CHEK

Decarbonising Shipping

Grant Agreement number	Project acronym
955286	**CHEK**

Project full title

deCarbonising sHipping by Enabling Key technology symbiosis on real vessel concept designs

D8.3
Cost comparison for the fuel options

Funded by the European Union

Document Identification

Status	Final
Version	1.0
Related WP	WP8
Related Deliverable(s)	D8.1, D8.2, D1.3
Lead Partner	Lloyd's Register EMEA (LR)
Contributors	Lloyd's Register EMEA (LR)
Due Date	31st December 2021
Submission Date	30.12.2021
Document Reference	D8.3
Dissemination Level	Public
Document Type	Report
Lead Author	Yildiz Williams (LR)
Reviewers	Kenneth Widell (Wartsila)
	Andrea Crosetti (MSC)

Legal Disclaimer
The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

Document Identification

List of Contributors

Name and surname	Beneficiary short name
Yildiz Williams	LR
Chris Hughes	LR

Revision History

Version	Date	Change editors	Changes
0.1	18.11.2021	Yildiz Williams	Initial structure and ToC created.
0.2	14.12.2021	Yildiz Williams Chris Hughes	All main sections completed, and draught version submitted to CHEK Internal reviewers.
1.0	20.12.2021	Yildiz Williams	Comments from internal reviewers are incorporated and final version submitted.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

Contents

List of Figures

List of Tables

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

Acronyms and abbreviations

Acronym or abbreviation	Description
$	United States Dollars
Bio-LNG	A biofuel made by processing organic waste flows, such as organic household and industrial waste, manure, and sewage sludge.
BTU	British thermal unit lower heating value
Capex	Capital expenditure
CCS	Carbon capture and storage
CH_4	Methane
CHEK	deCarbonising sHipping by Enabling Key technology symbiosis on real vessel concept designs
CISA	Cargill International SA
CO_2	Carbon dioxide
DAC	Direct air capture is a process of capturing carbon dioxide directly from the ambient air and generating a concentrated stream of CO_2 for sequestration or utilisation
DG CLIMA	Directorate-General for Climate Action
DG MOVE	Directorate-General for Mobility and Transport
EC	European Commission
E-fuel (electro fuels)	Fuels produced from renewable electricity
EU	European Union
FPV	Future Proof Vessel
GHG	Greenhouse gas
GJ	Giga Joule
H_2	Hydrogen
IMO	International Maritime Organization

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

LSHFO	Low Sulphur Heavy Fuel Oil
kg	Kilogram
kWh	Kilowatt-hour
LCP	Levelised cost of production
LNG	Liquefied natural gas
LR	Lloyd’s Register EMEA
m	metres
MEPC	IMO’s Marine Environment Protection Committee
MSC	MSC Cruises
NG	Natural gas
SMR	Steam methane reformer is the technology for hydrogen production from natural gas
UMAS	University Maritime Advisory Services
WMU	World Maritime University
WP	Work Package
yr	year

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors’ view and the European Commission is not responsible for any use that may be made of the information it contains.

Executive Summary

CHEK proposes to reach zero emission shipping by disrupting the way ships are designed and operated today. The project will develop and demonstrate two bespoke vessel designs – a wind energy optimised bulk carrier and a hydrogen powered cruise ship – equipped with an interdisciplinary combination of innovative technologies working in symbiosis to reduce greenhouse gas emissions by 99%, achieve at least 50% energy savings and reduce black carbon emissions by over 95%. Rather than "stacking" novel technologies onto existing vessel designs, the consortium is proposing to develop a unique Future-Proof Vessel (FPV) Design Platform to ensure maximised symbiosis between the novel technologies proposed and taking into consideration the vessels' real operational profiles (rather than just sea-trial performance). The FPV Platform will also serve as a basis for replicating the CHEK approach towards other vessel types such as tankers, container ships, general cargo ships and ferries. These jointly cover over 93% of the global shipping tonnage and are responsible for 85% of global GHG emissions from shipping.

This report provides a cost comparison for the fuel options considered for bulk carrier and cruise ship in specific to the titled project. It constitutes project deliverable D8.3, and is part of T8.2, Reference [1].

Bulk carrier will operate on LNG fuel, together with diesel/gas oil or biofuel as pilot fuel. Cruise ship will operate on LNG and/or hydrogen, together with diesel/gas oil or biofuel as pilot fuel. The source/type of LNG and hydrogen do not impact the ship design however it does have an impact on LCP.

Levelised cost of fuel production measures lifetime costs over its total energy production. Therefore, fuel price projections over lifetime of a production plant are important part of this work. In this report, we made some assumptions for fuel price projections and these values are provided below. For e-fuels (electro fuels - fuels produced from renewable electricity), we looked at their potential supply pathways and estimated the LCP over time, which is used as proxy for fuel prices, Reference [3]. Based on this, LCP had been identified for LNG and hydrogen fuels from various sources, see below Table 1. The results may be revisited on a later stage of the study considering the long project timeline.

Table 1: Levelised cost of production

Fuel	**LCP Lower bound $/GJ**				**LCP Upper bound $/GJ**			
	2020	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
E-hydrogen (pathway 1)	52	44	36	28	92	79	65	52
NG-hydrogen (pathway 2)	25	23	21	19	44	40	37	34
E-LNG (pathway 1)	69	60	51	42	113	98	84	69
Bio-LNG	24	27	29	33	27	54	81	108

Notes:
Two different pathways are assumed to produce hydrogen, pathway 1 (E-hydrogen) uses the electrolysis of water using renewable electricity; and pathway 2 (NG-hydrogen) uses the steam methane reforming with carbon capture and storage (SMR & CCS).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

Bio-LNG is a biofuel made by processing organic waste flows, such as organic household and industrial waste, manure, and sewage sludge. When anaerobic digestion of organic waste occurs, methane (CH_4) and carbon dioxide (CO_2) are emitted in the process.

The synthesis of LNG requires a liquefaction process, compressed hydrogen from hydrogen production pathway 1 (E-LNG), following methanation process and a chemical reaction aided by a catalyser at high temperatures, turns the carbon dioxide and carbon monoxide into methane, the main component of natural gas.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

1. Introduction

CHEK proposes to reach zero emission shipping by disrupting the way ships are designed and operated today. The project will develop and demonstrate two bespoke vessel designs – a wind energy optimised bulk carrier and a hydrogen powered cruise ship – equipped with an interdisciplinary combination of innovative technologies working in symbiosis to reduce greenhouse gas emissions by 99%, achieve at least 50% energy savings and reduce black carbon emissions by over 95%. Rather than "stacking" novel technologies onto existing vessel designs, the consortium is proposing to develop a unique Future-Proof Vessel (FPV) Design Platform to ensure maximised symbiosis between the novel technologies proposed and taking into consideration the vessels' real operational profiles (rather than just sea-trial performance). The FPV Platform will also serve as a basis for replicating the CHEK approach towards other vessel types such as tankers, container ships, general cargo ships and ferries. These jointly cover over 93% of the global shipping tonnage and are responsible for 85% of global GHG emissions from shipping.

In order to achieve real-world impact and the decarbonisation of the global shipping fleet, the consortium will undertake an analysis of framework conditions influencing long-distance shipping today (including infrastructure availability) and propose solutions to ensure the proposed vessel designs can and will be deployed in reality. A Foresight Exercise will simulate the deployment of the CHEK innovations on the global shipping fleet with the aim of reaching the IMO's goal of halving shipping emissions by 2050 and contributing to turning Europe into the first carbon-neutral continent by 2050 (as stipulated by the European Green Deal). A tailored communication and dissemination strategy led by the IMO-founded partner WMU will ensure appropriate involvement of stakeholders (e.g. MEPC, DG CLIMA, DG MOVE), including the engagement of the general public.

CHEK project has a list of beneficiaries and Lloyd's Register (LR) is one of these partners proudly working on a number of deliverables including this one. Other partners are listed below:

- University of Vaasa,
- Wartsila,
- Cargill International SA,
- MSC Cruises SA,
- World Maritime University,
- Silverstream Technologies UK Ltd,
- Hasytec Electronics GMBH,
- Deltamarine OY,
- Climeon AB, and
- BA Technologies Ltd.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

2. Background

This report provides a cost comparison for the fuel options considered for bulk carrier and cruise ship in specific to the titled project. It constitutes project deliverable D8.3, and is part of T8.2, Reference [1] descriptions of work are as follows:

D8.3: Document the estimates of supply costs of the fuel options considered in the project, and the relevant timescales (2030, 2050), including comparisons. The costs will be used as input to other tasks within the project. If successful this will not only provide the cost assumptions to be used in the project, but will also provide clear description and understanding of the methodology/sources used to obtain the costs to enable comparison, and review in the future. Refers to task: T8.2.

T8.2: Mapping and assessment of existing long-distance shipping infrastructure
Based on the operational profiles of the two vessel concepts elaborated in T1.1 (historical profile) and T1.2 (future profile) the infrastructure needs based on the CHEK technologies to be developed will be mapped. The exercise will focus mainly on the types of fuel (bio/synthetic LNG and hydrogen), port interfaces (including any air draft issues related to the fixed wing sails) and weather conditions along the envisaged routes (particularly relevant for wing sail, but also gate rudder). Any infrastructure gaps identified will be summarized in a report to be disseminated as part of WP10 (including recommendations in light of the EU Directive 2014/94/EU on the deployment of alternative fuels infrastructure). Levelised cost of production (LCP) comparisons of the different fuel options for the Kamsarmax bulker and the Meraviglia class cruise will be prepared.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

3. Fuel options

In this Section, types of fuels used on board both bulk carrier and cruise ship designs are briefly provided. Further details on fuel options have already been covered in D1.3, Reference [2].

3.1. Bulk carrier

The new design will operate on LNG fuel, together with diesel/gas oil or biofuel as pilot fuel. The pilot fuel consumptions and specifications will be determined by the engine characteristics (yet to be finalised), however it is not expected that this will vary significantly from current engine designs, and this does not have a significant impact on the ship design.

The source/type of LNG does not impact the ship design however it does have an impact on LCP.

3.2. Cruise ship

The new design will operate on LNG and/or hydrogen, together with diesel/gas oil or biofuel as pilot fuel. The fuel consumptions and specifications will be determined by the engine characteristics.

The source/type of LNG and hydrogen do not impact the ship design however it does have an impact on LCP.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

4. Levelised cost of production

4.1 Method used

Levelised cost of fuel production measures lifetime costs over its total energy production. We made some assumptions for fuel price projections based on Reference [3] and the values are provided in this report.

For e-fuels and NG-fuels, we looked at their potential supply pathways and estimated the LCP over time, which is used as proxy for fuel prices.

The price projections of other fuels have been estimated and they are distinguished as bio-LNG, e-fuels (electro fuels - fuels produced from renewable electricity) and NG with CCS-derived fuels (NG-hydrogen).

The renewable electricity price (Table 2) and natural gas projections (Table 3) are also provided in here and are used to estimate the LCP projections of all fuels in this report. The LCP is used as a proxy of future fuel price projections.

The underlying assumptions of these estimates (including the cost assumptions of key technologies such as CCS, DAC and electrolyser) as well as the biofuel price projections are based on Reference [3]. Other assumptions including assumed fuel emissions factors, fuel densities, and onboard technology costs are also based on Reference [3].

Renewable electricity price projections are derived from the IRENA 2017 Power Costs Study Reference [4]. Upper and lower cases are assumed to linearly decrease, as described in Table 2 below.

Table 2: Assumed renewable electricity prices.

Description	Unit	2020	2030	2040	2050
Upper case	$/kWh	0.100	0.083	0.066	0.050
Lower case	$/kWh	0.050	0.040	0.030	0.020

The assumptions on natural gas price projections are provided below in Table 3 and were derived from World Bank and IEA 2016, Reference [5].

Table 3: Assumed natural gas prices.

Description	Unit	2020	2030	2040	2050
Upper case	$/kWh	41	41	41	41
Lower case	$/kWh	17	17	17	17

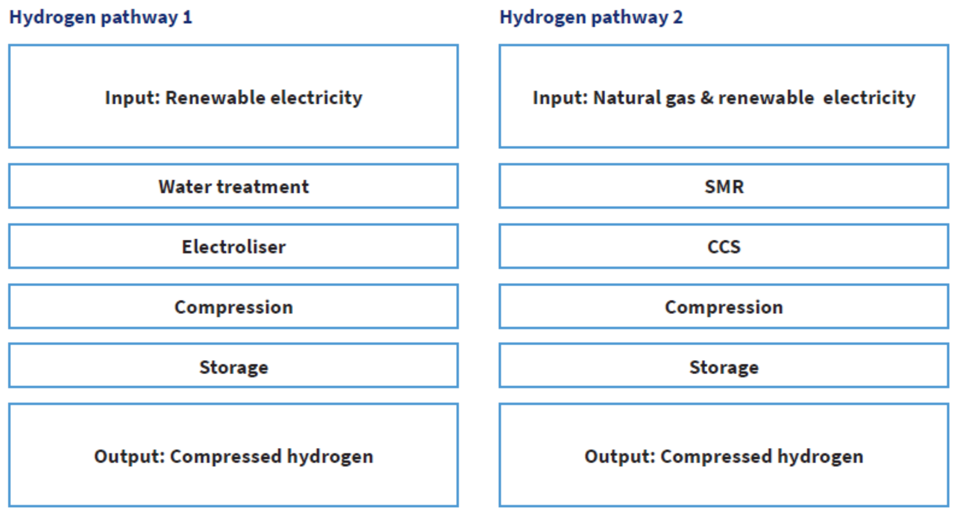
It should be noted that the LCP in this report is based on global fuel price projection therefore the gap between the upper and lower cases are wide. If the fuel price projection is more focused on a specific region, the gap between the upper and lower cases would be smaller therefore the LCP results may be more accurate, Reference [6].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

4.2 Hydrogen

Two different pathways are assumed to produce hydrogen, as shown in Figure 1. The first pathway uses the electrolysis of water using renewable electricity; and the second pathway uses the steam methane reforming with carbon capture and storage (SMR & CCS).

Figure 1: Hydrogen pathway diagram



Assumptions were made for the hydrogen production plant, as provided in Table 4 below. It is assumed that the capacity of all liquefaction plants is at a constant, large centralised production-level scale. Decentralised smaller liquefaction and storage plant would have increased costs due to smaller scale infrastructure.

Table 4: Hydrogen production plant assumptions.

Hydrogen plant assumptions	**Unit**	**Value**
Availability	%	90%
Utilisation rate	%	80%
Annual production	tonne/yr	360,000
Days active	days	292
Daily production	tonne/day	1,233
Plant capacity	tonne/yr	500,000

The interest rate is assumed constant at 10%. Other indirect costs include local taxes equal to 3% of annual capex and insurance equal to 1% of annual capex. The detailed assumptions for each component for both pathways are provided in Tables 5 and 6.

Table 5: Detailed assumptions for hydrogen pathway 1.

Hydrogen pathway 1 (renewable electricity)	**2020**	**2030**	**2040**	**2050**
Water treatment				
Capital costs ($\$/m^3$)	2.6314	2.6314	2.6314	2.6314
Operational costs (% of capex)	4.3%	4.3%	4.3%	4.3%
Efficiency (%)	45%	45%	45%	45%
Energy requirement (kWh/m^3)	3	3	3	3
Lifetime (year)	30	30	30	30
Electrolysers				

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

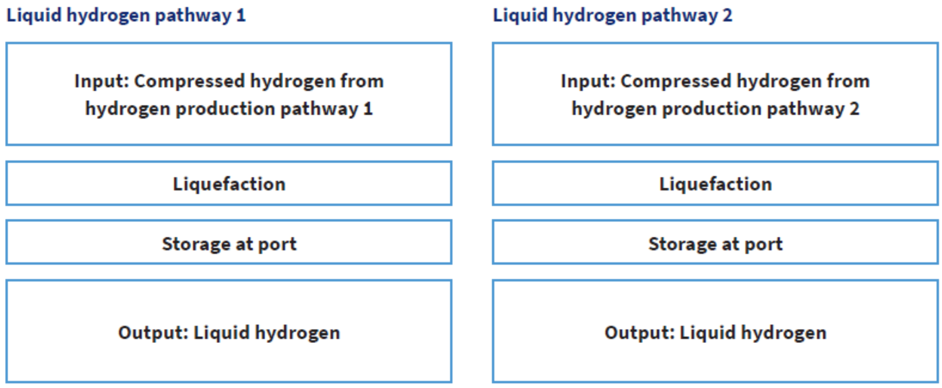
Capital costs ($/kWe)	472	472	472	472
Operational costs (% of capex)	3%	3%	3%	3%
Efficiency (%)	0.7	0.7	0.7	0.7
Energy requirement (kWh/kg)	56	56	56	56
Lifetime (year)	10.7	10.7	10.7	10.7
Operating hours	75,000	75,000	75,000	75,000
Compression				
Capital costs ($/kg)	0.965	0.965	0.965	0.965
Operational costs (% of capex)	3%	3%	3%	3%
Efficiency (%)	94%	94%	94%	94%
Energy requirement (kWh/kg)	2.85	2.85	2.85	2.85
Storage				
Capital costs ($/kWh)	0.02	0.02	0.02	0.02
Operational costs (% of capex)	3%	3%	3%	3%

Table 6: Detailed assumptions for hydrogen pathway 2.

Hydrogen pathway 2 (SMR&CCS)	**2020**	**2030**	**2040**	**2050**
Steam methane reforming				
Capital costs ($/kgH$_2$)	2.10	2.10	2.10	2.10
Operational costs (% of capex)	4.3%	4.3%	4.3%	4.3%
Electricity requirement (kWh / kg H$_2$)	8	8	8	8
NG consumption (million BTU NG / kg H$_2$)	0.165	0.165	0.165	0.165
Efficiency (%)	72%	72%	72%	72%
Compression				
Capital costs ($/kg)	0.965	0.965	0.965	0.965
Operational costs (% of capex)	3%	3%	3%	3%
Efficiency (%)	94%	94%	94%	94%
Energy requirement (kWh/kg)	2.85	2.85	2.85	2.85
Storage				
Capital costs ($/kWh)	0.02	0.02	0.02	0.02
Operational costs (% of capex)	3%	3%	3%	3%

Liquid hydrogen is assumed to be used on board ships, therefore the LCP is estimated for liquid hydrogen. This means that compressed hydrogen from both hydrogen production pathways is liquified and stored at bunkering ports. Figure 2 provides the schematic representation of the pathways; Table 7 provides the detailed assumptions as well as the resulting LCP under the upper and lower cases.

Figure 2: Liquid hydrogen pathway diagram.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

Table 7: Detailed pathway assumptions for liquid hydrogen.

Liquid hydrogen pathway	**2020**	**2030**	**2040**	**2050**
Liquefaction				
Capital costs ($/kg$H_2$)	0.94	0.94	0.94	0.94
Operational costs (% of capex)	5%	5%	5%	5%
Electricity requirement (kWh/kgH_2)	10.18	10.18	10.18	10.18
Efficiency (%)	77%	77%	77%	77%
Liquid storage at port and dispensing				
Capital costs ($/kg$H_2$)	18	18	18	18
Operational costs (% of capex)	5%	5%	5%	5%
Energy requirement (% boil off per day)	0.1	0.1	0.1	0.1
LCP pathway 1				
Upper case ($/GJ)	92.0	78.7	65.3	52.0
Lower case ($/GJ)	52.0	44.0	36.0	28.0
LCP pathway 2				
Upper case ($/GJ)	44.4	40.4	37.0	33.6
Lower case ($/GJ)	25.4	22.9	20.8	18.8

4.3 LNG

The synthesis of LNG requires a liquefaction process, as illustrated below in Figure 3. Compressed hydrogen from hydrogen production pathway 1, following methanation process and a chemical reaction aided by a catalyser at high temperatures, turns the carbon dioxide and carbon monoxide into methane, the main component of natural gas. After a final cleaning step, it can be used in the same way, transported and stored in the same containers and grids or used to directly power gas engines. This process results to product called e-LNG or synthetic LNG.

Figure 3: Synthetic LNG pathway diagram.

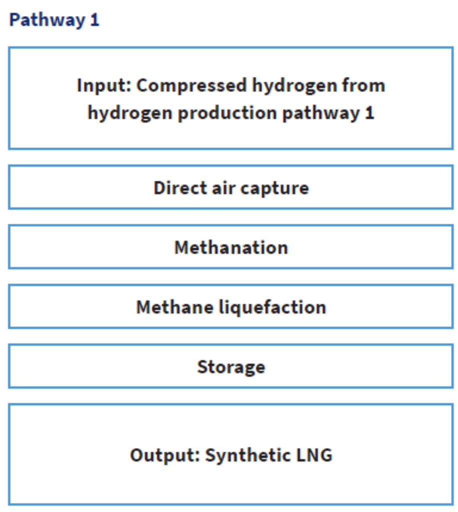


Table 8: Synthetic LNG plant assumptions.

Synthetic methane plant assumptions	Unit	Value
Hydrogen to methane ratio	kg CH_4 / kg H_2	1.990
Hydrogen to CO_2 ratio	kg CO_2 / kg H_2	7.261
Annual production of methane	tonne/yr	715,099
Annual production of CO_2	tonne/yr	1,960,841
Daily methane production	tonne/day	2,453

Table 9: Detailed pathway assumptions for synthetic LNG.

Synthetic LNG pathway	2020	2030	2040	2050
Carbon capture				
Capital costs (\$/kg CO_2)	1.50	1.50	1.50	1.50
Operational costs (% of capex)	4%	4%	4%	4%
Electricity requirement (kWh/kg CO_2)	2.631	2.631	2.631	2.631
Methanation				
Capital costs (\$/kW)	300	300	300	300
Operational costs (% of capex)	2%	2%	2%	2%
Efficiency (%)	78%	78%	78%	78%
Energy requirement (kW/kg)	0.299	0.299	0.299	0.299
Energy density (kWh/kg)	15.3	15.3	15.3	15.3
Liquefaction				
Capital costs (\$/kg)	0.85	0.85	0.85	0.85
Operational costs (% of capex)	2%	2%	2%	2%
Efficiency (%)	77%	77%	77%	77%
Storage				
Capital costs (\$/kg)	0.50	0.50	0.50	0.50
Operational costs (% of capex)	2%	2%	2%	2%
LCP pathway 1				
Upper case (\$/GJ)	113.4	98.5	83.5	68.6
Lower case (\$/GJ)	68.6	59.7	50.7	41.8

Bio-LNG is a biofuel made by processing organic waste flows, such as organic household and industrial waste, manure, and sewage sludge. When anaerobic digestion of organic waste occurs, methane (CH_4) and carbon dioxide (CO_2) are emitted in the process.

Marine biofuels fuel price projections are uncertain and current literature is poor. The approach of calculating LCP and use it as proxy of future fuel prices (as applied for the other fuels) is not appropriated for biofuels because it does not take into account the supply constraint on bioenergy. The supply/demand balance for these fuels implies that growth in demand for bioenergy could get the supply to its limit and therefore a significant increase in price.

It is difficult to assume that biofuels prices will decrease in the future. The consensus mirrors what was said in SCAB (2017) report, Reference [7], stating that biofuels (with some rare exceptions) will remain more expensive than fossil fuels in almost all cases.

The report by IRENA, Reference [4], provides evidence of potential decrease of costs of production but it does not factor any elements on bioenergy supply constraint or future competition among different sectors. For this reason, it cannot be considered a reliable source of data for this analysis.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

The approach taken in this analysis uses the averages of the current estimates of costs of production from existing studies; the range found for each fuel is used as starting point in 2020 for the upper and lower bounds.

To identify the lower bound up to 2050 (upper scenario), a first guess was made assuming prices will increase of 0.5% every year, in line with current literature describing how each biofuel price may change in the future due to future availability as well as due to the future feedstock and fuel competition with other sectors. Then, we overlaid to the estimated biofuel prices, the potential cost of substitution (as opposed to the cost of production). The cost of substitution is estimated as the LSHFO (Low Sulphur Heavy Fuel Oil) with an assumed carbon price ($/tonne 101, 194, 288 respectively in 2030, 2040, 2050) taken from a UK government report authored by the department for Business, Energy and Industrial Strategy (BEIS) in December 2017, Reference [8]. Therefore, our bio-LNG price projections can be seen in Table 10 below.

Table 10: Bio-LNG price projections

Bio-LNG	**2020**	**2030**	**2040**	**2050**
Upper case ($/GJ)	27	54	81	108
Lower case ($/GJ)	24	27	29	33

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

5. Conclusions

In this study, levelised cost of fuel production had been identified for LNG and hydrogen fuels from various sources, see below Table 11. The results may be revisited on a later stage of the study considering the long project timeline.

Table 11: Levelised cost of production

Fuel	**LCP Lower bound $/GJ**				**LCP Upper bound $/GJ**			
	2020	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
E-hydrogen (pathway 1)	52	44	36	28	92	79	65	52
NG-hydrogen (pathway 2)	25	23	21	19	44	40	37	34
E-LNG (pathway 1)	69	60	51	42	113	98	84	69
Bio-LNG	24	27	29	33	27	54	81	108

It should be noted that the LCP in this report is based on global fuel price projection therefore hence the gap between the upper and lower cases are wide. If the fuel price projection is more focused on a specific region, the gap between the upper and lower cases would be smaller therefore the LCP results may be more accurate, Reference [6].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

References

Reference [1]: Grant agreement-955286-CHEK- signed - dated 24.03.2021

Reference [2]: CHEK_D1.3 Report on Future operational profile_v1 - dated 12.10.2021

Reference [3]: Techno-economic assessment of zero-carbon fuels, Lloyd’s Register and UMAS, dated March 2020.

Reference [4]: IRENA (2017), Renewable Power Generation Costs in 2017.

Reference [5]: Atradius Economic Research Gas Prices Jan_2017 https://group.atradius.com/publications/gas-price-update-2017.html

Reference [6]: First movers in shipping's decarbonisation, The Lloyd’s Register Maritime Decarbonisation Hub, December 2021.

Reference [7]: SCAB (2017), Final Report European Commission, 2017. Building Up the Future Sub Group on Advanced Biofuels Sustainable Transport Forum

Reference [8]: BEIS (2017) ‘Data tables 1 to 19: supporting the toolkit and the guidance’, available at https://webarchive.nationalarchives.gov.uk /20190105010941/https://www.gov.uk/government/uploads/system/uploads/attachment_data /file/696677/Data_tables_1-19_ supporting_the_toolkit_and_the_guidance_2017__180403_.xlsx

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 955286. The content of this report reflects only the authors’ view and the European Commission is not responsible for any use that may be made of the information it contains.