RESOLUTION MEPC.376(80) (adopted on 7 July 2023)
GUIDELINES ON LIFE CYCLE GHG INTENSITY OF MARINE FUELS (LCA GUIDELINES)

ANNEX 14

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(adopted on 7 July 2023)

GUIDELINES ON LIFE CYCLE GHG INTENSITY OF MARINE FUELS (LCA GUIDELINES)

THE MARINE ENVIRONMENT PROTECTION COMMITTEE,

RECALLING Article 38(a) of the Convention on the International Maritime Organization (the Committee) concerning the functions of the Marine Environment Protection Committee conferred upon it by international conventions for the prevention and control of marine pollution from ships,

RECALLING ALSO that at its seventy-second session, the Committee adopted resolution MEPC.304(72) on *Initial IMO Strategy on Reduction of GHG Emissions from Ships* (Initial Strategy),

NOTING that the Initial Strategy calls for the development of robust life cycle GHG/carbon intensity guidelines for all types of fuels, in order to prepare for an implementation programme for effective uptake of alternative low-carbon and zero-carbon fuels,

NOTING ALSO that at its eightieth session, the Committee adopted resolution MEPC.377(80) on the *2023 IMO Strategy on Reduction of GHG Emissions from Ships* (2023 IMO Strategy) setting out the levels of ambition for the international shipping sector in reducing GHG emissions,

NOTING FURTHER that the 2023 IMO Strategy provides that the levels of ambition and indicative checkpoints should take into account the well-to-wake GHG emissions of marine fuels as addressed in the guidelines on life cycle GHG intensity of marine fuels developed by the Organization,

NOTING that the 2023 IMO Strategy provides that the basket of candidate mid-term GHG reduction measures should take into account the well-to-wake GHG emissions of marine fuels as addressed in the guidelines on life cycle GHG intensity of marine fuels developed by the Organization,

HAVING CONSIDERED, at its eightieth session, the draft guidelines on life cycle GHG intensity of marine fuels (LCA Guidelines),

1 ADOPTS the *Guidelines on life cycle GHG intensity of marine fuels (LCA Guidelines)*, as set out in the annex to the present resolution;

2 AGREES that any regulatory application and implications of the LCA Guidelines should be determined by the Committee in the process of developing regulatory provisions,

3 REQUESTS Member Governments to bring the annexed Guidelines to the attention of shipowners, ship operators, shipbuilders, ship designers, energy companies, fuel producers, bunkering companies, engine manufacturers and any other interested parties;

4 AGREES to keep these Guidelines under review in light of experience gained with their implementation.

GUIDELINES ON LIFE CYCLE GHG INTENSITY OF MARINE FUELS

(LCA Guidelines)

CONTENTS

PART I: GENERAL

1 INTRODUCTION

1.1 These guidelines provide guidance on life cycle GHG intensity assessment for all fuels and other energy carriers (e.g. electricity) used on board a ship. These guidelines aim at covering the whole fuel life cycle (with specific boundaries), from feedstock extraction/cultivation/ recovery, feedstock conversion to a fuel product, transportation as well as distribution/bunkering, and fuel utilization on board a ship. These guidelines also specify sustainability themes/aspects for marine fuels and define a Fuel Lifecycle Label (FLL), which carries information about fuel type, feedstock (feedstock type and feedstock nature/carbon source), conversion/production process (process type and energy used in the process), GHG emission factors, information on fuel blends and sustainability themes/aspects. These guidelines specify the elements of FLL subject to verification/certification and include a general procedure on how the certification scheme/standards could be identified.

2 SCOPE

2.1 The scope of these guidelines is to address well-to-tank (WtT), tank-to wake (TtW), and well-to-wake (WtW) greenhouse gases (GHG) intensity and sustainability themes/aspects related to marine fuels/energy carriers (e.g. electricity for shore power) used for ship propulsion and power generation onboard. The relevant GHGs included are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These guidelines are not intended to provide guidance for a complete IMO GHG inventory for international shipping. Emissions from cargo (e.g. volatile organic compounds (VOC)), or use of refrigerants are not included; other short-lived climate forcers and precursors such as non-methane volatile organic compounds (NMVOC), sulphur oxides (SO_x), carbon monoxide (CO), particulate matter (PM) and Black Carbon are not part of the scope of these LCA guidelines.

2.2 The system boundaries of the WtW GHG emission factors calculation, in the context of these guidelines span the life cycle of fuels from their sourcing to production, conversion, transport, distribution, and eventually their use on board ships based on an attributional approach.[1] The possibility to expand the system boundaries for specific pathways in which the feedstock is displaced from present use(s) will be assessed on a case-by-case basis.[2] As such, emissions associated with the following life cycle stages of the fuel life cycle chain will be accounted for:

.1 feedstock extraction/cultivation/acquisition/recovery;
.2 feedstock (early) processing/ transformation at source;
.3 feedstock transport to conversion site;
.4 feedstock conversion to product fuel;
.5 product fuel transport/storage/delivery/retail storage/bunkering; and
.6 fuel utilization on board a ship.

2.3 Consistently with the attributional approach and using best available scientific evidence, the WtT emissions calculations (i.e. emissions related to the fuel sourcing, production, conversion, transport and delivery) are assessed regardless of the final use of

1 Attributional Life Cycle Assessment (LCA): LCA aiming to describe the environmentally relevant physical flows to and from a system and its subsystems over their life cycle; Consequential Life cycle Analysis (LCA): LCA aiming to describe how environmentally relevant flows will change in response to possible decisions. (Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, et al. "Recent developments in life cycle assessment". *Journal of Environmental Management*. 2009;91(1):1-21).

2 Such as for captured CO_2 transportation and storage.

fuels/energy carriers, and the TtW emissions (i.e. emissions related to the fuel use) are quantified regardless of the sourcing/production/conversion/transport and delivery steps of the fuel/energy carrier. WtW emissions are given by the sum of the two parts, providing the full emission performance associated with the fuel production and use of a certain fuel/energy in a specific converter onboard.

2.4 The GHG emissions are calculated as CO_2-equivalent (CO_{2eq}), using the Global Warming Potential over a 100-year time-horizon (GWP100) to convert emissions of other gases than CO_2, as given in the fifth IPCC Assessment Report,[3] for CO_2, CH_4 and N_2O, as follows:

- $g_{CO_{2eq}(100y)} = GWP_{CO_2(100y)} \times g_{CO_2} + GWP_{CH_4(100y)} \times g_{CH_4} + GWP_{N_2O\,(100y)} \times g_{N_2O}$

(CO_2 1; CH_4 28; N_2O 265), this would read as:

- $g_{CO_{2eq}(100y)} = 1 \times gCO_2 + 28 \times gCH_4 + 265 \times gN_2O)$

These GWP100 values should be used for the purpose of quantifying the GHG intensity in accordance with these guidelines.

A calculation using a Global Warming Potential over a 20-year horizon (GWP20) may be provided as information for comparative purposes, as follows:

- $g_{CO_{2eq}(20y)} = GWP_{CO_2(20y)} \times g_{CO_2} + GWP_{CH_4(20y)} \times g_{CH_4} + GWP_{N_2O\,(20y)} \times g_{N_2O}$

(CO_2 1; CH_4 84; N_2O 264), this would read as:

- $g_{CO_{2eq}(20y)} = 1 \times gCO_2 + 84 \times gCH_4 + 264 \times gN_2O$

2.5 These guidelines provide:

.1 WtW GHG emission factors based on a life cycle attributional methodology, expressing the GHG profile of each representative fuel using on Global Warming Potential (GWP) values over a 100-year time-horizon of included GHG (CO_2, CH_4 and N_2O);

.2 WtT GHG emission factors (CO_2, CH_4 and N_2O) quantified consistently with the attributional approach;

.3 TtW GHG emission factors (CO_2, CH_4 and N_2O); and

.4 sustainability themes/aspects for marine fuels.

2.6 These guidelines define a FLL that carries information about fuel type, feedstock used, fuel production pathway, GHG emission factors, information on fuel blends and sustainability themes/aspects.

[3] The Global Warming Potential values as given in the IPCC Fifth Assessment Report (AR5) are used in the context of these guidelines.

2.7 The figure below shows a generic WtW supply chain for a fuel. The bunkering marks the last step in the WtT phase before the TtW phase starts.

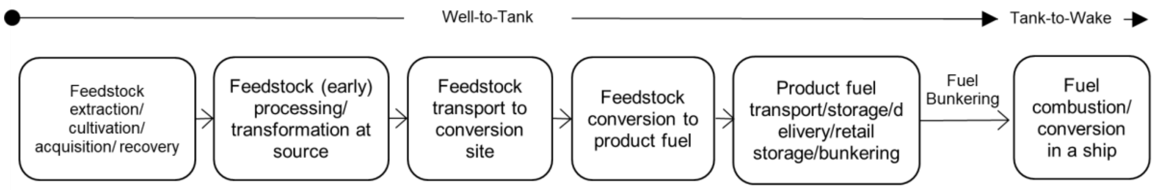

Figure 1: Generic well-to-wake supply chain

2.8 These guidelines include an initial non-exhaustive list of fuels in appendix 1 depicting the main current and expected future marine fuels.

PART II: METHODOLOGY

3 GENERAL APPROACH

3.1 A Life Cycle Assessment (LCA) based approach provides a holistic assessment of the product/service/system from well-to-wake using data specific to the activity considered. The LCA methodology follows the marine fuel from feedstock sourcing to its utilization onboard ships and assesses its life cycle GHG intensity. This approach, applied within the boundaries of the WtW GHG emissions quantification, is applicable across all geographical regions, where emissions occur and allows for quantifying the GHG intensity over the entire fuel/energy supply chain.

3.2 General principles and methodology can be found in ISO 14044:2006 *Environmental management — Lifecycle assessment — Requirements and guidelines*. ISO 14040:2006 *Environmental management — Lifecycle assessment — Principles and framework* sets the framework for the LCA, for the quantification of the environmental impact of products, processes and services in the supply chain. On this basis, a specific LCA methodology can be tailored for its application to marine fuels.

3.3 WtT emissions represent GHG emissions resulting from growing or extracting raw materials, producing and transporting the fuel up to the point of use, including bunkering.

3.4 TtW emissions represent GHG emissions resulting from fuel utilization onboard (e.g. combustion), including potential leaks (fugitive emissions and slip), when relevant for the GHG assessment.

3.5 WtW emissions are the sum of the WtT and TtW emissions and quantify the full life cycle GHG emissions for a given fuel and fuel pathway, used in a given energy converter on board.

3.6 The attributional approach considers all processes along the supply chain of fuel/energy carrier pathways, allowing the quantification of contributions per segment to the overall GHG intensity of the final fuel/energy product used on board a ship. The expansion of the system boundaries for specific pathways, in which the feedstock or intermediate products are diverted from existing use(s), may be considered on a case-by-case basis.

3.7 As regards the expansion of the system boundaries, with consequential elements such as Indirect Land Usage Change (ILUC), concerns with respect to uncertainties and the risk of arbitrariness suggest that the feedstocks with associated ILUC should only be assessed through a risk-based approach, in the framework of sustainability themes/aspects, as part of these guidelines.

3.8 When more than one product results from a conversion process, emissions related to the fuel production should be allocated between main product and co-products. Within such conversion processes, emissions are allocated using their energy content, the so-called "energy allocation" approach. Where co-products allocation cannot be performed based on their energy content (e.g. Oxygen resulting from water electrolysis for H_2 production), other methods such as mass allocation, market revenue allocation (also known as "economic allocation"), could be considered on a case-by-case basis.

3.9 A *co-product* is defined as "an outcome of a production process, which has economic value and elastic supply (intended as the existence of a clear evidence of the causal link between feedstock market value and the quantity of feedstock that can be produced)".

3.10 This definition applies also when a raw material used to produce the fuels is a waste (no economic value) or a residue (unavoidably produced and with negligible economic value, needing further processing to be used in the main conversion process). In case the feedstock is a waste, a residue or a by-product, emissions considered as WtT start at the feedstock collection point onwards until the point of use of the final fuel/energy product.

3.11 According to the *IPCC Guidelines for National Greenhouse Gas Inventories* ("the IPCC Guidelines"),[4] any carbon in the fuel derived from biomass should be reported as an information item and not included in the sectoral or national totals to avoid double counting, since the net emissions from biomass are already accounted for in the Agriculture Forestry and Other Land Use (AFOLU) sector at a national level.

3.12 The scope of the IMO LCA guidelines does not affect or change the IPCC Guidelines. According to the IPCC Guidelines, international waterborne navigation (international bunkers) is grouped under "Mobile combustion" under the Energy sector, but emissions from fuel used by ships in international transport should not be included in national totals in national GHG inventories.

3.13 A fuel batch may be a mix of fuels made from various feedstocks and sources (e.g. by blending 20% biodiesel into fossil MGO) and/or through different production pathways. The calculation should be done using the weighted averages of the energy of the various fuel components. Relevant information should accompany each component fuel in the FLL. Blended fuels should be included in the certification schemes and relevant GHG default or actual emission factors (gCO_2/MJ) determined in proportion to the energy of each fuel part of the blend.

4 WELL-TO-TANK (WtT)

4.1 The pathway of each relevant marine fuel should be clearly described and the GHG emissions during each step of the fuel pathway should be calculated. Specific GHG emissions of a specific non-conventional and non-fossil fuel's pathway may take into account different characteristics across geographic regions, where feedstock production and/or conversion occurs, as appropriate.

[4] *2006 IPCC Guidelines for National Greenhouse Gas Inventories*

4.2 Any further reference in this document to a "fuel pathway" should be understood to include the feedstock structure (the so-called nature/carbon source and feedstock type pair) and the production or conversion process (noting that the same feedstock and fuel type pair can have a different production or conversion process).

4.3 The aim of the WtT methodology is to quantify and evaluate the GHG intensity of fuel production, including all steps mentioned in figure 2. The carbon feedstock and production pathway of a fuel should be identified in order to apply the methodology and is included as part of the FLL. The production steps to be included in the WtT are presented in figure 2.

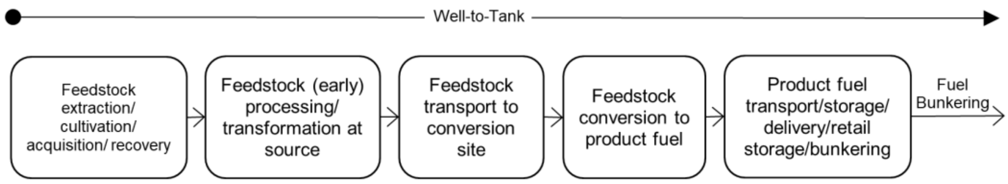

Figure 2: Generic well-to-tank supply chain

4.4 The WtT GHG emission factor ($gCO_{2eq}/MJ_{(LCV)}$ fuel or electricity) is calculated according to Equation (1).

Equation (1)

$$GHG_{WtT} = e_{fecu} + e_l + e_p + e_{td} - e_{sca} - e_{ccs}$$

Term	Units	Explanation
e_{fecu}	gCO_{2eq}/ $MJ_{(LCV)}$	Emissions associated with the feedstock extraction/cultivation/acquisition/recovery
e_l	gCO_{2eq}/ $MJ_{(LCV)}$	Emissions (annualized emissions (over 20 years) from carbon stock changes caused by direct land-use change)[5]
e_p	gCO_{2eq}/ $MJ_{(LCV)}$	Emissions associated with the feedstock processing and/or transformation at source and emissions associated with the conversion of the feedstock to the final fuel product, including electricity generation
e_{td}	gCO_{2eq}/ $MJ_{(LCV)}$	Emissions associated with the feedstock transport to conversion plant, and the emissions associated with the finished fuel transport and storage, local delivery, retail storage and bunkering
e_{sca}	gCO_{2eq}/ $MJ_{(LCV)}$	Emissions (annualized emission savings (over 20 years) from soil carbon accumulation via improved agricultural management)[6]

[5] Pending further methodological guidance to be developed by the Organization, the value of parameter e_l should be set to zero.

[6] Pending further methodological guidance to be developed by the Organization, the value of parameter e_{sca} should be set to zero.

Term	Units	Explanation
e_{ccs}	gCO_{2eq} / $MJ_{(LCV)}$	Emissions credit from carbon capture and storage (e_{ccs}), that have not already been accounted for in e_p. This should properly account the avoided emissions through the capture and sequestration of emitted CO_2, related to the extraction, transport, processing and distribution of fuel (c_{sc}). From the above-mentioned emission credit, all the emissions resulting from the process of capturing (e_{cc}) and transporting (e_t) the CO_2 up to the final storage (including the emissions related to the injection, etc.) need to be deducted. This element should be calculated with the following formula: $$e_{CCS} = c_{SC} - e_{cc} - e_t - e_{st} - e_x$$
c_{sc}	g CO_2 stored / $MJ_{(LCV)}$	Emissions credit equivalent to the net CO_2 captured and stored (long-term: 100 years)
e_{cc}	gCO_{2eq} / $MJ_{(LCV)}$	Emissions associated with the process of capturing, compression and/or cooling and temporary storage of the CO_2
e_t	gCO_{2eq} / $MJ_{(LCV)}$	Emissions associated with transport to a long-term storage site
e_{st}	gCO_{2eq} / $MJ_{(LCV)}$	Any emissions associated with the process of storing (long-term: 100 years) the captured CO_2 (including fugitive emissions that may happen during long-term storage and/or the injection of CO_2 into the storage)
e_x	gCO_{2eq} / $MJ_{(LCV)}$	Any additional emissions related to the CCS

4.5 The WtT emissions in Equation (1) include emissions associated with raw materials extraction or cultivation, primary energy sources used for production of goods and utilities such as energy carriers (e.g. fuels and electricity), transport and distribution (including bunkering), direct land use change and changes in carbon stocks (soil carbon accumulation).

4.6 Processing incorporates all steps and operations needed for the extraction, capture or cultivation of the primary energy source. Process includes basic transformation at source and operations needed to make the resource transportable to the marketplace (e.g. drying, chemical/physical upgrade such as gas-to-liquid, etc.).

4.7 Transportation, processing and distribution include transportation of the products in the fuel pathway to the place of transformation, conditioning (such as compression, cooling), distribution to the marketplace (i.e. bunkering) and eventual leakages, as well as fugitive emissions at any of these stages.

4.8 Allocation of emissions to co-products based on their energy content should be used, as the most appropriate and reliable methodology considering the establishment of an appropriate certification method using values that are predictable, reproducible and stable.

4.9 Land use (direct and indirect) for the production of biofuels may lead to land use change (LUC). LUC can be classified as direct LUC (DLUC) and indirect LUC (ILUC).

4.10 The DLUC definition is based on ISO 14067:2018 described as a change in the use or management of land within the product system being assessed. The DLUC impacts comprises the emissions and sequestration resulting from carbon stock changes in biomass, dead organic matter and soil organic matters, evaluated in accordance with the IPCC Guidelines. When available, sector or country-specific data on carbon stocks may be used; otherwise, IPCC's Tier 1 default emission factors may be considered. Two terms in the WtT Equation (1) capture respectively emissions resulting from direct land use change, i.e. e_l, and sequestration or otherwise increase in the content of soil organic carbon: e_{sca}.

4.11 The ILUC definition is based on ISO 14067:2018, described as a change in the use or management of land, which is a consequence of direct land use change, but which occurs outside the product system being assessed. ILUC occurs as a result of the economic impacts induced by increased biofuel demand on commodity prices with resulting shifts in demand and supply across economic sectors, including primarily food and feed production. ILUC cannot be directly measured and is projected with economic models instead.

4.12 Owing to the variability of assumptions underlying the evaluation of indirect effects, quantitative assessment of GHG effects of ILUC is subject to uncertainty, high quantitative variability and to the risk of arbitrary conclusions. For these reasons, ILUC should be at this stage addressed using a risk-based approach, meaning that quantitative values will not be calculated and assigned to each fuel pathway. The ILUC emissions, as well as the spatial dimension of the ILUC effects, are dependent on a variety of factors such as local/regional conditions and practices for agriculture, current and expected food import demand, national current accounts, the type of feedstock, the alternative economic uses of the same feedstock, etc.

4.13 A qualitative risk-based approach to ILUC includes consideration on the following:

.1 *Low-ILUC risk* qualifies and characterizes biofuel production projects that supply additional feedstock without disrupting existing land uses. When productivity is increased on an area which is in agricultural production, only additional yields should be considered as low-ILUC rather than the entire production; and

.2 *High-ILUC risk* qualifies and characterizes biofuel production projects based on, or displacing, food and feed crops resulting in a significant expansion of the feedstock production area shifting into land with high-carbon stock.

4.14 WtT default emission factors are provided in appendix 2 of these guidelines.

5 TANK-TO-WAKE (TtW)

5.1 The aim of the TtW methodology is to quantify and evaluate the intensity of CO_2, CH_4 and N_2O emitted on board a ship related to the fuel usage, including combustion/conversion and all relevant fugitive emissions with a Global Warming Potential.

5.2 The TtW GHG emission factors should be calculated using Equation (2):

Equation (2)

$$GHG_{TtW} = \frac{1}{LCV}\left(\left(1 - \frac{1}{100}\left(C_{slip\_ship} + C_{fug}\right)\right) \times \left(C_{fCO_2} \times GWP_{CO_2} + C_{fCH_4} \times GWP_{CH_4} + C_{fN_2O} \times GWP_{N_2O}\right) + \left(\frac{1}{100}\left(C_{slip\_ship} + C_{fug}\right) \times C_{sfx} \times GWP_{fuelx}\right) - S_{Fc} \times e_c - S_{Fccu} \times e_{ccu} - e_{OCCS}\right)$$

Note: terms S_{Fccu}, e_{ccu} and e_{occs} are pending further methodological guidance to be developed by the Organization. For more details refer to footnotes 11 to 13.

Term	Units	Explanation
C_{slip_ship}	% of total fuel mass	Factor accounting for fuel (expressed in % of total fuel mass delivered to the ship) which escapes from the energy converter without being oxidized (including fuel that escapes from combustion chamber/oxidation process and from crankcase, as appropriate) $C_{slip\_ship} = C_{slip} * (1 - C_{fug}/100)$
C_{slip}	% of total fuel mass	Factor accounting for fuel (expressed in % of total fuel mass consumed in the energy converter) which escapes from the energy converter without being oxidized (including fuel that escapes from combustion chamber/oxidation process and from crankcase, as appropriate)
C_{fug}	% of fuel mass	Factor accounting for the fuel (expressed in % of mass of the fuel delivered to the ship) which escapes between the tanks up to the energy converter which is leaked, vented or otherwise lost in the system[7]
C_{sfx}	gGHG/g fuel	Factor accounting for the share of GHG in the components of the fuel (expressed in g GHG/g fuel) Example: for LNG this value is 1
C_{fCO2}	gCO_2/g fuel	CO_2 emission conversion factor (gCO_2/g fuel completely combusted) for emissions of the combustion and/or oxidation process of the fuel used by the ship
C_{fCH4}	gCH_4/g fuel	CH_4 emission conversion factor (gCH_4/g fuel delivered to the ship) for emissions of the combustion and/or oxidation process of the fuel used by the ship[8]
C_{fN2O}	gN_2O/g fuel	N_2O emission conversion factor (gN_2O/g fuel delivered to the ship) for emissions of the combustion and/or oxidation process of the fuel used by the ship
GWP_{CH4}	gCO_{2eq}/g CH_4	Global Warming Potential of CH_4 over 100 years (based on the fifth IPCC Assessment Report 5)[9] Definition as per https://www.ipcc.ch/assessment-report/ar5/

7 Pending further methodological guidance to be developed by the Organization to determine appropriate factor(s), the value of C_{fug} should be set to zero.

8 For LNG/CNG fuel, the C_{slip_engine} is covering the role of C_{fCH4}, so C_{fCH4} is set to zero for these fuels.

9 Set at 28 based on IPCC AR5.

Term	Units	Explanation
GWP_{N2O}	$gCO_{2eq}/g\ N_2O$	Global Warming Potential of N_2O over 100 years (based on the fifth IPCC Assessment Report 5).[10] Definition as per https://www.ipcc.ch/assessment-report/ar5/
GWP_{fuelx}	gCO_{2eq}/g GHG	Global Warming Potential of GHG in the components of the fuel over 100 years (based on the fifth IPCC scientific Assessment Report)
S_{Fc}	0 or 1	Carbon source factor to determine whether the emissions credits generated by biomass growth are accounted for in the calculation of the TtW value
e_c	gCO_{2eq}/g fuel	Emissions credits generated by biomass growth
e_{ccu}[11]	gCO_{2eq}/g fuel	Emission credits from the used captured CO_2 as carbon stock to produce synthetic fuels in the fuel production process and utilization (that was not accounted under e_{fecu} and e_p)
S_{Fccu}[12]	0 or 1	Carbon source factor to determine whether the emissions credits from the used captured CO_2 as carbon stock to produce synthetic fuels in the fuel production process are accounted for in the calculation of the TtW value
e_{occs}[13]	gCO_{2eq} / g fuel	Emission credit from carbon capture and storage (e_{occs}), where capture of CO_2 occurs onboard. This should properly account for the emissions avoided through the capture and sequestration of emitted CO_2, if CCS occurs on board. From the above-mentioned emission credit, all the emissions resulting from the process of capturing (e_{cc}), and transporting (e_t) the CO_2 up to the final storage (including the emissions related to the injection, etc.) need to be deducted. This element should be calculated with the following formula: $$e_{OCCS} = c_{SC} - e_{cc} - e_t - e_{st} - e_x$$
c_{sc}	gCO_2 / g fuel	Credit equivalent to the CO_2 captured and stored (long-term: 100 years)
e_{cc}	gCO_{2eq} / g fuel	Any emission associated with the process of capturing, compress and temporarily store on board the CO_2

10 Set at 265 based on IPCC AR5.

11 Pending further methodological guidance to be developed by the Organization, the value of the multiplication $S_{Fccu} \times e_{ccu}$ should be set to zero.

12 Pending further methodological guidance to be developed by the Organization, the value of the multiplication $S_{Fccu} \times e_{ccu}$ should be set to zero.

13 Pending further methodological guidance to be developed by the Organization, the value of e_{occs} should be set to zero.

Term	Units	Explanation
e_t	gCO_{2eq} / g fuel	Emissions associated with transport to long-term storage site
e_{st}	gCO_{2eq} / g fuel	Any emission associated with the process of storing (long-term: 100 years) the captured CO_2 (including fugitive emissions that may happen during long-term storage and/or the injection of CO_2 into the storage)
e_x	gCO_{2eq} / g fuel	Any additional emission related to the CCS
LCV	MJ/g	Lower Calorific Value is the amount of heat that would be released by the complete combustion of a specified fuel

5.3 In order to have LCA guidelines that will allow for their clear, robust and consistent application to any possible measure, the methodology allows to calculate two TtW values as follows:

.1 TtW GHG intensity value 1: calculated regardless of the carbon source, therefore the e_c and e_{ccu} parameters should not be taken into account and the S_{Fc} and S_{Fccu} value should be always 0; and

.2 TtW GHG intensity value 2: calculated taking into account the carbon source for fuels of biogenic origins or made from captured carbon, therefore the e_c and e_{ccu} parameters should be taken into account and the S_{Fc} and S_{Fccu} values should be always 1.

5.4 The actual GHG intensity depends both on the properties of the fuel and on the efficiency of the energy conversion. For CO_2, the emission factors are based on the molar ratio of carbon to oxygen multiplied with the carbon mass of the fuel, assuming that all the carbon in the fuel is oxidized (stoichiometric combustion). The CH_4 and N_2O emissions factors are dependent on the combustion and/or conversion process in the energy converter.

5.5 For future use of, for example, fuel cells with a reforming unit, also electro-chemical reactions forming GHGs can be taken into account by this TtW methodology.

5.6 TtW default emission factors are provided in appendix 2 of these guidelines.

6 WELL-TO-WAKE (WtW)

6.1 The aim of the WtW methodology is to integrate WtT and TtW parts, to quantify the full life cycle emissions related to the production and use of a fuel.

6.2 The WtW GHG emission factor (gCO_{2eq}/MJ_{LCV} fuel or electricity) is calculated as follows:

Equation (3)

$$GHG_{WtW} = GHG_{WtT} + GHG_{TtW}$$

where:

Term	Units	Explanation
GHG_{WtW}	$gCO_{2eq}/MJ_{(LCV)}$	Total well-to-wake GHG emissions per energy unit from the use of the fuel or electricity in a consumer on board the ship
GHG_{WtT}	$gCO_{2eq}/MJ_{(LCV)}$	Total well-to-tank GHG upstream emissions per energy unit of the fuel provided to the ship
GHG_{TtW}	$gCO_{2eq}/MJ_{(LCV)}$	Total tank-to-wake GHG downstream emissions per energy unit from the use of the fuel or electricity in a consumer on board the ship

Equation (4)

$$GHG_{WtW} = e_{fecu} + e_l + e_p + e_{td} - e_{sca} - e_{ccs} + \frac{1}{LCV}\left(\left(1 - \frac{1}{100}\left(C_{slip\_ship} + C_{fug}\right)\right) \times \left(C_{fCO_2} \times GWP_{CO_2} + C_{fCH_4} \times GWP_{CH_4} + C_{fN_2O} \times GWP_{N_2O}\right) + \left(\frac{1}{100}\left(C_{slip_{ship}} + C_{fug}\right) \times C_{sfx} \times GWP_{fuelx}\right) - S_{Fc} \times e_c - S_{Fccu} \times e_{ccu} - e_{OCCS}\right)$$

Note: terms S_{Fccu}, e_{ccu} and e_{occs} are pending further methodological guidance to be developed by the Organization. For more details refer to section 5.2.

6.3 For the purpose of calculating WtW, the TtW value 2 as calculated in accordance with paragraph 5.3.2 should be used.

7 SUSTAINABILITY

7.1 The sustainability of marine fuels should be assessed considering the following themes/aspects on a life cycle basis:

.1 greenhouse gases (GHG);
.2 carbon source;
.3 source of electricity/energy;
.4 carbon stock – direct land use change (DLUC);
.5 carbon stock – indirect land use change (ILUC);
.6 water;
.7 air;
.8 soil;
.9 waste and chemicals; and
.10 conservation.

Other social and economic sustainability themes/aspects may be considered at a later stage.

7.2 The principle/objective in conjunction with the associated metrics/indicators of each of the sustainability theme/aspect are specified below.

Table 1: Sustainability themes/aspects

Theme/aspect	Principle/Objective	Metric/Indicator
1. Greenhouse Gases (GHG)	Sustainable marine fuels generate lower GHG emissions than conventional marine fuels (energy-based weighted average of liquid petroleum products on 3 specific years of DCS data) on a life cycle basis.	1. GHG intensity in gCO_{2eq}/MJ (GWP100); and GHG intensity in gCO_{2eq}/MJ (GWP20) for comparative purposes.
2. Carbon source	Sustainable marine fuels do not increase GHG intensity from the use of fossil energy sources and the permanence of captured and stored carbon is ensured while also avoiding double counting across economic sectors.	1. Carbon source indicator, including its content (in %) and origin in feedstock used to produce final fuel product, i.e. Fossil, Biogenic, Captured Carbon (including direct air capture (DAC), point source fossil (PSF) and point source biogenic (PSB)), and Others (including mixture of sources).
3. Source of electricity/energy	Sustainable marine fuels requiring significant electricity input during WtT phase and electricity delivered directly to ships are produced by using electricity/energy from renewable, nuclear or biogenic sources, which are additional to current or long-standing demand levels, or by using surplus electricity during off-peak hours.	1. The GHG intensity of electricity used in the production of marine fuels or delivered directly to ships (annual average, expressed in g CO_{2eq}/kWh based on total emissions and actual hours of production.
4. Carbon stock – direct land use change (DLUC)	Sustainable marine fuels are not made from biomass obtained from land with high carbon stock; production of sustainable marine fuels minimizes emissions resulting from Direct Land Use Change.	1. Sustainable marine fuel feedstock does not include biomass obtained from land with high carbon stock (e.g. primary forests, wetlands, or peat lands referred to a specific cut-off date for conversion), or a sustainable land management plan and reporting schedule are in

Theme/aspect	Principle/Objective	Metric/Indicator
		place to ensure that the biomass is obtained from activities or ecosystem services that do not negatively impact the soil carbon stock; 2. The production of sustainable marine fuels does not occur in lands converted from primary forest, forestland, grassland or legally protected land, taking (1 January 2008)[14] as the cut-off date; and 3. Direct land-use change (DLUC) indicator, expressed in GHG (including CO_2, CH_4 and N_2O emissions) intensity, i.e. mass of CO_2 equivalent / MJ of production or yield of feedstock.
5. Carbon stock – indirect land use change (ILUC)	Cultivation of feedstock of sustainable marine fuels minimizes inducing negative changes in the use or management of land which occurs outside the product system being assessed.	1. Indirect carbon stock risk associated with cultivation of feedstock for sustainable marine fuels (see para. 4.13).
6. Water	Production of sustainable marine fuels maintain or enhance water quality and availability.	1. Operational practices are in place to (1) maintain water quality; and (2) use water efficiently and to avoid the depletion of water resources (including surface water, renewable water and fossil/underground water) beyond replenishment capacities; 2. Respect of decision-making of local population on water management; 3. Water environment impact (weighted water consumption on water scarcity);

[14] Pending further guidance to be developed by the Organization.

Theme/aspect	Principle/Objective	Metric/Indicator
		4. Water Use Indicator expressed in m^3/year per MJ or production or yield of feedstock; 5. Freshwater eutrophication indicator, e.g. expressed in kg of phosphorus equivalent (P_{eq}) and kg of nitrogen equivalent (N_{eq}) released to fresh water/kg of feedstock produced or per MJ respectively; and 6. Marine eutrophication indicator, e.g. expressed in kg of phosphorus equivalent (P_{eq}) and kg of nitrogen equivalent (N_{eq}) released to marine water/kg of feedstock produced or per MJ respectively.
7. Air	Production of sustainable marine fuels minimizes negative impacts on air quality.	1. The marine fuel is made in a facility that fully complies with all local, national and regional air pollution laws and regulations.
8. Soil	Production of sustainable marine fuels maintain or enhance soil health.	1. Agricultural and forestry best management practices for feedstock production or residue collection have been implemented to maintain or enhance soil health, such as physical, chemical and biological conditions; and 2. The marine fuel is made in a facility that fully complies with all local, national and regional laws and regulations about soil health.
9. Waste and chemicals	Production of sustainable marine fuels maintain or enhance responsible management of waste and use of chemicals.	1. Operational practices are implemented to ensure that waste arising from, and chemicals used in, production processes are minimized at storage, handling and disposal steps. Reuse or recycling of chemicals and waste is

Theme/aspect	Principle/Objective	Metric/Indicator
		encouraged. 2. Procedures are in place to minimize the use of materials that are neither recyclable nor biodegradable; 3. Average (in tonnes) of hazardous wastes generated per MJ of fuel produced; and 4. Average (in tonnes) of specified industrial chemicals consumed per MJ of fuel produced.
10. Conservation	Production of sustainable marine fuels maintain or enhance biodiversity and ecosystems, or conservation services.	1. The marine fuel is not made from feedstock obtained from areas that due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over the area. Evidence is provided that the activity does not interfere with the protection purposes; and 2. Low invasive-risk feedstock is selected for cultivation and appropriate controls are adopted with the intention of preventing the uncontrolled spread of cultivated alien species and modified microorganisms.

8 FUEL LIFECYCLE LABEL (FLL)

8.1 The FLL is a technical tool to collect and convey the information relevant for the life cycle assessment of marine fuels and energy carriers (e.g. electricity for shore power) used for ship propulsion and power generation onboard in the context of these guidelines.

8.2 The FLL consists of five main parts, as illustrated below:

Part A-1	**Part A-2**	**Part A-3**	**Part A-4**	**Part A-5**
Fuel type (blend)	Fuel Pathway Code	Lower Calorific Value (LCV, MJ/g)	share in fuel blend (%$MJ_{(LCV)}$ / $MJ_{(LCV)}$)	WtT GHG emission factor (GWP100, $gCO_{2eq}/MJ_{(LCV)}$)

+

Part B-1	**(Part B-2)**[15]
Emissions credits related to biogenic carbon source (e_c, in gCO_2/g fuel based on GWP100)	Emissions credits related to source of captured carbon (e_{ccu}, in gCO_2/g fuel based on GWP100)

+

Part C-1	**Part C-2**	**Part C-3**
Value 1 (carbon source NOT taken into account): TtW GHG emission factor (GWP100, $gCO_{2eq}/MJ_{(LCV)}$)	Value 2 (carbon source taken into account): TtW GHG emission factor (GWP100, $gCO_{2eq}/MJ_{(LCV)}$)	Energy Converter

+

Part D	**Part E**
WtW GHG emission factor (GWP100, $gCO_{2eq}/MJ_{(LCV)}$) Note: Part D = Part A-5 + Part C-2	Sustainability (Certification)[16]

8.3 Different parties (fuel suppliers, owners/operators, Administration/RO, etc.) may use different parts of the FLL for different purposes along the fuel pathway. As such, each interested party may use those parts of the FLL as relevant to their activities and purposes rather than the complete, integrated document.

8.4 The five main parts of the FLL are explained below.

.1 **Part A** of the FLL indicates:

.1 fuel type (Part A-1);

.2 fuel pathway code (Part A-2);

.3 lower calorific value (Part A-3, in MJ/g); and

.4 WtT GHG emission factor (Part A-5, in $gCO_{2eq}/MJ_{(LCV)}$ calculated on GWP100).

Part A-4 is only applicable when a fuel batch is supplied to the ship as a blend of fuels with different fuel pathway code (hereinafter referred to as the "fuel blend") and indicates the share of each blend component in the fuel

15 Pending further methodological guidance to be developed by the Organization (see section 5).

16 Pending further guidance to be developed by the Organization.

blend (in $\%MJ_{(LCV)}/MJ_{(LCV)}$). If fuel blends are denoted on volume-basis, a re-calculation on energy basis based on the LCV values of the blend components is required;

For the fuel blend supplied to a ship, the information on fuel type for the mixture is presented under Part A-1 on top of its components, named by percentual order of composition in the fuel, e.g. X (70%), Y (20%), Z (10%). Part A-5, Part C-1, Part C-2 and Part D are the average value weighted on energy share ($\% MJ_{(LCV)}$) /$MJ_{(LCV)}$)) of each fuel component, while Part A-2 to A-4, Part B and Part E are kept blank. Each component of the fuel blend with a specific fuel pathways code is presented in a separate row below the row for the fuel blend;

.2 **Part B** of the FLL indicates the carbon credits related to the carbon source, including:

.1 e_c (Part B-1, in gCO_2 / g fuel calculated on GWP100); (and

.2 e_{ccu} (Part B-2, in gCO_2/g fuel calculated on GWP100)),[17]

as defined in section 5 of these guidelines;

.3 **Part C** of the FLL indicates the TtW GHG emission factor of the fuel type in conjunction with the energy converter(s) on board the ship (Part C-3). The TtW GHG emission factor of the fuel type is further categorized as:

.1 Value 1 where carbon source is not taken into account (Part C-1, in $gCO_{2eq}/MJ_{(LCV)}$ calculated on GWP100); and

.2 Value 2 where carbon source is taken into account (Part C-2, in $gCO_{2eq}/MJ_{(LCV)}$ calculated on GWP100),

as defined in section 5 of these guidelines;

.4 **Part D** of the FLL indicates the WtW GHG emission factor of the fuel type (in $gCO_{2eq}/MJ_{(LCV)}$ calculated on GWP100), which is always the sum of Part A-5 and Part C-2; and

.5 **Part E** of the FLL indicates the sustainability performance of the fuel as per Section 7 of these guidelines.

PART III: DEFAULT EMISSION FACTORS AND ACTUAL VALUES

9 DEFAULT EMISSION FACTORS

9.1 The principles and the procedure described for the determination of default emission factors under this section 9 have been used for the establishment of default emission factors and should remain valid for the factors that will be established.

17 Pending further methodological guidance to be developed by the Organization. For more details on the e_{ccu} parameter and Part B-2 of the FLL, refer to sections 5.2 and 8.2, respectively.

9.2 WtT default emission factors should be calculated using representative and conservative assumptions, which encompass variable performance of feedstock-fuel pathways across world regions and States.

9.3 To establish a WtT default emission factor, at least three reference values from three different, representative, sources should be considered. Among the three (or more) values considered, the upper emission value should be selected as default, and the range of available emission factors should be provided for informative purposes. The reference values should be accompanied by the relevant technical and scientific information (see Template set out in appendix 4) and evaluated against the corresponding information as appropriate, including the agreement between the reference values.

9.4 Emissions related to carbon stock changes caused by direct land-use change (DLUC) (e_l) and emissions savings from soil carbon accumulation via improved agricultural management (e_{sca}) are considered as zero for the establishment of the initial default emission factors. Similarly, this is the case also for the parameters related to carbon capture and storage (ccs), which require further development.

9.5 TtW default emission factors, including slip factors per fuel type and per converter types, are set out in appendix 2 (for those fuels and converters for which such factors are available in resolution MEPC.364(79) on the *2022 Guidelines on the method of calculation of the attained energy efficiency design index (EEDI) for new ships* and the *Fourth IMO GHG Study 2020*). Further TtW default emission factors (with the exception of C_{fCO2} provided in resolution MEPC.364(79)) may be established by following the same rules as for the WtT default emission factors described in paragraph 9.3. No default emission factors are provided for the use of onboard CCS (e_{occs}), and the amount of captured carbon per unit of fuel mass should be specifically certified. The parameters related to emission credits from the used captured CO_2 as carbon stock to produce synthetic fuels (e_{ccu}) requires further development.

9.6 As the definition of C_{fug} factors is considered a difficult parameter to be measured, C_{fug} factors should be established by the best existing knowledge and will be dealt with at a later stage. Until C_{fug} factors are defined, C_{fug} should be set as 0.

9.7 In case additional categories of energy converters (not listed in appendix 2) are proposed, the rules to establish TtW default emission factors as described in paragraph 9.5 above may be followed to ensure that these new converters (e.g. fuel cells) may also be associated with a default emission factor.

10 ACTUAL EMISSION FACTORS

10.1 The aim of actual emission factors is to allow demonstration of superior GHG performance compared to the default emission factors, subject to verification and certification by a third party.

10.2 WtT and TtW emission factors should be based on methodologies established in these guidelines. Actual values provide the WtW (WtT and TtW) GHG intensity for the specific fuel over the life cycle (from fuel production to its use on board).

10.3 For the pathways contained in appendix 1, the description and the calculation method for providing WtT actual emission factors should be provided. In addition, for the pathways not contained in appendix 1, a detailed description of the pathway should be provided.

10.4 The use of actual WtT emission factors is not applicable to purely fossil pathways. However, for fuels which are produced from captured carbon of fossil origin and for fossil fuels where the technology of CCS/CCUS is applied, actual values are allowed. For the fossil component of a blended fuel, fossil fuel default emission factors should be used.

10.5 Actual TtW emission factors are allowed for all fuel pathways[18] and provided in these guidelines.

PART IV: VERIFICATION AND CERTIFICATION

11 ELEMENTS SUBJECT TO VERIFICATION/CERTIFICATION

11.1 When used as evidence for performances, the FLL needs to be verified and certified by a third party, taking into account further guidance to be developed by the Organization.

11.2 The verification and certification of Part A, Part B, Part C, and Part E of the FLL may be carried out separately by different verification bodies. The verification and certification of Part D of the FLL needs to be based on the verified Part A, Part B and Part C.

11.3 For fuel types with a specific fuel pathway code and which will be consumed in a specified energy converter, the default emission factors for Part A-5, Part C-1, Part C-2 and Part D of the FLL are provided in appendix 2. As long as Part A-1 to Part A-4 and Part C-3 of the FLL have been duly verified, the default emission factors contained in these guidelines can be consequently applied without further verification.

11.4 In the case where lower emission factors are claimed compared to the default emission factors for Part A-5, Part C-1, Part C-2 and/or Part D, the actual emission factors can be used only after the verification and certification by a third party, taking into account further guidance referred to in paragraph 11.1.

12 IDENTIFICATION OF CERTIFICATION SCHEMES/STANDARDS

12.1 The verification and certification of individual parts of the FLL will use relevant certification schemes/standards. Different parts of the FLL may be verified using different certification schemes/standards as applicable, while a specific part of the FLL may be addressed by multiple certification schemes/standards with similar scopes.

12.2 The certification schemes/standards used for the purposes specified in paragraph 12.1 above should be recognized by the Committee, taking into account guidance to be developed by the Organization. The list of recognized certification schemes/standards should be publicly available and kept under review.

12.3 Proposals to recognize international certification schemes/standards should be submitted to the Committee for consideration, including an assessment of a set of predetermined criteria which will be further developed for this purpose.

12.4 The framework, criteria and procedures leading to the recognition of certification schemes should be implemented uniformly to guarantee the quality, reliability and robustness of the IMO framework as a whole and to ensure a level playing field among certification schemes.

[18] Verification and certification methodologies would need further work to be established.

PART V: REVIEW

13 CONTINUOUS REVIEW PROCESS

13.1 To ensure that new technological advances and scientific knowledge are taken into account, these guidelines should be kept under continuous technical review taking into account emerging and evolving technologies.

13.2 In particular, the following elements should be kept under review:

.1 WtT, TtW and WtW default emission factors as specified in appendix 2; and

.2 new proposed fuel pathways and the corresponding default emission factors in addition to those specified in appendix 1.

APPENDIX 1

FUEL LIST WITH FUEL PATHWAY CODES

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
1	HFO (VLSFO)	Heavy Fuel Oil (ISO 8217 Grades RME, RMG and RMK, 0.10 < S ≤ 0.50%)	Crude Oil	Fossil	Standard refinery process	Grid mix electricity	HFO(VLSFO)_f_SR_gm
2	HFO (HSHFO)	Heavy Fuel Oil (ISO 8217 Grades RME, RMG and RMK exceeding 0.50% S)	Crude Oil	Fossil	Standard refinery process	Grid mix electricity	HFO(HSHFO)_f_SR_gm
3	LFO (ULSFO)	Light Fuel Oil (ISO 8217 Grades RMA, RMB and RMD maximum 0.10% S)	Crude Oil	Fossil	Standard refinery process	Grid mix electricity	LFO(ULSFO)_f_SR_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
4	LFO (VLSFO)	Light Fuel Oil (ISO 8217 Grades RMA, RMB and RMD, 0.10 < S ≤ 0.50%)	Crude Oil	Fossil	Standard refinery process	Grid mix electricity	LFO(VLSFO)_f_SR_gm
5	Diesel/Gas oil (ULSFO)	Marine Diesel/Gas Oil (ISO 8217 Grades DMX, DMA, DMZ and DMB maximum 0.10 % S)	Crude Oil	Fossil	Standard refinery process	Grid mix electricity	MDO/MGO(ULSFO)_f_SR_gm
6	Diesel/Gas oil (VLSFO)	Marine Diesel/Gas Oil (ISO 8217 Grades DMX, DMA, DMZ and DMB, 0.10 < S ≤ 0.50%)	Crude Oil	Fossil	Standard refinery process	Grid mix electricity	MDO/MGO(VLSFO)_f_SR_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
7	Diesel/Gas oil (ULSFO)	Bio co-processed marine fuel (ISO 8217 Grades DMX, DMA, DMZ and DMB maximum 0.10 % S)	Crude Oil + mixed biomass	Fossil/Biogenic	CoProcessing (CP) in refinery	Grid mix electricity	MDO/MGO(ULSFO)_f_b_CP_gm
8	Diesel/Gas oil (VLSFO)	Bio co-processed marine fuel (ISO 8217 Grades DMX, DMA, DMZ and DMB, 0.10 < S ≤ 0.50%)	Crude Oil + mixed biomass	Fossil/Biogenic	CoProcessing (CP) in refinery	Grid mix electricity	MDO/MGO(VLSFO)_f_b_CP_gm
9	Diesel/Gas oil (ULSFO)	Co-processed marine fuel (ISO 8217 Grades DMX, DMA, DMZ and DMB maximum 0.10 % S)	Crude Oil + recycled carbon	Fossil/Recycled carbon	CoProcessing (CP) in refinery	Grid mix electricity	MDO/MGO(ULSFO)_f_r_CP_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
10	Diesel/Gas oil (VLSFO)	Co-processed marine fuel (ISO 8217 Grades DMX, DMA, DMZ and DMB, 0.10 < S ≤ 0.50%)	Crude Oil + recycled carbon	Fossil/Recycled carbon	CoProcessing (CP) in refinery	Grid mix electricity	MDO/MGO(VLSFO)_f_r_CP_gm
11	LPG[19]	Liquefied Petroleum Gas (Propane)	Crude Oil	Fossil	Standard refinery process and liquefaction	Grid mix electricity	LPG(Propane)_f_SR_gm
12	LPG	Liquefied Petroleum Gas (Propane)	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Propane)_fCO2_fH2_FT_gm
13	LPG	Liquefied Petroleum Gas (Propane)	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture[20] H_2: from Renewable electricity	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Propane)_fCO2_rH2_FT_gm

19 Regarding LPG, these guidelines consider the final product form the refineries to be always liquefied.

20 CO_2: Fossil Point Source Carbon Capture includes captured CO_2 stemming from fuel combustion and captured CO_2 stemming from extraction of resources underground.

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
14	LPG	Liquefied Petroleum Gas (Propane)	CO_2 + H_2	CO_2: Fossil Point Source Carbon Capture H_2: Industrial by-product hydrogen	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Propane)_fCO2_ibpH2_FT_gm
15	LPG	Liquefied Petroleum Gas (Propane)	CO_2 + H_2	CO_2: Direct Air Capture H_2: Fossil Steam Methane Reformation	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Propane)_rCO2_fH2_FT_gm
16	LPG	Liquefied Petroleum Gas (Propane)	CO_2 + H_2	CO_2: Direct Air Capture H_2: from Renewable electricity	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Propane)_rCO2_rH2_FT_gm
17	LPG	Liquefied Petroleum Gas (Propane)	CO_2 + H_2	CO_2: Direct Air Capture H_2: Industrial by-product hydrogen	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Propane)_rCO2_ibpH2_FT_gm
18	LPG	Liquefied Petroleum Gas (Propane)	CO_2 + H_2	CO_2: Biogenic Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Propane)_bCO2_fH2_FT_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
19	LPG	Liquefied Petroleum Gas (Propane)	CO_2 + H_2	CO_2: Biogenic Point Source Carbon Capture H_2: from Renewable electricity	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Propane)_bCO2_rH2_FT_gm
20	LPG	Liquefied Petroleum Gas (Propane)	CO_2 + H_2	CO_2: Biogenic Point Source Carbon Capture H_2: Industrial by-product hydrogen	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Propane)_bCO2_ibpH2_FT_gm
21	LPG	Liquefied Petroleum Gas (Butane)	Crude Oil	Fossil	Standard refinery process and liquefaction	Grid mix electricity	LPG(Butane)_f_SR_gm
22	LPG	Liquefied Petroleum Gas (Butane)	CO_2 + H_2	CO_2: Fossil Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Butane)_fCO2_fH2_FT_gm
23	LPG	Liquefied Petroleum Gas (Butane)	CO_2 + H_2	CO_2: Fossil Point Source Carbon Capture H_2: from	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Butane)_fCO2_rH2_FT_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
				Renewable electricity			
24	LPG	Liquefied Petroleum Gas (Butane)	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture H_2: Industrial by-product hydrogen	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Butane)_fCO2_ibpH2_FT_gm
25	LPG	Liquefied Petroleum Gas (Butane)	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: Fossil Steam Methane Reformation	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Butane)_rCO2_fH2_FT_gm
26	LPG	Liquefied Petroleum Gas (Butane)	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: from Renewable electricity	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Butane)_rCO2_rH2_FT_gm
27	LPG	Liquefied Petroleum Gas (Butane)	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: Industrial by-product hydrogen	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Butane)_rCO2_ibpH2_FT_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
28	LPG	Liquefied Petroleum Gas (Butane)	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Butane)_bCO2_fH2_FT_gm
29	LPG	Liquefied Petroleum Gas (Butane)	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture H_2: from Renewable electricity	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Butane)_bCO2_rH2_FT_gm
30	LPG	Liquefied Petroleum Gas (Butane)	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture H_2: Industrial by-product hydrogen	Fischer-Tropsch Synthesis and liquefaction	Grid mix electricity	LPG(Butane)_bCO2_ibpH2_FT_gm
31	LNG	Liquefied Natural Gas (Methane)	Natural Gas	Fossil	Standard LNG production including liquefaction	Grid mix electricity	LNG_f_SLP_gm
32	LNG	Liquefied Natural Gas (Methane)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Thermochemical gasification followed by methanation and liquefaction	Grid mix electricity	LNG_b_G_M_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
33	LNG	Liquefied Natural Gas (Methane)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Bio-derived LNG via Anaerobic Digestion, separation and liquefaction	Grid mix electricity	LNG_b_AD_gm
34	LNG	Liquefied Natural Gas (Methane)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Bio-derived LNG via Anaerobic Digestion, separation with Point Source Carbon Capture (PSCC) and long-term storage and liquefaction	Grid mix electricity	LNG_b_AD_CCS_gm
35	LNG	Liquefied Natural Gas (Methane)	CO_2 + H_2	CO_2: Fossil Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Methanation and liquefaction	Grid mix electricity	LNG_fCO2_fH2_M_gm
36	LNG	Liquefied Natural Gas (Methane)	CO_2 + H_2	CO_2: Fossil Point Source Carbon Capture H_2: from Renewable electricity	Methanation and liquefaction	Grid mix electricity	LNG_fCO2_rH2_M_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
37	LNG	Liquefied Natural Gas (Methane)	CO_2 + H_2	CO_2: Fossil Point Source Carbon Capture H_2: Industrial by-product hydrogen	Methanation and liquefaction	Grid mix electricity	LNG_fCO2_ibpH2_M_gm
38	LNG	Liquefied Natural Gas (Methane)	CO_2 + H_2	CO_2: Direct Air Capture H_2: Fossil Steam Methane Reformation	Methanation and liquefaction	Grid mix electricity	LNG_rCO2_fH2_M_gm
39	LNG	Liquefied Natural Gas (Methane)	CO_2 + H_2	CO_2: Direct Air Capture H_2: from Renewable electricity	Methanation and liquefaction	Grid mix electricity	LNG_rCO2_rH2_M_gm
40	LNG	Liquefied Natural Gas (Methane)	CO_2 + H_2	CO_2: Direct Air Capture H_2: Industrial by-product hydrogen	Methanation and liquefaction	Grid mix electricity	LNG_rCO2_ibpH2_M_gm
41	LNG	Liquefied Natural Gas (Methane)	CO_2 + H_2	CO_2: Biogenic Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Methanation and liquefaction	Grid mix electricity	LNG_bCO2_fH2_M_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
42	LNG	Liquefied Natural Gas (Methane)	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture H_2: from Renewable electricity	Methanation and liquefaction	Grid mix electricity	LNG_bCO2_rH2_M_gm
43	LNG	Liquefied Natural Gas (Methane)	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture H_2: Industrial by-product hydrogen	Methanation and liquefaction	Grid mix electricity	LNG_bCO2_ibpH2_M_gm
44	CNG	Compressed Natural Gas (Methane)	Natural Gas	Fossil	Standard refinery process and compression	Grid mix electricity	CNG_f_SR_gm
45	CNG	Compressed Natural Gas (Methane)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Thermochemical gasification followed by methanation and compression	Grid mix electricity	CNG_b_G_M_gm
46	CNG	Compressed Natural Gas (Methane)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Bio-derived LNG via Anaerobic Digestion and separation and compression	Grid mix electricity	CNG_b_AD_gm
47	CNG	Compressed Natural Gas (Methane)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Bio-derived LNG via Anaerobic Digestion, separation with	Grid mix electricity	CNG_b_AD_CCS_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
					Point Source Carbon Capture (PSCC) and long-term storage and compression		
48	CNG	Compressed Natural Gas (Methane)	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Methanation and compression	Grid mix electricity	CNG_fCO2_fH2_M_gm
49	CNG	Compressed Natural Gas (Methane)	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture H_2: from Renewable electricity	Methanation and compression	Grid mix electricity	CNG_fCO2_rH2_M_gm
50	CNG	Compressed Natural Gas (Methane)	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture H_2: Industrial by-product hydrogen	Methanation and compression	Grid mix electricity	CNG_fCO2_ibpH2_M_gm
51	CNG	Compressed Natural Gas (Methane)	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: Fossil Steam	Methanation and compression	Grid mix electricity	CNG_rCO2_fH2_M_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
				Methane Reformation			
52	CNG	Compressed Natural Gas (Methane)	CO_2 + H_2	CO_2: Direct Air Capture H_2: from Renewable electricity	Methanation and compression	Grid mix electricity	CNG_rCO2_rH2_M_gm
53	CNG	Compressed Natural Gas (Methane)	CO_2 + H_2	CO_2: Direct Air Capture H_2: Industrial by-product hydrogen	Methanation and compression	Grid mix electricity	CNG_rCO2_ibpH2_M_gm
54	CNG	Compressed Natural Gas (Methane)	CO_2 + H_2	CO_2: Biogenic Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Methanation and compression	Grid mix electricity	CNG_bCO2_fH2_M_gm
55	CNG	Compressed Natural Gas (Methane)	CO_2 + H_2	CO_2: Biogenic Point Source Carbon Capture H_2: from Renewable electricity	Methanation and compression	Grid mix electricity	CNG_bCO2_rH2_M_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
56	CNG	Compressed Natural Gas (Methane)	CO_2 + H_2	CO_2: Biogenic Point Source Carbon Capture H_2: Industrial by-product hydrogen	Methanation and compression	Grid mix electricity	CNG_bCO2_ibpH2_M_gm
57	Ethane	Ethane	Natural Gas	Fossil	Standard refinery process	Grid mix electricity	Ethane_f_SR_gm
58	Vegetable oil-based fuel	Straight Vegetable Oil	1st Gen. feedstock	Biogenic	Extraction and purification	Grid mix electricity	SVO_b_EP _1stgen_gm
59	Vegetable oil-based fuel	Used oils and fats	2nd Gen. feedstock	Biogenic	Extraction and purification	Grid mix electricity	UOF_b_EP _2ndgen_gm
60	Vegetable oil-based fuel	Algae oil	3rd Gen. feedstock	Biogenic	Extraction and purification	Grid mix electricity	AO_b_EP _3rdgen_gm
61	Diesel	Diesel (FAME)	1st Gen. feedstock	Biogenic	Transesterification	Grid mix electricity	FAME_b_TRE_1stgen_gm_
62	Diesel	Diesel (FAME)	2nd Gen. feedstock	Biogenic	Transesterification	Grid mix electricity	FAME_b_TRE_2ndgen_gm_
63	Diesel	Diesel (FAME)	3rd Gen. feedstock	Biogenic	Transesterification	Grid mix electricity	FAME_b_TRE_3rdgen_gm_
64	Diesel	Renewable Diesel (Bio FT-Diesel)	1st Gen. feedstock	Biogenic	Gasification and Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_b_G_FT_1stgen_gm_
65	Diesel	Renewable Diesel (Bio FT-Diesel)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Anaerobic digestion and methane separation and	Grid mix electricity	FT-Diesel_b_AD_FT_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
					Fischer-Tropsch Synthesis		
66	Diesel	Renewable Diesel (Bio FT-Diesel)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Anaerobic digestion and methane separation and Fischer-Tropsch Synthesis with Point Source Carbon Capture (PSCC) and long-term storage	Grid mix electricity	FT-Diesel_b_AD_FT_CCS_gm
67	Diesel	Renewable Diesel (FT-Diesel)	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_fCO2_fH2_FT_gm
68	Diesel	Renewable Diesel (FT-Diesel)	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture H_2: from Renewable electricity	Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_fCO2_rH2_FT_gm
69	Diesel	Renewable Diesel (FT-Diesel)	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture	Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_fCO2_ibpH2_FT_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
				H_2: Industrial by-product hydrogen			
70	Diesel	Renewable Diesel (FT-Diesel)	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: Fossil Steam Methane Reformation	Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_rCO2_fH2_FT_gm
71	Diesel	Renewable Diesel (FT-Diesel)	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: from Renewable electricity	Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_rCO2_rH2_FT_gm
72	Diesel	Renewable Diesel (FT-Diesel)	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: Industrial by-product hydrogen	Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_rCO2_ibpH2_FT_gm
73	Diesel	Renewable Diesel (FT-Diesel)	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_bCO2_fH2_FT_gm
74	Diesel	Renewable Diesel (FT-Diesel)	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture	Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_bCO2_rH2_FT_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
				H_2: from Renewable electricity			
75	Diesel	Renewable Diesel (FT-Diesel)	CO_2 + H_2	CO_2: Biogenic Point Source Carbon Capture H_2: Industrial by-product hydrogen	Fischer-Tropsch Synthesis	Grid mix electricity	FT-Diesel_bCO2_ibpH2_FT_gm
76	Diesel	Renewable Diesel (HVO)	1st Gen. feedstock	Biogenic	Hydrogenation	Grid mix electricity	HVO_b_HD_1stgen_gm_
77	Diesel	Renewable Diesel (HVO)	2nd Gen. feedstock	Biogenic	Hydrogenation	Grid mix electricity	HVO_b_HD_2ndgen_gm_
78	Diesel	Renewable Diesel (HVO)	3rd Gen. feedstock	Biogenic	Hydrogenation	Grid mix electricity	HVO_b_HD_3rdgen_gm_
79	DME	Dimethyl Ether (DME)	1st Gen. feedstock	Biogenic	Gasification and DME Synthesis	Grid mix electricity	DME_b_G_DMES_1stgen_gm_
80	DME	Dimethyl Ether (DME)	2nd Gen. feedstock	Biogenic	Gasification and DME Synthesis	Grid mix electricity	DME-b-G-DMES_2ndgen_gm_
81	DME	Dimethyl Ether (DME)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Anaerobic digestion and methane separation and DME Synthesis	Grid mix electricity	DME_b_AD_DMES_gm
82	DME	Dimethyl Ether (DME)	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Anaerobic digestion and methane separation and	Grid mix electricity	DME_b_AD_DMES_CCS_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
					DME Synthesis with Point Source Carbon Capture (PSCC) and long-term storage		
83	DME	Dimethyl Ether (DME)	Natural Gas	Fossil	Gasification and DME Synthesis	Grid mix electricity	DME_f_G_DMES_gm
84	Diesel	Upgraded Pyrolysis Oil	2nd Gen. feedstock	Biogenic	Pyrolysis, Fast Pyrolysis, and/or Catalytic Fast Pyrolysis and upgrading	Grid mix electricity	UPO_b_UPO_2ndgen_gm_
85	Diesel	Hydrothermal Liquefaction (HTL) Oil	2nd Gen. feedstock	Biogenic	Hydrothermal liquefaction and upgrading	Grid mix electricity	HTL_b_HTL_2ndgen_gm_
86	Methanol	Methanol	Natural Gas	Fossil	Steam Methane Reformation of Natural Gas and Methanol Synthesis	Grid mix electricity	MeOH_f_SMR_gm
87	Methanol	Methanol	Natural Gas	Fossil	Steam Methane Reformation of Natural Gas with Carbon Capture & Storage and Methanol Synthesis	Grid mix electricity	MeOH_f_SMR_CCS_gm
88	Methanol	Methanol	Coal	Fossil	Gasification of Coal and Methanol Synthesis	Grid mix electricity	MeOH_f_G_MS_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
89	Methanol	Methanol	Coal	Fossil	Gasification of Coal with Carbon Capture & Storage and Methanol Synthesis	Grid mix electricity	MeOH_f_G_MS_CCS _gm
90	Methanol	Methanol	2nd and 3rd Gen. feedstock	Biogenic	Gasification of Biomass and Methanol Synthesis	Grid mix electricity	MeOH_b_G_MS_gm
91	Methanol	Methanol	Mixed 1st, 2nd and 3rd Gen. feedstock	Biogenic	Reforming of Renewable Natural Gas (biomethane from Anaerobic Digestion) and Methanol Synthesis	Grid mix electricity	MeOH_b_AD_MS_gm
92	Methanol	Methanol	CO_2 + H_2	CO_2: Fossil Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Methanol Synthesis	Grid mix electricity	MeOH_fCO2_fH2_MS_gm
93	Methanol	Methanol	CO_2 + H_2	CO_2: Fossil Point Source Carbon Capture H_2: from Renewable electricity	Methanol Synthesis	Grid mix electricity	MeOH_fCO2_rH2_MS_g m

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
94	Methanol	Methanol	$CO_2 + H_2$	CO_2: Fossil Point Source Carbon Capture H_2: Industrial by-product hydrogen	Methanol Synthesis	Grid mix electricity	MeOH_fCO2_ibpH2_MS_gm
95	Methanol	Methanol	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: Fossil Steam Methane Reformation	Methanol Synthesis	Grid mix electricity	MeOH_rCO2_fH2_MS_gm
96	Methanol	Methanol	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: from Renewable electricity	Methanol Synthesis	Grid mix electricity	MeOH_rCO2_rH2_MS_gm
97	Methanol	Methanol	$CO_2 + H_2$	CO_2: Direct Air Capture H_2: Industrial by-product hydrogen	Methanol Synthesis	Grid mix electricity	MeOH_rCO2_ibpH2_MS_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
98	Methanol	Methanol	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture H_2: Fossil Steam Methane Reformation	Methanol Synthesis	Grid mix electricity	MeOH_bCO2_fH2_MS_gm
99	Methanol	Methanol	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture H_2: from Renewable electricity	Methanol Synthesis	Grid mix electricity	MeOH_bCO2_rH2_MS_gm
100	Methanol	Methanol	$CO_2 + H_2$	CO_2: Biogenic Point Source Carbon Capture H_2: Industrial by-product hydrogen	Methanol Synthesis	Grid mix electricity	MeOH_bCO2_ibpH2_MS_gm
101	Ethanol	Ethanol	1st Gen. feedstock	Biogenic	Fermentation	Grid mix electricity	EtOH_b_FR_1stgen_gm_
102	Ethanol	Ethanol	2nd Gen. feedstock	Biogenic	Pretreatment/hydrolysis step and Fermentation	Grid mix electricity	EtOH_b_FR_2ndgen_gm_
103	Ethanol	Ethanol	3rd Gen. feedstock	Biogenic	Fermentation	Grid mix electricity	EtOH_b_FR_3rdgen_gm_

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
104	Hydrogen	Hydrogen	Natural Gas	Fossil	Steam Methane Reformation of Natural Gas	Grid mix electricity	H2_f_SMR_gm
105	Hydrogen	Hydrogen	Natural Gas	Fossil	Steam Methane Reformation of Natural Gas with Carbon Capture and long-term storage	Grid mix electricity	H2_f_SMR_CCS_gm
106	Hydrogen	Hydrogen	Natural Gas	Fossil	Methane Pyrolysis into carbon and hydrogen	Grid mix electricity	H2_f_MPO_gm
107	Hydrogen	Hydrogen	Coal	Fossil	Gasification or Carbonization of Coal	Grid mix electricity	H2_f_G_gm
108	Hydrogen	Hydrogen	Coal	Fossil	Gasification or Carbonization of Coal with Carbon Capture and long-term storage	Grid mix electricity	H2_f_G_CCS _gm
109	Hydrogen	Hydrogen	2nd Gen. feedstock	Biogenic	Gasification of biomass and Syngas separation with Point Source Carbon Capture (PSCC) and long-term storage	Grid mix electricity	H2_b_G_SS_CCS_2ndgen_gm_
110	Hydrogen	Hydrogen	Water + Electricity	Renewable	Dedicated Photovoltaic and/or Wind and/or	Renewable electricity	LH2_EL_r_Liquefied

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
					other Electrolysis and liquefaction		
111	Hydrogen	Hydrogen	Water + Electricity	Fossil/Renewable	Electrolysis and liquefaction	Grid mix electricity	LH2_EL_gm_Liquefied
112	Hydrogen	Hydrogen	Water + Electricity	Nuclear	Thermochemical Cycles or Electrolysis and liquefaction	Nuclear	LH2_EL_n_Liquefied
113	Hydrogen	Hydrogen		Industrial by-product hydrogen		Grid mix electricity	LH2_ _ibp_gm _Liquefied
114	Ammonia	Ammonia	Natural Gas	Fossil	Methane Pyrolysis into pure carbon and hydrogen and Haber Bosch process	Grid mix electricity	NH3_f_MPO_HB_gm
115	Ammonia	Ammonia	Natural Gas	Fossil	Steam Methane Reformation of Natural Gas and Haber Bosch process	Grid mix electricity	NH3_f_SMR_HB_gm
116	Ammonia	Ammonia	Natural Gas	Fossil	Steam Methane Reformation of Natural Gas with Point Source Carbon Capture (PSCC) and long-term storage and	Grid mix electricity	NH3_f_SMR_HB_CCS_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
					Haber Bosch process		
117	Ammonia	Ammonia	Coal	Fossil	Gasification of Coal and Haber Bosch process	Grid mix electricity	NH3_f_G_HB_gm
118	Ammonia	Ammonia	Coal	Fossil	Gasification of Coal with Carbon Capture and long-term storage and Haber Bosch process	Grid mix electricity	NH3_f_G_HB_CCS_gm
119	Ammonia	Ammonia	2nd Gen. feedstock	Biogenic	Gasification	Grid mix electricity	NH3_b_G_2ndgen_gm_
120	Ammonia	Ammonia	$N_2 + H_2$	N_2: separated with renewable electricity H_2: produced from renewable electricity	Haber Bosch process	Grid mix electricity	NH3_rN2_rH2_HB_gm
121	Ammonia	Ammonia	$N_2 + H_2$	N_2: separated with renewable electricity H_2: Fossil Steam Methane Reformation	Haber Bosch process	Grid mix electricity	NH3_rN2_fH2_HB_gm

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
122	Ammonia	Ammonia	N_2 + H_2	N_2: separated with renewable electricity H_2: Industrial by-product hydrogen	Haber Bosch process	Grid mix electricity	NH3_rN2_ibpH2_HB_gm
123	Ammonia	Ammonia	N_2 + H_2	N_2: separated with grid mix electricity H_2: Fossil Steam Methane Reformation	Thermochemical Cycles or Electrolysis	Nuclear	NH3_gmN2_fH2_EL_n
124	Ammonia	Ammonia	N_2 + H_2	N_2: separated with grid mix electricity H_2: produced from renewable electricity	Thermochemical Cycles or Electrolysis	Nuclear	NH3_gmN2_rH2_EL_n
125	Ammonia	Ammonia	N_2 + H_2	N_2: separated with grid mix electricity H_2: Industrial by-product hydrogen	Thermochemical Cycles or Electrolysis	Nuclear	NH3_gmN2_ibpH2_EL_n
126	Electricity	Electricity		Fossil/Renewable	-	Grid mix electricity	Electricity_gm
127	Electricity	Electricity		Renewable	Dedicated Photovoltaic and/or Wind and/or other	Renewable electricity	Electricity_renewable

Order	Group	Fuel type	Feedstock structure		Conversion/Production process		Fuel Pathway Code
			Feedstock Type	Nature/Carbon Source	Process Type	Energy used in the process	
128	Wind propulsion						

APPENDIX 2

INITIAL DEFAULT EMISSION FACTORS PER FUEL PATHWAY CODE

Order	Fuel type	Fuel Pathway Code	WtT GHG intensity (gCO_{2eq}/MJ)	LCV (MJ/g)	Energy Converter	C_f CO_2 (gCO_2/g fuel)	C_f CH_4 (gCH_4/g fuel)	C_f N_2O (gN_2O/g fuel)	C_{slip} /C_{fug} (mass %)	e_c gCO_{2eq} /g fuel	TtW GHG intensity (gCO2eq /MJ)	NOTE
1	Heavy Fuel Oil (ISO 8217 Grades RME, RMG and RMK, 0.10 < S ≤ 0.50%)	HFO(VLSFO)_f_SR_gm	16.8	0.0402	ALL ICEs	3.114	0.00005	0.00018				Resolution MEPC.364(79) Fourth IMO GHG study
2	Heavy Fuel Oil (ISO 8217 Grades RME, RMG and RMK exceeding 0.50% S)	HFO(HSHFO)_f_SR_gm	14.9	0.0402	ALL ICEs	3.114	0.00005	0.00018				Resolution MEPC.364(79) Fourth IMO GHG study
3	Light Fuel Oil (ISO 8217 Grades RMA, RMB and RMD maximum 0.10% S)	LFO(ULSFO)_f_SR_gm		0.0412	ALL ICEs	3.151	0.00005	0.00018				Resolution MEPC.364(79) Fourth IMO GHG study
4	Light Fuel Oil (ISO 8217 Grades RMA, RMB and RMD, 0.10 < S ≤ 0.50%)	LFO(VLSFO)_f_SR_gm		0.0412	ALL ICEs	3.151	0.00005	0.00018				Resolution MEPC.364(79) Fourth IMO GHG study

Order	Fuel type	Fuel Pathway Code	WtT GHG intensity (gCO_{2eq}/MJ)	LCV (MJ/g)	Energy Converter	C_f CO_2 (gCO_2/g fuel)	C_f CH_4 (gCH_4/g fuel)	C_f N_2O (gN_2O/g fuel)	C_{slip} /C_{fug} (mass %)	e_c gCO_{2eq} /g fuel	TtW GHG intensity (gCO2eq /MJ)	NOTE
5	Marine Diesel/Gas Oil (ISO 8217 Grades DMX, DMA, DMZ and DMB maximum 0.10 % S)	MDO/MGO(ULSFO)_f_SR_gm	17.7	0.0427	ALL ICEs	3.206	0.00005	0.00018				Resolution MEPC.364(79) Fourth IMO GHG study
6	Marine Diesel/Gas Oil (ISO 8217 Grades DMX, DMA, DMZ and DMB, 0.10 < S ≤ 0.50%)	MDO/MGO(VLSFO)_f_SR_gm		0.0427	ALL ICEs	3.206	0.00005	0.00018				Resolution MEPC.364(79) Fourth IMO GHG study
11	Liquefied Petroleum Gas (Propane)	LPG(Propane)_f_SR_gm		0.0463	ALL ICEs	3.000	0.00005	0.00018				Resolution MEPC.364(79) Fourth IMO GHG study
21	Liquefied Petroleum Gas (Butane)	LPG(Butane)_f_SR_gm		0.0457	ALL ICEs	3.030	0.00005	0.00018				Resolution MEPC.364(79) Fourth IMO GHG study

Order	Fuel type	Fuel Pathway Code	WtT GHG intensity (gCO_{2eq}/MJ)	LCV (MJ/g)	Energy Converter	C_f CO_2 (gCO_2/g fuel)	C_f CH_4 (gCH_4/g fuel)	C_f N_2O (gN_2O/g fuel)	C_{slip} /C_{fug} (mass %)	e_c gCO_{2eq}/g fuel	TtW GHG intensity (gCO2eq /MJ)	NOTE
31	Liquefied Natural Gas (Methane)	LNG_f_SLP_gm		0.0480	LNG Otto (dual fuel medium speed)	2.750	0	0.00011	3.5/-			Resolution MEPC.364(79) Fourth IMO GHG study
					LNG Otto (dual fuel slow speed)				1.7/-			
					LNG Diesel (dual fuel slow speed)				0.15/-			
					LBSI (Lean-Burn Spark-Ignited)				2.6/-			
					Steam Turbines and boilers				0.01/-			

Order	Fuel type	Fuel Pathway Code	WtT GHG intensity (gCO_{2eq}/ MJ)	LCV (MJ/g)	Energy Converter	C_f CO_2 (gCO_2/g fuel)	C_f CH_4 (gCH_4/g fuel)	C_f N_2O (gN_2O/g fuel)	C_{slip} /C_{fug} (mass %)	e_c gCO_{2eq}/g fuel	TtW GHG intensity (gCO2eq /MJ)	NOTE
33	Liquefied Natural Gas (Methane)	LNG_b_AD_gm			LNG Otto (dual fuel medium speed)	2.750						
					LNG Otto (dual fuel slow speed)							
					LNG Diesel (dual fuel slow speed)							
					LBSI (Lean-Burn Spark-Ignited)							
					Steam Turbines and boilers							
62	Diesel (FAME)	FAME_b_TRE_gm_2ndgen	20.8	0.0372	ALL ICEs							
77	Renewable Diesel (HVO)	HVO_b_HD_gm_1stgen	14.9	0.044	ALL ICEs							

Order	Fuel type	Fuel Pathway Code	WtT GHG intensity (gCO_{2eq}/MJ)	LCV (MJ/g)	Energy Converter	C_f CO_2 (gCO_2/g fuel)	C_f CH_4 (gCH_4/g fuel)	C_f N_2O (gN_2O/g fuel)	C_{slip} /C_{fug} (mass %)	e_c gCO_{2eq}/g fuel	TtW GHG intensity (gCO2eq /MJ)	NOTE
105	Hydrogen	H2_f_SMR_CCS_gm		0.12	ALL ICEs	0						
					Fuel cell							
121	Ammonia	NH3_rN2_fH2_HB_gm		0.0186	ALL ICEs	0						
					Fuel cell							

APPENDIX 3

ABBREVIATIONS AND GLOSSARY

Abbreviations

AR – IPCC Assessment Report
BDN – Bunkering Delivery Note
C_f – Emission conversion factors $C_{fCO2/CH4/N2O}$ (g GHG (CO_2/CH_4/N_2O)/g fuel) for emissions of the combustion and/or oxidation process, including the fuel with relevant GWP effect resulting from the combustion energy conversion
CH_4 – Methane
CO_2 – Carbon dioxide
CO_{2eq} – Carbon dioxide equivalent
CCS – Carbon Capture and Storage
CCU – Carbon Capture and Utilization
DAC – Direct Air Capture
DCS – IMO ship fuel oil consumption Data Collection System
DLUC – Direct Land Use Change
FLL – Fuel Lifecycle Label
GHG – Greenhouse gas
GWP – Global Warming Potential
ILUC – Indirect Land Use Change
IPCC – Intergovernmental Panel on Climate Change
LCA – Life Cycle Assessment
LCV – Lower Calorific Value (MJ/g fuel)
NMVOC – Non-Methane Volatile Organic Compounds
N_2O – Nitrous oxide
NTC – NO_x Technical Code
RFNBO – Renewable Fuels of Non-Biological Origin
SLCF – Short-Lived Climate Forcers
TtW – Tank-to-Wake
WtT – Well-to-Tank
WtW – Well-to-Wake
VOC – Volatile Organic Compounds

Glossary

Co-product – an outcome of a production process, which has a relevant economic value and elastic supply (intended as the existence of a clear evidence of the causal link between feedstock market value and the quantity of feedstock that can be produced).

Biomass – Biomass is renewable organic material that comes from plants and animals.

Renewables – any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. Renewables are obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes low-carbon technologies such as solar energy, hydropower, wind, tide and waves and ocean thermal energy, as well as renewable fuels such as biomass.

Global Warming Potential – Global Warming Potential indicates the potential of a greenhouse gas to trap extra heat in the atmosphere over time in relation to carbon dioxide. The enhanced heat trapping in the atmosphere (i.e. the "greenhouse effect") is caused by the absorption of infrared radiation by a given gas. The GWP also depends on the atmospheric lifetime of a gas, and the time-horizon considered (for example, GWP20 is based on the energy absorbed over 20 years, whereas GWP100 is based on the energy absorbed over 100 years. Each greenhouse gas has a specific global warming potential which is used to calculate the CO_2-equivalent (CO_{2eq}).

Land Use Change - Production of bio-based fuels leads to land use change (LUC). LUC can be classified as direct LUC (DLUC) and indirect LUC (ILUC).

Life Cycle Assessment (LCA) framework – Life Cycle Assessment determines the potential environmental impacts of products, processes or services from cradle to grave, e.g. from acquisition/extraction of raw materials through to processing, transport, use and disposal.

System boundaries – The system boundary determines which entities (unit processes) are inside the system and which are outside. It essentially determines which life cycle/supply chain stages and processes are included in the assessment and need to be in accordance with the goal and scope of the study.

System expansion – ISO 14040 recommends the use of system expansion whenever possible. System expansion is part of the consequential LCA method that seeks to capture change in environmental impact as a consequence of a certain activity.

Well-to-Wake - WtW studies estimate the energy requirements and the resulting greenhouse gas (GHG) emissions in the production of a fuel and its use in a ship, based on the broader Life Cycle Assessment (LCA) methodology. The term 'Well' is used for fuels from all sources, because although the term is most applicable to conventional crude oil resources, it is widely used and understood.

APPENDIX 4

TEMPLATE FOR WELL-TO-TANK DEFAULT EMISSION FACTOR SUBMISSION

1 ***Explanatory remarks on the general scope of the template:*** *This template aims at collecting and presenting in a clear and structured manner the input data used to calculate a "default emission factor" for a specific "feedstock-to-fuel" pathway. A "default emission factor" aims as representing the quantitative results of a high-level assessment about the carbon intensity (*gCO_{2eq}*/MJ) of a feedstock-to-fuel value chain. The default emission factor is not meant to represent the best available way to produce a fuel, rather a value potentially describing a feedstock production then converted in a standard plant, located in a generic region. A default emission factor does not have to capture process improvement, with respect to current production, nor innovative technologies. The goal of default emission factor is, at least, twofold:*

.1 allow for a carbon intensity comparison among different technologies;

.2 allow for operators to demonstrate lower core life cycle emissions compared to the default core life cycle, thought a certification process.

2 Operators (e.g. fuel producers) can ask for being certified, in order to prove better performances than the default emission factor (that cannot therefore be the representation of the best available technology), obtain a certified "actual value". Actual values may also be used when the fuel producer has defined a new pathway that does not have a default core life cycle emission factor.

3 This template allows presenting the minimum set of data required for the calculation of default core LCA emission factors, ensuring quality in terms of data relevance, adequacy, quality, transparency and accessibility.

PATHWAY DESCRIPTION

4 This section should clearly present the pathway modelled, with the aim for providing at least information on: the type of feedstock used, a description of the technology used for converting such feedstock in the final fuel, and any other relevant information, consistently with the system boundary of the LCA guidelines.

5 ***Explanatory remarks on the pathway description:*** *The default emission factors are based on the WtT methodology, aiming at evaluating the amount of GHG emissions for the fuel production and distribution. The production steps to be included in the WtT are:*

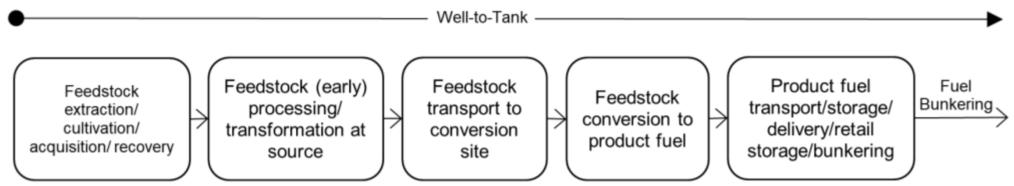

Figure 2 – Generic well-to-tank supply chain

The system boundaries defined for describing a specific feedstock-to-fuel pathway shall be in line with the definitions contained in the guidelines.

Additional details and relevant information may be added in appendices, such as location, production capacity, age of production facility or facilities.

INPUT DESCRIPTION

6 This section should clearly present the input used for the modelling exercise.

7 Source of the data and of the used model should be reported.

8 ***Explanatory remarks on the input description****: In order to provide guidance to fill the template, please see below some tables aiming at presenting the data that should be reported, per pathway (example based on a lipid feedstock production and conversion). As, in practical terms, the tables are "pathway specific", please adapt when needed.*

Table 1: e_{fecu} inputs and outputs for XXX feedstock

				XXXX, per dry kg	**Data source/Model used**
	XXX feedstock	Agricultural Inputs	Total N (g)	…	zzz et al. 2010
e_{fecu}			P_2O_5 (g)	…	ecoinvent
			K_2O (g)	…	GREET
			Diesel (MJ)	…	…
			…	…	…
		per kg XXXX oil			
		Oil Extraction Inputs		Values	Data source/ Model used
			Feedstock (g, dry)	…	zzz et al. 2010
			NG (MJ)	…	ecoinvent
			N-Hexane (MJ)	…	GREET
			Electricity (MJ)	…	…
			Electricity (MJ)	…	…
			…	…	…
			Co-product, zzz(g)	…	…
			Co-product, zzz (g)	…	…
		Oil Extraction Outputs	Co-product, zzz (g)	…	…
			…	…	…

Table 2: e_p Inputs and outputs for XXXX conversion process *Explanatory remark: including all the needed steps to pre-treat the feedstock in order to be able to convert it into the fuel, via the selected conversion process.*

	per MJ fuel		
		Values	**Data source/model used**
Inputs	Feedstock (g oil)	…	zzz et al. 2010
	NG (MJ)	…	ecoinvent
	H_2 (MJ)	*	GREET
	Electricity (MJ)	…	…
	Explanatory remark: *placeholder for key material inputs (e.g. chemicals, etc.)*	…	…
Outputs	Co-product, propane mix (MJ)	**	…
	Co-product, naphtha (MJ)	**	…
	Co-product, xxxx (MJ)	…	…
	…	…	…

*H_2 derived from NG steam reforming, included in NG input; ** Inputs after allocation

Table 3: Inputs for regional electricity generation mixes

	US (%)[1]	**EU (%)[2]**	**India[3] (%)**	**Xxx (%)**
Residual oil	…	…	…	…
Natural gas	…	…	…	…
Coal	…	…	…	…
Nuclear power	…	…	…	…
Biomass	…	…	…	…
Hydroelectric	…	…	…	…
Geothermal	…	…	…	…
Wind	…	…	…	…
Solar PV	…	…	…	…
Others	…	…	…	…

[1] GREET 20xx, [2] EEA, 20xx (EU electricity mix 20xx), [3]International Energy Agency 20xx.

Table 4: e_{td} Inputs for transportation of feedstock and fuels *Explanatory remark: in filling the table, please add the fuel used - In the "Data source/model used" please specify the type of fuel, the specific efficiency and energy converter, if available*.

	Feedstock Transportation		Data source/model used
e_{td} Inputs for Transport and Distribution	Distance (km)	xxx; xxx	
	Mode	Heavy-duty truck; Train; Ship	
	Share (%)	yy; yy; yyy	
	Fuel Transportation		
	Distance (km)	xxx; xxxx; xx	
	Mode	Barge; Rail; Heavy-duty truck	
	Share (%)	y; yy; yy	
	Fuel Distribution		
	Distance (km)	xx	
	Mode	Heavy-duty truck	
	Share (%)		
	…	…	
	Any other Transportation and Distribution		

MAIN RESULTS

9 This section should present the results of the modelled pathway.

Table 5: Fuel identification

Fuel Pathway Code	LCV (MJ/g)	Density (kg/m^3)	$CfCO_2$

Table 6: Proposed default emission factors for XXX-converted in a YYYY pathway

Region	efecu Feedstock cultivation/extraction	etd Feedstock transportation	ep Fuel production	(Sum of the terms) Proposed WtT GHG intensity (gCO_{2eq}/MJ) emission factors
ZZZZ				
AAAA				
BBBB				
…				

APPENDIX

10 Brief description of the pathway

11 Brief description of the technology
….

REFERENCES

12 REF (APA format)

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