NAUTILUS

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This deliverable has been submitted to the European Commission and is currently under review.

The final version after the approval may differ.

This project has received funding from the European Union's Horizon 2020
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NAUTILUS

D7.4 – LCA final report
Life Cycle Assessment report of the final genset

Project Acronym:	Nautilus
Project Title:	Nautical Integrated Hybrid Energy System for Long-haul Cruise Ships
Project coordinator:	Dr. Asif Ansar, Deutsches Zentrum für Luft – und Raumfahrt (DLR)
Programme:	Horizon 2020 Framework Programme
Topic:	LC-MG-1-8-2019 Retrofit Solutions and Next Generation Propulsion for Waterborne Transport
Instrument:	Research & Innovation Action (RIA)

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Deliverable D7.4 – LCA final report Life Cycle Assessment report of the final genset

Short summary: This deliverable is part of the EU project Nautilus - Nautical Integrated Hybrid Energy System for Longhaul Cruise Ships and is prepared within the framework of WP7. In this final LCA report, a life cycle assessment was performed to evaluate the overall environmental impacts of an integrated marine energy and propulsion system based on SOFC-Battery hybrid gensets.

For comparison against ICE diesel (NO_x tier II) and ICE HFO in acidification, eutrophication (marine and terrestrial) and photochemical ozone formation, the 90% reduction in pollutants is possible for almost all fuels. Only conventionally produced ammonia and hydrogen fall slightly over the threshold, ammonia in more categories than hydrogen. In the other impact categories where SO_x, NO_x and PM emissions are relevant, namely freshwater eutrophication, all but one of the studied SOFC fuels fail to have a positive impact compared to ICE diesel (NO_x tier II). LNG has potentially lower impact in this category, but the 99% reduction is not met.

When the pollutant comparison (SO_x, NO_x and PM) is done between SOFC and ICE diesel (NO_x tier III) or ICE LNG, the reduction potential is significantly lower. Against diesel (NO_x tier III), the best SOFC options seem to be green hydrogen, bio-methanol and green ammonia. Green hydrogen is potentially the best option of the three in most of the studied impact categories. ICE LNG has the lowest impacts of all reference ICE technologies in all studied impact categories. The reduction potential of SOFC with different fuels is approximately the same as when compared to the NO_x tier III diesel.

For the GHGs, only green ammonia, green hydrogen and bio-methanol can achieve the 50% reduction in emissions when compared to the ICE references.

The fuel conversion emissions of this assessment were modelled using only literature data as there was no data available from the actual emission measurements of the project. The used emission factors are not specific for the actual SOFC system of Nautilus project but act as benchmarks. The ICE reference system was modelled using literature, cruise simulation and load dependent emissions and is quite close to state-of-the-art. Some uncertainties are related to engine type. Therefore, these results can only be seen as indicative for SOFC systems. In the future, experimental data would need to be collect using much more sophisticated emission analyzers and including cold starts and part load.

Due date: 31/12/2023
WP, leader: [WP 7, TUD]
Authors: Lotta Hepo-oja, (VTT)

Dissemination Level		
PU	Public	☐
PP	Restricted to other programme participants (including the Commission Services)	☐

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RE	Restricted to a group specified by the consortium (including the Commission Services)	☐
CO	Confidential, only for members of the consortium (including the Commission Services)	☒

Document history

Version	Date	Name	Chapters edited	Reason for change
V0.1	26/05/23	Lotta Hepo-oja	All	Draft created
V.1.0	1/12/23	Lotta Hepo-oja	All	1st version for WP leader check
V.1.1	14/12/2023	Lotta Hepo-oja	All	Revision based on WP comments
V.1.2	20/12/2023	Lotta Hepo-oja	All	2nd revision including updated emission factors
V.1.3	22.12.2023	Lotta Hepo-oja	3, 4, 5	Final revision before submission

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List of participants		
Participant No	**Participant organisation name**	**Country**
1 Coordinator	Deutsches Zentrum für Luft –und Raumfahrt (DLR)	DE
2	Chantiers de l'Atlantique (CdA)	FR
3	Carnival Maritime GmbH (CM)	DE
4	Ecole Polytechnique Fédérale de Lausanne (EPFL)	CH
5	GRANT Garant (GG)	CZ
6	Lloyd's Register EMEA (LR)	UK/DE
7	MAN Energy Solutions (MAN)	DE
8	Meyer Werft PAPENBURG (MW)	DE
9	Rijksuniversiteit Groningen (RUG)	NL
10	Rheinisch-Westfälische Technische Hochschule Aachen (RWTH)	DE
11	SolydEra SPA (SE_SPA)*	IT
12	Technische Universiteit Delft (TUD)	NL
13	Lunds Universitet (ULUND)	SE
14	Teknologian tutkimuskeskus VTT (VTT)	FI
15	SolydEra SA (SE_SA)*	CH

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1 Introduction

This public deliverable is part of the EU project “Nautilus - Nautical Integrated Hybrid Energy System for Long-haul Cruise Ships” and was prepared according to the framework of WP7-Technology impact analysis. The project aim is to develop, evaluate and validate a highly efficient and dynamic integrated marine energy system. This energy system, responsible to cater for all heat & power needs of a vessel, consists of a modular Solid Oxide Fuel Cell (SOFC)-battery hybrid genset with coupling with the existing Internal Combustion Engine (ICE) based generators and gradually replacing these ICEs. The project will develop and deliver a complete process design and digital demonstrator of a fully integrated on-board energy system for two types of cruise ships: 1000 and 5000+ passenger vessels, sized 5 MW and 60MW. A small physical demonstrator for a 60kW system is also developed.

Life cycle assessment (LCA) is carried out to evaluate the overall environmental impacts of an integrated marine energy and propulsion system based on SOFC-Battery hybrid gensets using LNG as a fuel. In addition, potential other future fuels were also assessed. The methodology is based on the ISO 14040 and 14044 standards for LCA. The assessment covers the emissions from well to tank (emissions derived from the fuel acquisition, including extraction, upgrading and transportation) and tank to propeller (emissions derived from the use of the fuel, i.e. exhaust gases).

The impacts are compared to the current solutions, i.e. use of ICE technology. The needed life cycle inventory (LCI) data is combined from collected primary data on processes from project partners and from secondary data on from LCI databases. It is expected that the SOFC-battery hybrid genset has a clear potential to comply with the emission regulation of IMO. 50% lower greenhouse gases (GHGs) and 99% lower pollutants (SO_x, NO_x and PM) are targeted to be achieved, compared to the commonly used fuels. The production emissions of the equipment i.e. gensets and fuel storage tanks are not considered as their design is still ongoing within the project. In this deliverable, impacts on climate, air quality, water systems and resource availability are considered.

Since this is the final LCA done on the project, the results are final and intended only to project internal usage: the results provide information for project partners to support decision-making and to see where the environmentally potential risks may be in the system. As there was no data from the demonstrator, this deliverable is considered an update to the screening LCA deliverable. New emission factors have been added as well as new impact categories.

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