Hydrogen-based cold ironing systems: ship emissions reduction and energy efficiency analysis for the Port of Trieste

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Introduction

The increasing volume of global maritime traffic has brought significant environmental challenges, particularly in relation to particulate and green-house gases emission caused by ships when at port, due to the burning of fossil fuels in their engines [1]. Owing to emission regulations, ships are sometimes restricted or even prohibited to use traditional fuels when in port [2]. Hydrogen-based cold ironing could be an effective approach for reducing emissions, providing electrical power to berthed ships using hydrogen as the primary energy source and fuel cells for its conversion in electrical energy. However, the current hydrogen supply chain is in its early stages of development, leading to limited hydrogen availability in port areas. To tackle hydrogen distribution challenges, the use of standardized containers could be a feasible logistic solution. For this reason, in this work authors decided to consider a cold ironing system composed of a swapping pre-filled LH_2 tank container that can be used as an energy storage for feeding a Polymer Electrolyte Membrane Fuel Cell (PEMFC) generator. The author's awareness is that LH_2 containers could kick-start a supply chain without a fully developed hydrogen infrastructure and regulatory framework to be in place [3]. This work assesses the energy efficiency of a hydrogen-based cold ironing system and evaluates its impact on emission reduction for ships at berth. Additionally, a preliminary economic analysis regarding system cost and pay-back time is presented.

Methodology

In this work, the Port of Trieste case study is considered. The evaluation of the number of ship calls, the types of ships involved, the busiest berth areas, and the time ships spend at berth has been elaborated from the data in [4]. For each type of ship, emissions have been calculated using vessels emissions and fuel consumption data [5]. This allows to identify the quays with major pollutant emissions and those that can benefit most from cold ironing systems. Subsequently, the power demand and energy requirements for cold ironing are evaluated for each considered mooring area, taking into account the hoteling power required for each type of ship and their time spent at berth. These data allow to size the LH_2 storage tank and the fuel cell system. The evaluation of the fuel cell system performance is based on previous experimental data collected by the authors [6]. Emission reduction potential is subsequently evaluated by comparing the ship's emissions at berth with those of conventional grid-connected and hydrogen-based cold ironing systems, taking into account different hydrogen sources. Furthermore, by means of a literature analysis, the costs for grid-connected onshore power supply are evaluated and compared.

Case study definition

The Port of Trieste, located in northeaster Italy, is one of the most important ports in the Adriatic Sea and serves as a significant gateway for trade and passenger traffic. The port is composed of several berthing areas, and in the 2019, approximately 2,100 ship calls were documented. On average, eight ships are berthed simultaneously throughout the year, with the highest recorded peak being 22 ships occupying various mooring areas of the port. Figure 1 shows the ship calls divided by ship type [4]. It is possible to observe as Ro-Ro cargo, Full container and Liquid bulk ships account for the majority of the calls.

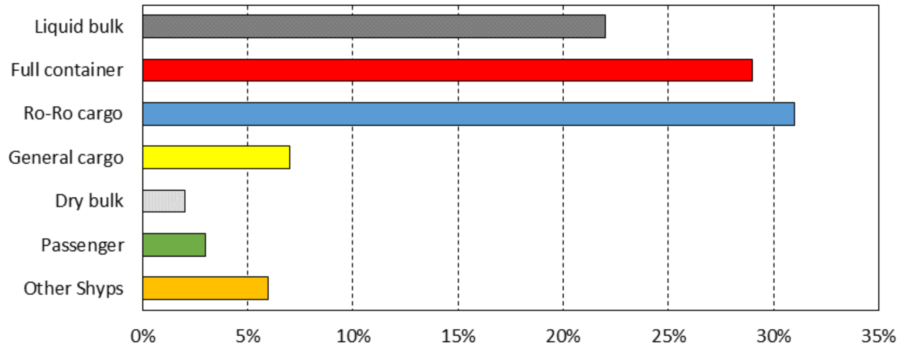

Figure 1. Distribution of ship calls by ship type for the Port of Trieste: year 2019. Elaborated from [4].

Zero emission cold ironing system

In Figure *2*, a schematic representation of the hydrogen-based cold ironing infrastructure is shown. In order to convert the chemical energy of hydrogen into electrical energy, PEMFC generators have been chosen as they allow high energy conversion efficiencies with zero local emissions. Conventional PEMFCs are typically fed with gaseous hydrogen at ambient temperature. However, since LH_2 is stored at approximately 20 K (Figure *2*a), a vaporizer system is required to convert the liquid hydrogen into gaseous form before it can be used in the fuel cell.

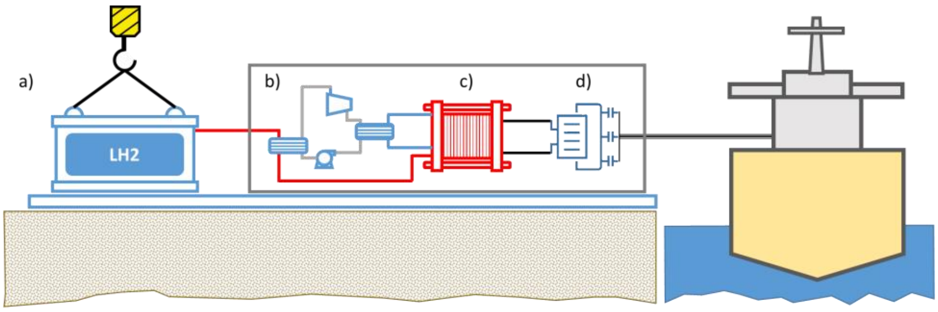

Figure 2. Simplified schematic of the considered system: a) LH_2 storage system container, b) Cold energy recovery/vaporizer system, c) PEMFC generator d) Power converter.

As for Liquid Natural Gas (LNG), regasification of LH_2 can be accomplished by means of sea water heat exchangers or air heat exchangers. However, due to the significant temperature difference between LH_2 and PEMFC cooling water, a cold energy recovery system can be integrated for both increasing the overall electrical efficiency and allowing the LH_2 to evaporate [7]. In this study, the considered cold energy recovery system chosen is an Organic Rankine Cycle. The obtained gaseous hydrogen is then processed by the PEMFC generator (Figure 2c) and the produced electrical current is transformed in alternate current (Figure 2d) before being supplied to the berthed ship.

Preliminary results

The survey performed on the port of Trieste reveals as Bulk Ships account for about one third of the total ships dock time, followed by Ro-Ro Cargo ships, Container and General Cargo ships. The energy analysis shows that the proposed power system allows for higher or comparable energy conversion efficiencies respect to on-board auxiliary internal combustion engines. Furthermore, the overall system efficiency can be still improved if more sophisticated cold energy recovery plants are considered. As expected, the emission analysis indicate that hydrogen-based cold ironing substantially reduce emission when ships are hoteling however hydrogen and system cost still hamper the diffusion of this technology.

Acknowledgements

Authors acknowledge the financial support from the project sHYpS (sustainable HYdrogen powered Shipping, Horizon Europe call Horizon-CL5-2021-D5-01).

References

[1] Barberi, S.; Sambito, M.; Neduzha, L.; Severino, A.,"Pollutant Emissions in Ports: A Comprehensive Review", Infrastructures, 2021, Vol. 6, pag.114.
[2] IMO, "International Convention for the Prevention of Pollution from Ships (MARPOL)".
[3] "sHYpS: Sustainable HYdrogen powered Shipping", Horizon Europe call Horizon-CL5-2021-D5-01, website link: https://www.shyps.eu/.
[4] Autorità di Sistema Portuale del Mare Adriatico Orientale Porti di Trieste e Monfalcone "Documento di Pianificazione Energetico Ambientale del Sistema Portuale", 24/11/2021.
[5] United States Environmental Protection Agency "Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data", EPA420-R-00-002, 2000;
[6] A.Pietra, M.Gianni, N.Zuliani, S.Malabotti, R.Taccani," Experimental characterization of a PEM fuel cell for marine power generation", EFC21, E3S Web of Conferences 334, 05002 (2022).
[7] Lenger, M., Heinke, S., Tegethoff, W. et al. Synergies of fuel cell system thermal management and cryogenic hydrogen exergy utilization. Sci Rep 12, 22065 (2022).