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2nd Symposium on Ammonia Energy

Environmental life cycle analysis of an ammonia-ethanol fuelled ICE for power generation

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Introduction

Climate change has been a significant worldwide concern in recent decades due to the excessive generation of greenhouse gases (GHG). To mitigate GHG emissions, there is a need to increase the use of renewable energy sources, which are expected to increase globally as governments attempt to achieve their environmental and regulatory responsibilities [1]. The use of low-carbon fuels and biofuels blended with fossil fuels has been seen as an attractive alternative to diminishing greenhouse emissions. However, in the coming decades, fossil fuels will no longer be available due to the depletion of oil reserves by 2066 [2].

Therefore, using carbon-free fuels such as ammonia is being promoted as a promising solution for decarbonizing the energy, transport, and industrial sectors. Ammonia is a carbon-free carrier used as a fuel for stationary power generation and as a backbone fuel for decarbonizing the international shipping sector. Life cycle assessments (LCA) have been extensively used to evaluate the environmental impact of using ammonia as a fuel vector for private road transport [3], and some have been developed to assess the use of ammonia as a fuel vector for other purposes [4–8].

Despite previous research, no Life Cycle Assessment (LCA) study has incorporated an operational emissions profile to determine the ecological consequences of using the ammonia-ethanol blend in power generation systems. Therefore, this study aims to evaluate the environmental profile of ammonia-ethanol blend as a substitute fuel for internal combustion engines (ICE) for power generation systems.

Materials and Methods

This study is the first to offer insights into using ethanol blended with ammonia in a single-cylinder spark-ignition engine that employs direct injection. The experiments were conducted using three different fuel compositions (in mole fraction) of ethanol/ammonia: 75/25, 50/50, and 25/75. A homogeneous strategy of injection was conducted with three different indicated mean energy, 1.3, 3.5, and 5.3 kWh at 1000 rpm, corresponding to low and medium loads. The scope of this work considers a cradle-to-gate approach, and the functional unit (FU) is set as 1 kWh (Fig. 1).

This study considered green ammonia from renewable energy sources (wind, solar, and hydro) and grey ammonia from natural gas. The ammonia production processes inventory was obtained from Boero et al. [9], which considers Australia (AUS), Morocco (MR), Chile (CH), Brazil (BR), and the United Kingdom (UK) as countries with green and grey ammonia production facilities. The ethanol production processes inventory were obtained from Arcentales et al. [10] and the Ecoinvent 3.7.1 database [11] for a case study in Ecuador (ECU) and Brazil (BR), respectively. The ICE manufacturing was obtained from Ecoinvent 3.7.1 database [11]. The ammonia-ethanol blend combustion emissions values are obtained from an experimental study conducted in a single-cylinder long-stroke spark-ignition engine [12]. Global warming potential (GWP), terrestrial acidification potential (TAP), and photochemical oxidation formation potential (POFP) were assessed in this study.

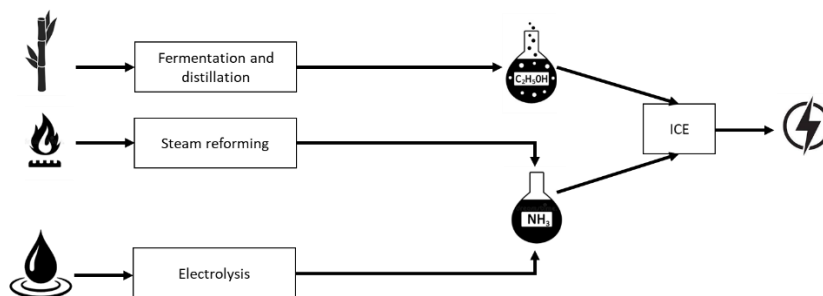


Fig. 1. System boundaries for the LCA of an ammonia-ethanol fuelled ICE for power generation (1 kWh).

Results and Discussions

The results correspond to the homogeneous ammonia/ethanol injection strategy at the lowest load. The variability in GWP results is associated with ethanol/ammonia compositions and their geographical production conditions, as seen in Table 1. The carbon footprint (GWP) of an ethanol/ammonia-based ICE fluctuates between 0.07 and 0.95 kg CO₂/kWh. The scenario using ethanol from Brazil and grey ammonia produced in the United Kingdom with a higher proportion of ammonia (75%) depicts the worst environmental performance regarding GWP impact. It is noteworthy that GWP impact is mainly affected by the ammonia production process when natural gas is used as a raw material to produce ammonia. For comparison purposes, we evaluated the GWP performance of the average electricity production mix in France, the United Kingdom, and Europe showing values of 0.079, 0.31, and 0.39 kg CO₂/kWh, respectively. This latter shows that some of our scenarios depict GWP results below the value for electricity production in the United Kingdom.

Regarding the POFP and TAP results, there is a noticeable reduction when the ammonia proportion (%) is reduced. The POFP values range between 0.032 and 0.047 kg NMVOC/kWh. The TAP values range between 0.022 and 0.069 kg SO₂/kWh.

Table 1. GWP, POFP and TAP results for different ethanol/ammonia compositions for 1.3 kWh

Scenarios	Global warming potential (kg CO ₂ /kWh)			Photochemical oxidation formation potential (kg NMVOC/kWh)			Terrestrial acidification potential (kg SO ₂ /kWh)		
	25% E - 75% A	50% E- 50% A	75% E- 25% A	25% E - 75% A	50% E- 50% A	75% E- 25% A	25% E - 75% A	50% E- 50% A	75% E- 25% A
E (ECU) - A (UK)	0.23	0.27	0.30	0.046	0.044	0.039	0.068	0.033	0.025
E (ECU) - A (CH)	0.45	0.36	0.30	0.047	0.0448	0.039	0.069	0.033	0.025
E (ECU) - A (AUS)	0.24	0.28	0.30	0.046	0.0445	0.039	0.068	0.033	0.025
E (ECU) - A (BR)	0.43	0.35	0.33	0.046	0.044	0.039	0.068	0.033	0.025
E (ECU) - A (MR)	0.39	0.28	0.30	0.047	0.044	0.0398	0.069	0.033	0.025
E (BR) - A (UK)	0.07	0.08	0.08	0.041	0.038	0.03264	0.06647	0.03052	0.02238
E (BR) - A (UK)*	0.95	0.42	0.21	0.041	0.038	0.03272	0.066	0.03	0.02242
Electricity mix, UK	0.313			0.00061			0.00077		
Electricity mix, FR	0.079			0.00022			0.00031		
Electricity mix, EUR	0.39			0.00086			0.00163		

*ammonia produced from natural gas. EUR: Europe, FR: France.

Conclusions

Various power generation systems are currently being investigated for their potential to utilize ammonia. This study aimed to assess the environmental characteristics of an ammonia-ethanol blend as a potential alternative fuel for internal combustion engines (ICEs) used in power generation systems, considering its entire life cycle. The GWP results for the lowest load (1.3 kWh) are between 0.07 and 0.95 kg CO₂/kWh. Compared to the GWP impact shown from the average electricity production in the United Kingdom, France, and Europe, some scenarios show better performance. Ethanol-ammonia blended fuel for power generating systems could be an important option to contribute to the decarbonization of the electric sector.

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