reactions occurring at the SOFC anode. This thermal coupling helps maintain the overall energy balance of the system and supports efficient integrated operation. The biogas volumetric flow rate is set to $140\ Nm^3/h$. Within the REFORMER block, the main reactions considered are steam methane reforming and the water–gas shift reaction, expressed as follows:

$$CH_4 + H_2O \rightarrow CO + 3H_2 \tag{1}$$

$$CO + H_2O \rightarrow CO_2 + H_2 \tag{2}$$

The steam-to-carbon (S/C) ratio is a key parameter in steam methane reforming, as improper values can negatively affect reaction kinetics and overall system efficiency. In this study, an S/C ratio of 2 is adopted within the REFORMER block to prevent carbon deposition and ensure stable operation. To maintain the desired S/C ratio, a design specification (DS-REC) is implemented in Aspen®, which regulates the recirculated stream “BG-6” to supply the required amount of water vapor. This approach allows the system to exploit the water produced during the electrochemical reactions, avoiding a simple equal split of the anode exhaust stream “BG-5” and instead dynamically adjusting the recycle flow to meet process requirements. Aspen Plus® then calculates the reforming products and outlet conditions for the downstream units. The REFORMER block operates at a temperature of $750\ °C$, close to the SOFC operating temperature (approximately $800\ °C$), to minimize thermal gradients and avoid material stress within the system. The resulting product stream “BG-4”, mainly composed of syngas, is fed into the SOFC anode block (SOFC-AN), which is modeled as an RGibbs reactor. Within this block, the remaining methane reforming reactions and the electrochemical oxidation of hydrogen (H_2) are simulated, leading to the generation of both electrical and thermal energy. Since ion transport cannot be explicitly modeled in Aspen Plus®, the overall reactions occurring at the anode are represented through global equilibrium reactions, as reported below:

$$H_2 + 1/2O_2 \rightarrow H_2O \tag{3}$$

$$CH_4 + H_2O \rightarrow CO + 3H_2 \tag{4}$$

$$CO + H_2O \rightarrow CO_2 + H_2 \tag{5}$$

Hydrogen is assumed to be the only species undergoing electrochemical oxidation at the anode. Although direct oxidation of the pre-reformed fuel “BG-4” may occur at temperatures above $1000\ °C$ even in the absence of a catalyst, this pathway is less favourable compared to the indirect route involving methane reforming and the water-gas shift reaction, which produces hydrogen as the main electrochemically active species. Therefore, hydrogen is considered the primary fuel in the electrochemical reactions, while other species are assumed to contribute indirectly through reforming and shift reactions. This assumption simplifies the sensitivity analysis while still providing an accurate representation of the SOFC electrochemical behavior [10]. The SOFC anode is modeled in Aspen Plus® using an RGibbs reactor block, which assumes thermodynamic equilibrium at a fixed operating temperature of $800\ °C$. To simplify the simulation, the system is considered to operate at a constant pressure of 1.2 bar, and pressure drops across all components are neglected. Although the electrochemical reactions are not explicitly modeled as reversible processes, the high operating temperature results in very large equilibrium constants, allowing the model to closely approximate the actual electrochemical conversion occurring within the fuel cell. Under these conditions, both the equilibrium and exhaust temperatures are assumed to be equal to $800\ °C$, Akkaya et al. [11] investigated whether this temperature assumption is consistent with the one determined by the thermodynamic equilibrium of exit gas composition. At this temperature, steam methane reforming is nearly complete. The hydrogen participating in the electrochemical oxidation (Eq. 3) is therefore composed of both the hydrogen produced via steam methane reforming and the water–gas shift reactions (Eqs. 1 and 2), as well as any residual hydrogen present in the incoming fuel stream "BG-4".

3.2. Stoichiometric air supply to the cathode

The cathode side of the fuel cell is modeled in Aspen Plus® using a separator block (CATHODE), configured as a variable oxygen flow splitter. This unit divides the incoming air stream "AIR-4" into two streams: an oxygen-rich stream "O2-CATH", which supplies the oxidant required for the electrochemical reactions, and a remaining air stream "AIR-5", which is directed to the afterburner for combustion. A dedicated calculator block (C-INPUT) is implemented to determine the required air flow rate and the electrical current generated by the fuel cell, based on the biogas input and Faraday's law. The inlet air stream "AIR-4" is set to a volumetric flow rate of $1043\ Nm^3/h$ and consists of 21% O_2 and 79% N_2. The C-INPUT block employs an iterative procedure that accounts for the available fuel, the electrochemical reactions, and a target Fuel Utilization (FU) factor of 0.7 [12]. Based on these inputs, the stoichiometric oxygen requirement and the total current produced by the fuel cell are calculated as follows:

$$OXY - FLOW = \frac{C_{total}}{4 \cdot F} \tag{6}$$

$$C_{total} = N_{fuel} \cdot FU \cdot F \cdot 8 \cdot 0.7 \tag{7}$$

where C_{total} represents the total electrical current generated by the fuel cell, and N_{fuel} is the volumetric flow rate of the biogas, set to $140\ Nm^3/h$ according to the plant operating conditions. The fuel utilization factor (FU) is fixed at 0.7, while F denotes Faraday's constant. The coefficient 8 corresponds to the number of electrons transferred per mole of fuel involved in the electrochemical reactions, whereas the factor 4 in Eq. 6 accounts for the four electrons required per molecule of O_2 in the cathodic reaction.

3.3. Afterburner

After the electrochemical and chemical reactions within the SOFC, a portion of the depleted fuel stream is recirculated and mixed with the incoming biogas to supply the steam required for the pre-reforming process. The remaining fraction of the anode off-gas "BG-7" is directed to the combustion chamber. In the afterburner, the residual combustible species, mainly H_2 and CO, react with the oxygen contained in the depleted air stream "AIR-5", leading to complete oxidation. These exothermic reactions release a significant amount of heat, generating a high-temperature exhaust stream "EX-1", which is subsequently utilized for pre-heating both the fuel and air streams, thereby improving overall system efficiency. The combustion process is simulated in Aspen Plus® using an RGibbs reactor block (A-BURNER), which determines the equilibrium composition of the exhaust gases by minimizing the Gibbs free energy of the system. This approach allows for an accurate representation of the conversion of the remaining fuel species into fully oxidized products. This equilibrium-based reactor model assumes complete combustion, thereby neglecting any kinetic limitations that may arise in practice, such as incomplete oxidation or reaction rate constraints.

3.4. Mathematical model

The mathematical model includes the simultaneous heat and mass transfer characteristics of the biogas-powered fuel cell system to provide combined heat and power. The main simulation postulates are the following: i) steady state simulation for the fuel cell, ii) the air supplied to the fuel cell is composed of 79% N_2 and 21% O_2, iii) fuel supplied to the system is biogas having composition of 60% CH_4 and 35% CO_2, iv) system working pressure is 1.2 bar and zero pressure drop is considered across each component block, and v) the Gibbs free energy is minimised in all chemical reactions. Tab. 1 reports the main input parameters adopted in the model.

Table 1: Input parameters to the simulation model.

Parameter	**Value**
Inlet biogas composition	CH_4 60% and CO_2 35%
Pre-reformer operating temperature [16]	750 °C
Fuel cell operating temperature [2]	800 °C
Fuel cell exhausts temperature (streams BG-5)	800 °C
Inlet air temperature (stream AIR-4)	800 °C
Inlet biogas temperature (stream BG-4)	750 °C
Afterburner efficiency	95%
Overall fuel utilisation factor [12]	70%
S/C ratio	2
Pressure drops inside the SOFC	Neglected

The cell operating voltage (V_{OP}) is a key parameter in fuel cell modeling, as it directly affects the evaluation of the power that can be extracted from the system to meet the energy demands of the biogas plant. An operating voltage of $0.8\ V$ is selected as a reference value, since it provides a good trade-off between efficiency and performance, as reported in the scientific literature [12, 13]. The electrical power output and the total current are calculated through equations implemented in a FORTRAN code within the calculator block:

$$ELEC = C_{total} \cdot VOP \tag{8}$$

$$C_{total} = N_{fuel} \cdot FU \cdot F \cdot 8 \cdot 0.7 \tag{9}$$

4. Results and comments

4.1. CHP performance evaluation

The proposed simulation model has been developed to evaluate the performance of a biogas-powered SOFC based on the variable stream composition of the biogas fed.

Table 2: Comparison of CHP and electrical efficiency between current and recent studies.

	Current Study	Ref. [7]	Ref. [15]	Ref. [17]
η_e	51.6%	> 53%	51.6%	51.12%
η_{CHP}	80.1%	> 80%	—	—

Fig. 3 shows the simulation results, provided the power outputs of $345\ kW_{th}$ of thermal energy which will be provided to the biogas digester and $438\ kW_e$ of electrical power output, achieving an overall electrical efficiency of 51.6% and combined heat and power efficiency of 80.1%. It is worthy to be noted that; these efficiency values are derived under idealized modeling conditions and should be interpreted with caution, as the simplifying assumptions inherent to the simulation such as steady-state operation, idealized heat integration, and fixed fuel utilization which ultimately not be able to fully capture real world scenario based upon performance. Nevertheless, the results are predominantly consistent with those discussed in [7, 15, 17], as reported in Table 2.

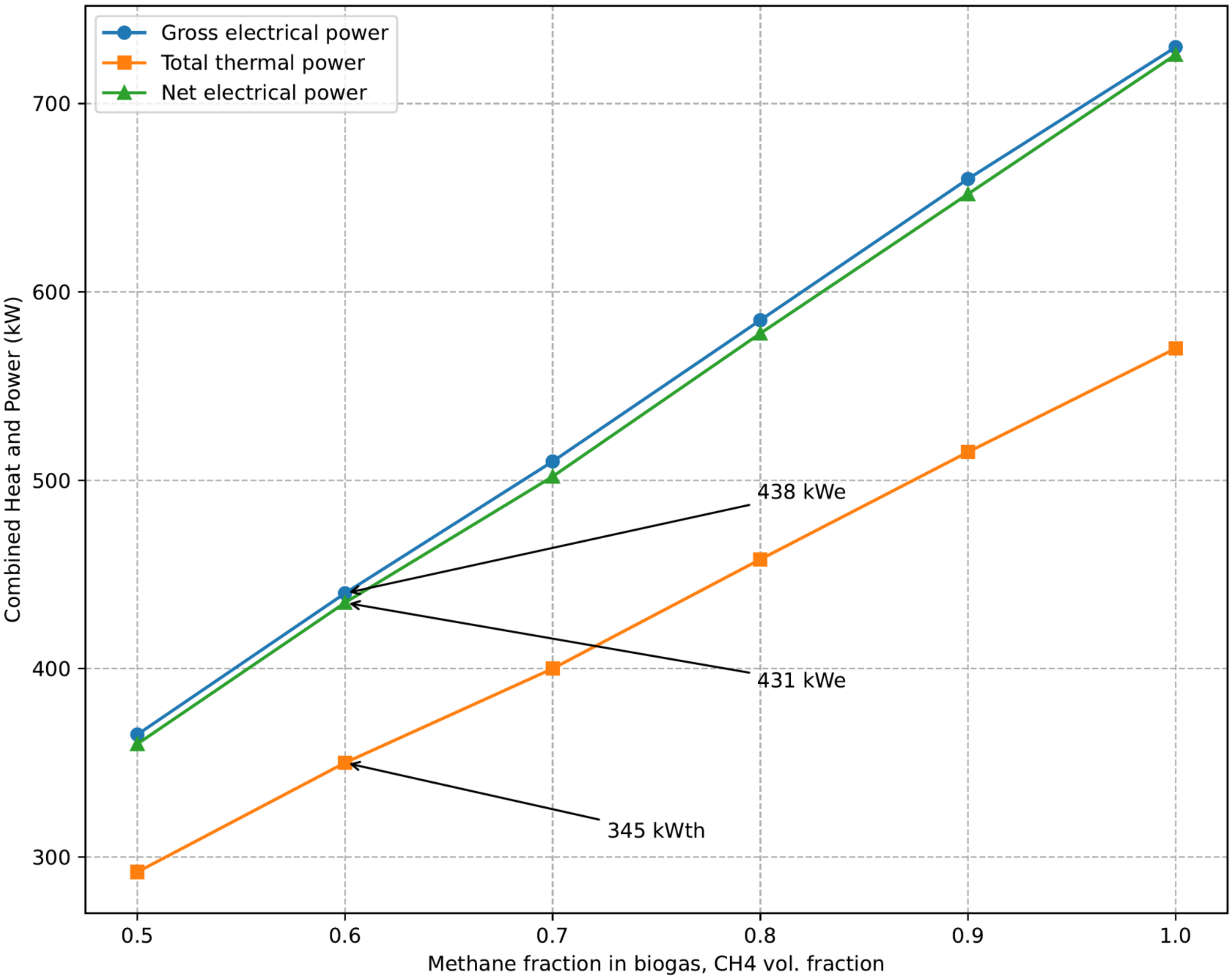

Figure 3: CHP performance of biogas-based SOFC system as a function of methane fraction in biogas.

The biogas composition is initially defined based on the digester outlet stream, assuming equimolar fractions of CH_4 and CO_2. A sensitivity analysis is then performed by increasing the CH_4 concentration in the biogas feed, reflecting the capability of the patented upgrading technology to deliver nearly pure methane. The simulation results show that increasing the CH_4 fraction in the fuel stream enhances both the electrical and thermal power output of the fuel cell. A fuel utilization factor of 70% is adopted based on the biogas flow rate, representing a conservative lower bound for stable operation [14]. The operating voltage is set to $0.8\ V$, which is commonly used as a nominal condition in commercial SOFC stacks [15]. The pre-reformer operating temperature is fixed at 750 °C, while the fuel cell operates at 800 °C [16]. The steam-to-carbon (S/C) ratio in the pre-reformer is maintained at 2 (see Tab. 1). The comparison between the results of the present simulation model and those reported in recent modeling and experimental studies indicates that the model provides reliable and consistent predictions for biogas-powered SOFC systems.

4.2. S/C ratio effect on SOFC performance

The S/C ratio is a key parameter for the integrated biogas-based CHP system, as a certain amount of steam is required to prevent carbon deposition in the pre-reformer. In particular, the S/C ratio determines the composition of the reformed fuel gases and affects the performance of the stack and system. For a better comprehension, a sensitivity analysis is performed by varying the S/C ratio of the inlet flow rate while keeping other parameters fixed. System performance is evaluated at S/C ratios of 0.5, 1.0, 1.5, 2, and 2.5. Fig. 4 illustrates how the S/C ratio affects the mole fraction of reformed products.

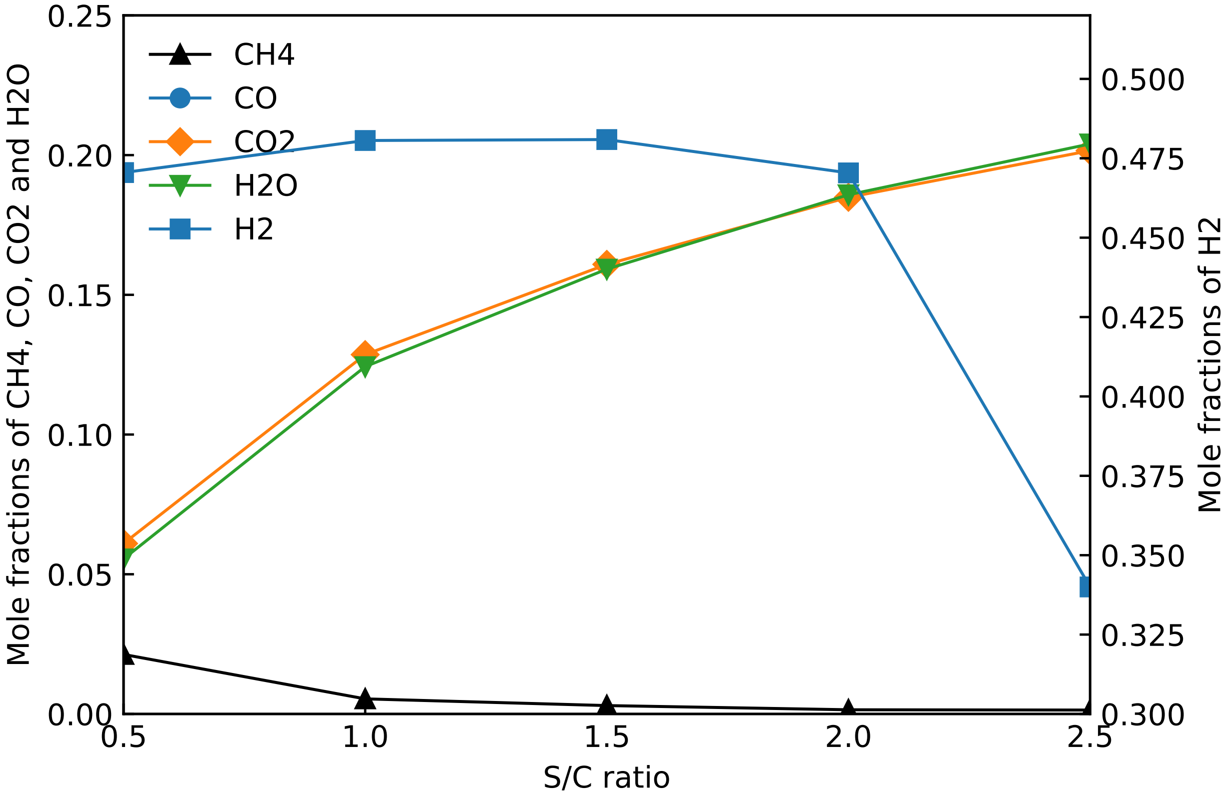

Figure 4: S/C ratio effect on the mole fractions of the pre-reformed products.

As the S/C ratio increases from 0.5 to 2.5, CH_4 conversion in the pre-reformer increases, resulting in a lower CH_4 mole fraction to the pre-reformer downstream, although the H_2 is not optimal at this point, but the core objective is to reduce the CH_4 concentration over the pre-reformer downstream. The additional H_2O promotes the WGS reaction, which consumes CO and produces CO_2. Overall, increasing the S/C ratio up to 2 raises the concentration of oxidative products CO_2 and H_2O in the anode inlet gas. The S/C ratio creates direct impact for the CH_4 conversion and generation of H_2 therefore higher electrical and thermal outputs. As a result, the anodic flow becomes more oxidative at higher S/C ratios. In addition to this, both resistive heating and heat released by electrochemical reactions decrease.

5. Conclusions

A steady-state thermodynamic model of a biogas-fueled SOFC system for CHP generation was developed and implemented in Aspen Plus®, coupling built-in unit operation blocks with user-defined subroutines to represent specific system behaviors. The model was calibrated and validated against performance data available in the literature, and the results suggest that the system is capable of operating in CHP mode, delivering approximately $438\ kW_{\mathrm{e}}$ of electrical power and $345\ kW_{\mathrm{th}}$ of thermal output, corresponding to an electrical efficiency of about 51.6% and an overall CHP efficiency of 80.1%. Furthermore, an increase in the methane content of the biogas leads to significant improvements in both electrical and thermal performance. The influence of the steam-to-carbon (S/C) ratio on the gas composition downstream of the pre-reformer is also investigated. As the S/C ratio increases from 0.5 to 2.5, methane conversion is enhanced, but the optimal point for S/C ratio was 2, resulting in a lower CH_4 mole fraction at the pre-reformer outlet. While these figures are quite promising, they should be interpreted in light of several inherent modeling limitations. This steady state model does not account the change in temperature and pressure with respect to time across the fuel cell; technically, it does not capture the transient thermodynamic interactions while integrating the coupling of exothermic and endothermic processes within the SOFC, which may lead to deviations from the modeled performance under real dynamic operating conditions. Furthermore, the electrochemical sub-model relies on simplified representations of charge transfer kinetics and polarization losses, which may not fully reflect the complexity of actual cell behaviour across varying current densities and fuel compositions. Finally, validation was conducted exclusively against scientific literature data rather than purpose-collected experimental measurements, which limits the degree of confidence that can be placed in the absolute performance predictions. Future developments will focus on the implementation of a dynamic model to capture the complex thermodynamic interactions associated with exothermic and endothermic processes within the cell, additionally, the transitional behaviour associated with the cell start-up and loading-off. Experimental validation under controlled conditions will also be essential to consolidate the reliability of the modeling framework and to refine the electrochemical assumptions adopted in the present work.

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Nomenclature

Abbreviations

SOFC	Solid Oxide Fuel Cell
BG	BioGas
BG-BLOW	BioGas Blower
AIR-BLOW	Air Blower
BG-HX	Biogas Heat Exchanger
AIR-HX	Air Heat Exchanger
BG-BLOW	BioGas Blower
DS-REC	Design Specification - Recirculation
OXY-FLOW	Oxygen-Flowrate
SOFC-AN	Solid Oxide Fuel Cell-Anode
A-BURNER	After-Burner
C_{total}	Total Current
ELEC	Electricity Generation
FU	Fuel Utilization
Greek Letters	
η	Efficiency
Constants	
F	Faraday's Constant
Variables	
S/C ratio	S/C ratio
VOP	Operating Voltage

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