CO2 footprint and life cycle analysis of inland vessels powered with renewable technologies

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While there is a general consensus that renewable technologies such as hydrogen and battery-based solutions provide significant improvement of the CO_2 footprint for inland vessels, there are still some questions related to the overall life cycle impact of these new technologies. For example, what are the dominant factors in the overall CO_2 footprint, and more specifically, what is the contribution of the production phase in comparison to the operational phase of inland vessels? Together with the Technical University of Eindhoven, we performed a comprehensive desktop study based on available life cycle data and literature, using the *FPS Maas* as the test case. We concluded that the most dominant phase in the lifecycle of an inland vessel - with the highest CO_2 footprint - is the operational phase. We also found that the CO_2 emissions impact of the production phase of the fuel cells, batteries and hydrogen storage tanks is much smaller than the operational CO_2 footprint of the existing vessels. Thus, a combination of renewable hydrogen and PEM (Proton Exchange Membrane) fuel cells provided the lowest CO_2 footprint for the investigated case.

To provide more insight into the results, we will focus on the two main phases of the life cycle: the production phase of main components and the operational phase including fuel production. The results of the production phase in Figure 1provide a detailed view of three scenarios and are based on the CO2 footprint values shown in Table 1.

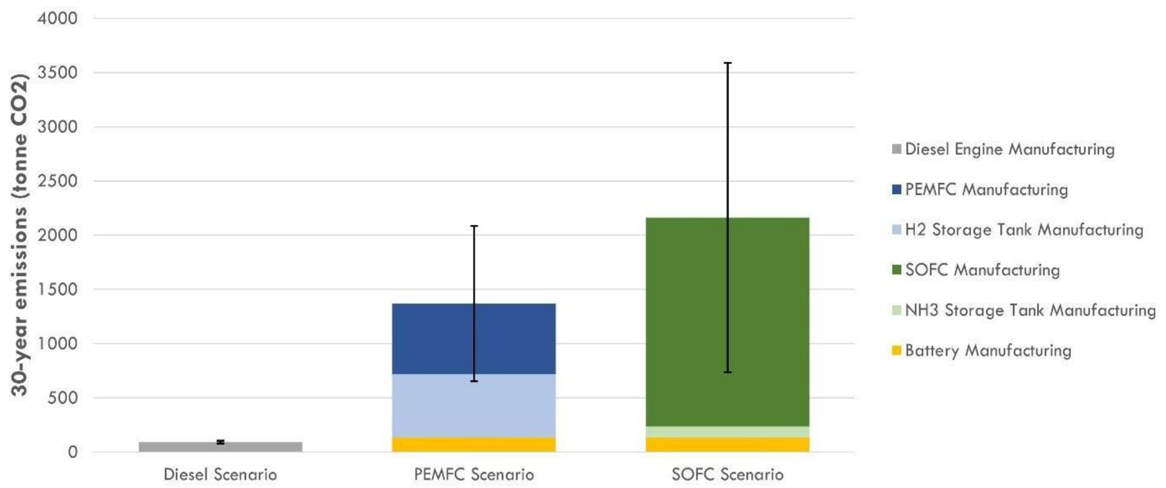

Figure 1: CO_2 footprint of the powertrain of an inland vessel based on diesel, PEM fuel cell and compressed hydrogen storage, and SOFC and ammonia storage.

The presented scenarios include manufacturing of a diesel engine versus manufacturing of the Li-Ion batteries, PEM fuel cells and compressed hydrogen storage that is based on the composite/carbon fiber tanks (Type IV), and SOFC (Solid Oxide Fuel Cells) with an ammonia storage tank. While the production of hydrogen storage is more carbon intensive than that of ammonia storage, the manufacturing of the SOFC has a somewhat higher footprint than that of the PEM fuel cells. For PEM fuel cells, the dominant factor is the CO_2 footprint associated with the platinum production, while for the SOFC, it is the quantity of material and energy required during manufacturing.

Table 1: Embodied emission of key materials and processes in manufacturing phase of the PEMFC, SOFC, H2 storage tank, NH3 tank and Li-ion batteries.

Key Material/ Process	Unit	30-Year Demand	Embodied Emissions (kg CO_2/Unit)	Source
		PEMFC		
Platinum	kg	2,6 ± 10%	21743 ± 44%	[1],[2],[3]
Nafion	kg	131 ± 64%	781 ± 6%	[1],[2]
Graphite	kg	11604 ± 48%	0,0523 ± 63%	[1],[2],[3]
Thermoset Plastic	kg	2910 ± 35%	4,0 ± 16%	[1],[2],[4]
Steel	kg	2898 ± 83%	3,0 ± 48%	[1],[2],[3]
Plant Electricity	MWh	24 ± 113%	344 ± 72%	[1],[2],[3]
		SOFC		
Electronic Components	kg	924	154	[4]
Stainless Steel	kg	15763 ± 72%	2.8 ± 59%	[1],[4],[7]
Zinc Oxide	kg	7739 ± 105%	4,6	[4],[7]
Plant Electricity	MWh	977 ± 36%	344 ± 72%	[4],[7]
		H_2 STORAGE TANK (TYPE IV)		
Carbon Fibre	kg	16620 ± 17%	33,8 ± 70%	[1],[5],[6]
HDPE	kg	7558 ± 123%	2,0	[5],[6]
Epoxy Resin	kg	7474 ± 27%	7,3 ± 8%	[5],[6]
		NH_3 STORAGE TANK (TYPE III)		
Carbon Fibre	kg	8016 ± 49%	33,8 ± 70%	[5],[8]
Aluminium	kg	9568 ± 49%	8,3 ± 13%	[2],[4],[5],[8]
Epoxy Resin	kg	5344 ± 49%	7,3 ± 8%	[5],[8]
		LI-ION BATTERY		
Cathode	kg	1512 ± 26%	-	[9],[10],[11]
Anode	kg	789 ± 21%	-	[9],[10],[11]
Process Energy	MWh	337 ± 101%	-	[10],[12]

During the manufacturing phase, the diesel engine has lower emissions than the fuel cells. But when compared for the overall lifetime and including the operational phase, the fuel cell and alternative fuel pathways offer the lowest CO_2 footprint. Figure 2 shows the comparison of CO_2 emissions for different fuels (diesel, hydrogen and ammonia) that include the technology manufacturing, fuel production and fuel consumption footprint for a 30-year operational period.

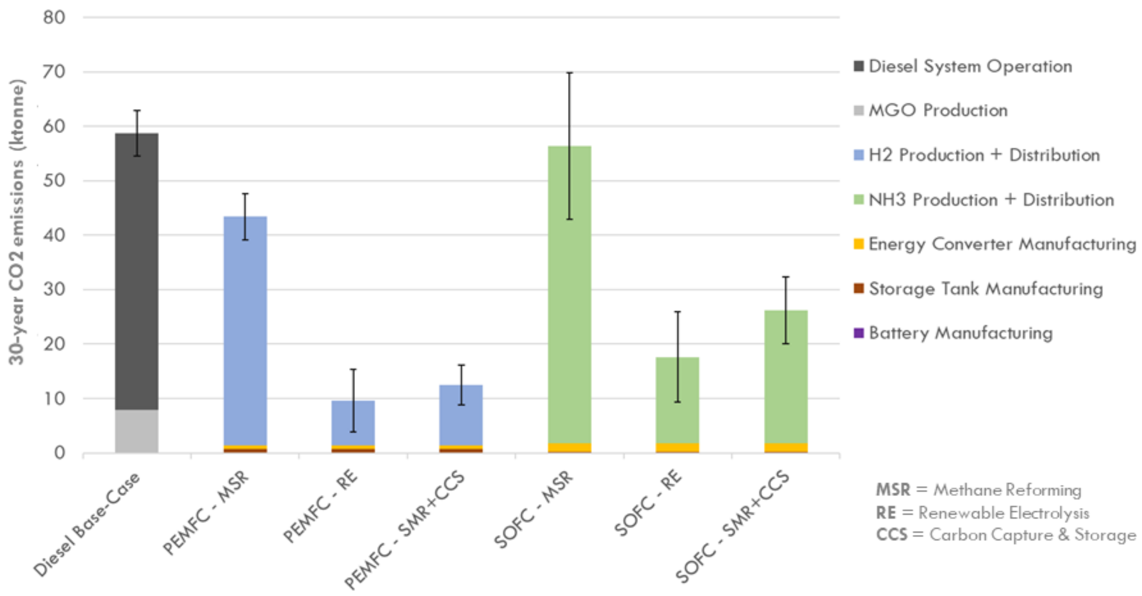

Figure 2: Comparison of CO_2 emissions of an inland vessel operating between the Netherlands and Belgium for 30 years.

The results are based on the case study of an inland container vessel that sails according to the operational profile presented in our previous paper [13]. The reference case (Diesel Base Case) results in almost 60.000 tonnes of CO_2. In the case of hydrogen produced by renewable technologies, such as wind-powered electricity, the results change drastically, and the total CO_2 emissions drop to 10.000 tonnes over the 30-year period. This low footprint is associated with the production of the infrastructure for renewable electricity and hydrogen while the operation of the vessel becomes a true zero-emission operation. Figure 1 also includes CO_2 emissions for SOFC ammonia-based solutions that inherently have higher emissions because the green ammonia production requires green hydrogen.

To conclude, due to the long operational life and the high number of annual working hours, the operational phase is the dominant contributor to CO_2 emissions for a typical inland vessel. The production of hydrogen based on renewable technologies remains a must-have, and in combination with PEM fuel cells, it provides a solution with the least negative environmental impact out of the pathways considered.

Please note that we are preparing a publication to be submitted to a relevant journal where additional aspects will be presented. The list of references used, and a detailed explanation of the methodology can be found in the graduation work of Vince Evers [14].

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