ALTERNATIVE LOW EMISSION FUEL FOR THE MARITIME INDUSTRY

SHIPOWNERS

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ALTERNATIVE LOW EMISSION FUEL FOR THE MARITIME INDUSTRY

In line with the UN Sustainable Development Goal 13, Climate Action, the maritime industry is urgently researching viable options for low emission alternative fuels. The aim is to meet the International Maritime Organization's (IMO) initial goals for international shipping to reduce Carbon Dioxide (CO_2) emissions by at least 40% by 2030 (pursuing efforts of a 70% reduction by 2050) and total annual Greenhouse Gas (GHG) emissions by at least 50% by 2050, compared to 2008 levels.

The Club believes that it is important for industry stakeholders to understand as best we can, which factors may influence the take up of low emission alternative fuels and what practical impacts may be experienced or require consideration by ship owners, operators, managers and crew. This document aims to assist with raising awareness and deepening understanding to this end.

Shipowner's P&I Club has collaborated with Colin Robertshaw, Doctoral Researcher at University College London (UCL) Energy Institute and a consultant to University Maritime Advisory Services (UMAS), who leveraged his PhD studentship, to produce this reference document which summarises the performance of fuel products against selected, important criteria. Colin specialises in low/zero GHG emission alternative fuels research for the maritime industry and is passionate about contributing to the effort of delivering sustainable and realistic solutions without compromising on safety in pursuit of the goal to combat climate change.

HOW TO USE THIS DOCUMENT

When interrogating particular fuel performance aspects, navigation is undertaken by clicking on the fields in the summary table (Page 3) and by using the 'return to summary' button throughout. Readers can also browse through at their leisure, if preferred.

OVERALL PERFORMANCE OF FUEL PRODUCTS

	Operational Safety and the Environment					Characteristics of Operational Utilisation				Characteristics of Fuel Production		
Fuel Product	Personnel Hazards	Vessel Hazards	Environmental Hazards	Applicable Regulations	Training Requirements	Fuel Characteristics	Production Methods	Carriage State	Possible Interchangeability	Sustainability Issues	Fuel Availability	Adoption Trends
Heavy Oil	Moderate	Very good	Very poor	Good	Very good	Very poor	Good	Good	Very good	Good	Very good	Good
Gas Oil	Good	Very good	Poor	Good	Very good	Very poor	Poor	Very good	Very good	Poor	Very good	Very good
FAME	Very good	Very good	Good	Poor	Good	Poor	Very poor	Good	Very good	Very poor	Poor	Very good
HVO	Very good	Very good	Moderate	Poor	Good	Poor	Very poor	Good	Very good	Very poor	Poor	Good
FT-Diesel	Good	Very good	Poor	Good	Very good	Poor	Moderate	Very good	Very good	Moderate	Good	Very good
Ethanol	Poor	Good	Moderate	Poor	Good	Moderate	Very poor	Moderate	Good	Very poor	Poor	Very poor
Methanol	Very poor	Good	Moderate	Poor	Good	Moderate	Good	Moderate	Good	Very good	Moderate	Very poor
Petroleum Gas	Good	Good	Very good	Good	Moderate	Good	Very good	Poor	Very poor	Very good	Good	Moderate
Dimethyl Ether	Very good	Poor	Very poor	Moderate	Poor	Moderate	Good	Poor	Poor	Very poor	Moderate	Poor
Ammonia	Moderate	Moderate	Poor	Very poor	Very poor	Very good	Good	Poor	Very poor	Moderate	Good	Very poor
Ethane	Moderate	Moderate	Poor	Good	Poor	Poor	Very good	Poor	Very poor	Good	Very poor	Poor
Methane	Poor	Moderate	Very good	Very good	Moderate	Poor	Good	Very poor	Very poor	Good	Good	Poor
Hydrogen	Very poor	Very poor	Very good	Moderate	Very poor	Very good	Good	Very poor	Very poor	Very good	Very poor	Very poor

Table Notes

Performance of the fuel products is specified in accordance with a five-point scale ranging from very poor to very good. Each specification refers to the individual fuel product for the corresponding aspect. These specifications do not relate to absolute performance of the fuel products rather with respect to one another when considered as a group of potential alternatives. As such, the introduction of further alternatives or the removal of those already considered above could result in changes to the rating. The criteria behind the assessment are further detailed in the following tables:

OPERATIONAL SAFETY AND THE ENVIRONMENT

Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Heavy Oil	**Negative Points** ▪ Category 1 aspiration hazard for personnel; ▪ Category 1B carcinogenicity hazard for personnel; ▪ Category 2 specific target organ toxicity hazard through repeated exposure for personnel; ▪ Category 2 reproductive toxicity hazard for personnel; ▪ Category 4 toxicity hazard (acute) through inhalation for personnel; ▪ High temperature systems are necessary to facilitate on board utilisation. **Positive Points** ▪ Creation of a deoxygenated atmosphere inhibited as semi-solid liquid in its natural state; ▪ Moderate levels of exposure through dermal contact and/or oral ingestion are necessary to cause medical issues.	**Negative Points** ▪ Storage at elevated temperatures is necessary; ▪ Moderate and variable flashpoint temperature; ▪ Moderate and variable auto-ignition temperature; ▪ Low oxygenated concentration for lower explosive limit; ▪ Moderate limiting Oxygen concentration for combustion. **Positive Points** ▪ Storage at atmospheric pressures and elevated temperatures with conventional ventilation arrangements; ▪ Low oxygenated concentration for upper explosive limit; ▪ Very small explosive envelope characteristics.	**Negative Points** ▪ Category 1 hazard (acute/chronic) to aquatic environment; ▪ Very high impact for algae/crustaceans, high impact for fish; ▪ Potential for bioaccumulation within the natural environment; ▪ Specific density can be comparable to and/or greater than that of seawater. **Positive Points** ▪ Insoluble in seawater; ▪ Slowly biodegradable in the environment; ▪ No additional global warming potential due to atmospheric release.	**Cargo Specific** ▪ Liquid hydrocarbon cargo carried in bulk; ▪ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▪ Vessel construction verification through international oil pollution prevention certificate (Form B); ▪ Insurance coverage required as per the international convention on civil liability for oil pollution damage. **Fuel Specific** ▪ Liquid hydrocarbon fuel carried in aggregate; ▪ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▪ Vessel construction verification through international oil pollution prevention certificate (Form A); ▪ Insurance coverage required as per the international convention on civil liability for bunker oil pollution damage.	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - oil tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Training requirements covered within the STCW convention with certification issued through flag state administrations; ▪ Forms the reference case against which the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code) measures requirements for alternative fuels.

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Gas Oil	**Negative Points** ▪ Category 1 aspiration hazard for personnel; ▪ Category 2 carcinogenicity hazard for personnel; ▪ Category 2 specific target organ toxicity hazard through repeated exposure for personnel; ▪ Category 2 skin corrosion/ irritation hazard for personnel; ▪ Category 4 toxicity hazard (acute) through inhalation for personnel; **Positive Points** ▪ Systems operating at atmospheric temperature to facilitate on board utilisation; ▪ Creation of a deoxygenated atmosphere inhibited as liquid in its natural state; ▪ Moderate levels of exposure through dermal contact and/or high levels of oral ingestion are necessary to cause medical issues.	**Negative Points** ▪ Low auto-ignition temperature; ▪ Low oxygenated concentration for lower explosive limit; ▪ Moderate limiting Oxygen concentration for combustion. **Positive Points** ▪ High and fixed flashpoint temperature; ▪ Storage at atmospheric pressures and temperatures with conventional ventilation arrangements; ▪ Low oxygenated concentration for upper explosive limit; ▪ Very small explosive envelope characteristics.	**Negative Points** ▪ Category 2 hazard (chronic) to aquatic environment; ▪ High impact for algae, moderate impact for crustaceans and fish; ▪ Low potential for bioaccumulation within the natural environment; ▪ Specific density close to but less than that of seawater. **Positive Points** ▪ Insoluble in seawater; ▪ Readily biodegradable in the environment; ▪ No additional global warming potential due to atmospheric release.	**Cargo Specific** ▪ Liquid hydrocarbon cargo carried in bulk; ▪ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▪ Vessel construction verification through international oil pollution prevention certificate (Form B); ▪ Insurance coverage required as per the international convention on civil liability for oil pollution damage. **Fuel Specific** ▪ Liquid hydrocarbon fuel carried in aggregate; ▪ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▪ Vessel construction verification through international oil pollution prevention certificate (Form A); ▪ Insurance coverage required as per the international convention on civil liability for bunker oil pollution damage.	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - oil tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Training requirements covered within the STCW convention with certification issued through flag state administrations; ▪ Forms the reference case against which the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code) measures requirements for alternative fuels.

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Fatty Acid Methyl Ester (FAME)	**Negative Points** ▫ None applicable. **Positive Points** ▫ No hazard categorisations for personnel are associated with the product; ▫ Systems operating at atmospheric temperature to facilitate on board utilisation; ▫ Creation of a deoxygenated atmosphere inhibited as liquid in its natural state; ▫ Moderate levels of exposure through dermal contact and/or oral ingestion are necessary to cause medical issues.	**Negative Points** ▫ Very low auto-ignition temperature; ▫ Low oxygenated concentration for lower explosive limit; ▫ Moderate limiting Oxygen concentration for combustion. **Positive Points** ▫ Very high and fixed flashpoint temperature; ▫ Storage at atmospheric pressures and temperatures with conventional ventilation arrangements; ▫ Low oxygenated concentration for upper explosive limit; ▫ Very small explosive envelope characteristics.	**Negative Points** ▫ None applicable. **Positive Points** ▫ Categorised as non-hazardous to aquatic environment; ▫ Low impact for crustaceans; ▫ Very low impact for algae and fish; ▫ Low levels of solubility in seawater; ▫ Bioaccumulation within the natural environment is unlikely. ▫ Readily biodegradable in the environment; ▫ Specific density less than that of seawater;	**Cargo Specific** ▫ Liquid chemical cargo carried in bulk; ▫ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▫ Also regulated under the International Bulk Chemical (IBC) code; ▫ Vessel construction verification through international oil pollution prevention certificate (Form B); ▫ Construction standards also verified through certificate of fitness for the carriage of dangerous chemicals in bulk; ▫ Insurance coverage required as per the international convention on civil liability for oil pollution damage. **Fuel Specific** ▫ Liquid chemical fuel carried in aggregate; ▫ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▫ Vessel construction verification through international oil pollution prevention certificate (Form A); ▫ Insurance coverage required as per the international convention on civil liability for bunker oil pollution damage.	**Cargo Specific** ▫ Additional training requirements beyond those applicable to other vessel types - chemical tanker endorsement; ▫ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▫ Training requirements covered within the STCW convention with certification issued through flag state administrations; ▫ Forms the reference case against which the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code) measures requirements for alternative fuels.

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Hydrotreated Vegetable Oil (HVO)	**Negative Points** ▪ Category 1 aspiration hazard for personnel; **Positive Points** ▪ Systems operating at atmospheric temperature to facilitate on board utilisation; ▪ Creation of a deoxygenated atmosphere inhibited as liquid in its natural state; ▪ Moderate levels of exposure through dermal contact and/ or oral ingestion are necessary to cause medical issues.	**Negative Points** ▪ Very low auto-ignition temperature; ▪ Low oxygenated concentration for lower explosive limit; ▪ Moderate limiting Oxygen concentration for combustion. **Positive Points** ▪ High and fixed flashpoint temperature; ▪ Storage at atmospheric pressures and temperatures with conventional ventilation arrangements; ▪ Low oxygenated concentration for upper explosive limit; ▪ Very small explosive envelope characteristics.	**Negative Points** ▪ High impact for algae and crustaceans, moderate impact for fish; ▪ Specific density close to but less than that of seawater. **Positive Points** ▪ Categorised as non-hazardous to aquatic environment; ▪ Practically insoluble in seawater; ▪ Bioaccumulation within the natural environment is unlikely; ▪ Rapidly biodegradable in the environment; ▪ No additional global warming potential due to atmospheric release.	**Cargo Specific** ▪ Liquid chemical cargo carried in bulk; ▪ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▪ Also regulated under the International Bulk Chemical (IBC) code; ▪ Vessel construction verification through international oil pollution prevention certificate (Form B); ▪ Construction standards also verified through certificate of fitness for the carriage of dangerous chemicals in bulk; ▪ Insurance coverage required as per the international convention on civil liability for oil pollution damage. **Fuel Specific** ▪ Liquid chemical fuel carried in aggregate; ▪ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▪ Vessel construction verification through international oil pollution prevention certificate (Form A); ▪ Insurance coverage required as per the international convention on civil liability for bunker oil pollution damage.	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - chemical tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Training requirements covered within the STCW convention with certification issued through flag state administrations; ▪ Forms the reference case against which the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code) measures requirements for alternative fuels.

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Fischer-Tropsch Diesel	**Negative Points** ▪ Category 1 aspiration hazard for personnel; ▪ Category 2 carcinogenicity hazard for personnel; ▪ Category 2 specific target organ toxicity hazard through repeated exposure for personnel; ▪ Category 2 skin corrosion/ irritation hazard for personnel; ▪ Category 4 toxicity hazard (acute) through inhalation for personnel; **Positive Points** ▪ Systems operating at atmospheric temperature to facilitate on board utilisation; ▪ Creation of a deoxygenated atmosphere inhibited as liquid in its natural state; ▪ Moderate levels of exposure through dermal contact and/ or oral ingestion are necessary to cause medical issues.	**Negative Points** ▪ Very low auto-ignition temperature; ▪ Low but fixed flashpoint temperature; ▪ Low oxygenated concentration for lower explosive limit; ▪ Moderate limiting Oxygen concentration for combustion. **Positive Points** ▪ Storage at atmospheric pressures and temperatures with conventional ventilation arrangements; ▪ Low oxygenated concentration for upper explosive limit; ▪ Very small explosive envelope characteristics.	**Negative Points** ▪ Category 2 hazard (chronic) to aquatic environment; ▪ High impact for algae and crustaceans, moderate impact for fish; ▪ Potential for bioaccumulation within the natural environment; ▪ Specific density close to but less than that of seawater. **Positive Points** ▪ Low levels of solubility in seawater; ▪ Rapidly biodegradable in the environment; ▪ No additional global warming potential due to atmospheric release.	**Cargo Specific** ▪ Liquid hydrocarbon cargo carried in bulk; ▪ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▪ Vessel construction verification through international oil pollution prevention certificate (Form B); ▪ Insurance coverage required as per the international convention on civil liability for oil pollution damage. **Fuel Specific** ▪ Liquid hydrocarbon fuel carried in aggregate; ▪ Covered under MARPOL Annex I - regulations for the prevention of pollution by oil; ▪ Vessel construction verification through international oil pollution prevention certificate (Form A); ▪ Insurance coverage required as per the international convention on civil liability for bunker oil pollution damage.	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - oil tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Training requirements covered within the STCW convention with certification issued through flag state administrations; ▪ Forms the reference case against which the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code) measures requirements for alternative fuels.

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Ethanol	**Negative Points** ▪ Category 1 specific target organ toxicity hazard through single exposure for personnel; ▪ Category 1 specific target organ toxicity hazard through repeated exposure for personnel; ▪ Category 2 serious eye irritation hazard for personnel; ▪ Inert gas systems are necessary to facilitate on board utilisation. ▪ Low levels of exposure through dermal contact and/or oral ingestion are necessary to cause medical issues. **Positive Points** ▪ Systems operating at atmospheric temperature to facilitate on board utilisation; ▪ Creation of a deoxygenated atmosphere inhibited as liquid in its natural state; ▪ Moderate levels of exposure through inhalation is necessary to cause medical issues.	**Negative Points** ▪ Low auto-ignition temperature; ▪ Low but fixed flashpoint temperature; ▪ Moderate oxygenated concentration for lower explosive limit; ▪ Moderate oxygenated concentration for upper explosive limit; ▪ Low limiting Oxygen concentration for combustion; ▪ Large explosive envelope characteristics. **Positive Points** ▪ Storage at atmospheric pressures and temperatures with pressure vacuum controlled ventilation arrangements.	**Negative Points** ▪ Low toxicity to aquatic organisms in high concentrations; ▪ Moderate impact for algae; ▪ Fully miscible with seawater; ▪ Specific density close to but less than that of seawater. **Positive Points** ▪ Low impact for crustaceans and fish; ▪ Readily biodegradable in the environment; ▪ Bioaccumulation within the natural environment is unlikely; ▪ No additional global warming potential due to atmospheric release.	**Cargo Specific** ▪ Liquid chemical cargo carried in bulk; ▪ Covered under the International Bulk Chemical (IBC) code; ▪ Also regulated under MARPOL Annex II - regulations for the control of pollution by noxious liquid substances in bulk; ▪ Vessel construction verification through certificate of fitness for the carriage of dangerous chemicals in bulk; ▪ Construction standards also verified through international pollution prevention certificate for the carriage of noxious liquid substances in bulk. **Fuel Specific** ▪ Liquid chemical fuel carried in aggregate; ▪ At an advanced stage of incorporation into the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code); ▪ Covered under MSC.1-Circ.1621 - Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel; ▪ Also regulated under MARPOL Annex II - regulations for the control of pollution by noxious liquid substances in bulk.	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - chemical tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Training requirements covered within MSC.1-Circ.1621 - Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel with certification issued through flag state administrations; ▪ In accordance with the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code) additional training requirements should be commensurate with those applicable to chemical tanker endorsement.

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Methanol	**Negative Points** ▪ Category 1 specific target organ toxicity hazard through single exposure for personnel; ▪ Category 3 acute vapour inhalation toxicity for personnel; ▪ Category 3 acute oral toxicity for personnel; ▪ Category acute dermal toxicity for personnel; ▪ Inert gas systems are necessary to facilitate on board utilisation. ▪ Very low levels of exposure through inhalation, dermal contact and/or oral ingestion are necessary to cause medical issues. **Positive Points** ▪ Systems operating at atmospheric temperature to facilitate on board utilisation; ▪ Creation of a deoxygenated atmosphere inhibited as liquid in its natural state.	**Negative Points** ▪ Moderate auto-ignition temperature; ▪ Very low but fixed flashpoint temperature; ▪ High oxygenated concentration for upper explosive limit; ▪ Very low limiting Oxygen concentration for combustion; ▪ Large explosive envelope characteristics. **Positive Points** ▪ High oxygenated concentration for lower explosive limit; ▪ Storage at atmospheric pressures and temperatures with pressure vacuum controlled ventilation arrangements.	**Negative Points** ▪ Low toxicity to aquatic organisms in high concentrations; ▪ Fully miscible with seawater; ▪ Specific density close to but less than that of seawater. **Positive Points** ▪ Low impact for algae and fish; ▪ Very low impact for crustaceans; ▪ Readily biodegradable in the environment; ▪ Bioaccumulation within the natural environment is unlikely; ▪ No additional global warming potential due to atmospheric release.	**Cargo Specific** ▪ Liquid chemical cargo carried in bulk; ▪ Covered under the International Bulk Chemical (IBC) code; ▪ Also regulated under MARPOL Annex II - regulations for the control of pollution by noxious liquid substances in bulk; ▪ Vessel construction verification through certificate of fitness for the carriage of dangerous chemicals in bulk; ▪ Construction standards also verified through international pollution prevention certificate for the carriage of noxious liquid substances in bulk. **Fuel Specific** ▪ Liquid chemical fuel carried in aggregate; ▪ At an advanced stage of incorporation into the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code); ▪ Covered under MSC.1-Circ.1621 - Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel; ▪ Also regulated under MARPOL Annex II - regulations for the control of pollution by noxious liquid substances in bulk.	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - chemical tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Training requirements covered within MSC.1-Circ.1621 - Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel with certification issued through flag state administrations; ▪ In accordance with the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code) additional training requirements should be commensurate with those applicable to chemical tanker endorsement.

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Petroleum Gas (Propane/ Butane)	**Negative Points** ▪ Potential for creation of a deoxygenated atmosphere as gaseous in its natural state; ▪ Potential for accumulation in low level spaces due to specific density being greater than that of air; ▪ Moderate levels of exposure through inhalation are necessary to cause medical issues; ▪ Low temperature and/or high-pressure systems are necessary to facilitate on board utilisation. **Positive Points** ▪ No hazard categorisations for personnel are associated with the product; ▪ Exposure through dermal contact and/or oral ingestion are inapplicable.	**Negative Points** ▪ Moderate auto-ignition temperature; ▪ No applicable flashpoint temperature as flammable in its natural state; ▪ Very low oxygenated concentration for lower explosive limit; ▪ Storage at high pressures and/ or low temperatures with closed system pressure regulated ventilation arrangements. **Positive Points** ▪ Low oxygenated concentration for upper explosive limit; ▪ High limiting Oxygen concentration for combustion; ▪ Small explosive envelope characteristics.	**Negative Points** ▪ None applicable. **Positive Points** ▪ Categorised as non-hazardous to aquatic environment; ▪ No impact for algae, crustaceans and fish; ▪ Low levels of solubility in seawater; ▪ Bioaccumulation within the natural environment is unlikely; ▪ Readily biodegradable in the environment; ▪ Specific density less than that of seawater; ▪ No additional global warming potential due to atmospheric release.	**Cargo Specific** ▪ Refrigerated and/or pressurised liquid cargo carried in bulk; ▪ Covered under the International Gas Carrier (IGC) code; ▪ Vessel construction verification through certificate of fitness for the carriage of liquefied gases in bulk; **Fuel Specific** ▪ Refrigerated and/or pressurised liquid fuel carried in aggregate; ▪ Not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code); ▪ Similarity and copresence of Propane/Butane with Methane in Natural Gas allows for relative ease of incorporation for fuel type within the IGF Code.	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - gas tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Additional training requirements not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code); ▪ Similarity and copresence of Propane/Butane with Methane in Natural Gas allows for relative ease of incorporation for fuel type within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code).

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Dimethyl Ether (DME)	**Negative Points** ▪ Potential for creation of a deoxygenated atmosphere as gaseous in its natural state; ▪ Potential for accumulation in low level spaces due to specific density being greater than that of air; ▪ High levels of exposure through inhalation are necessary to cause medical issues; ▪ Low temperature and/or high-pressure systems are necessary to facilitate on board utilisation. **Positive Points** ▪ No hazard categorisations for personnel are associated with the product; ▪ Exposure through dermal contact and/or oral ingestion are inapplicable.	**Negative Points** ▪ Low auto-ignition temperature; ▪ No applicable flashpoint temperature as flammable in its natural state; ▪ Low oxygenated concentration for lower explosive limit; ▪ High oxygenated concentration for upper explosive limit; ▪ Low limiting Oxygen concentration for combustion; ▪ Very large explosive envelope characteristics. ▪ Storage at high pressures and/or low temperatures with closed system pressure regulated ventilation arrangements. **Positive Points** ▪ None applicable.	**Negative Points** ▪ Categorised as of low toxicity to aquatic organisms; ▪ Very high levels of solubility in seawater; ▪ Very high impact for crustaceans and fish, moderate impact for algae; ▪ Non-biodegradable in the environment; ▪ Additional global warming potential equivalent to that of Carbon Dioxide (CO_2eq = 1 x CO_2) due to atmospheric release in large quantities. **Positive Points** ▪ Bioaccumulation within the natural environment is unlikely; ▪ Specific density less than that of seawater.	**Cargo Specific** ▪ Refrigerated and/or pressurised liquid cargo carried in bulk; ▪ Covered under the International Gas Carrier (IGC) Code; ▪ Vessel construction verification through certificate of fitness for the carriage of liquefied gases in bulk; **Fuel Specific** ▪ Refrigerated and/or pressurised liquid fuel carried in aggregate; ▪ Not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code).	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - gas tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Additional training requirements not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code).

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Ammonia	**Negative Points** ▪ Category 1 skin corrosion/ irritation hazard for personnel; ▪ Category 1 serious eye damage/ eye irritation for personnel; ▪ Category acute inhalation toxicity for personnel; ▪ Potential for creation of a deoxygenated atmosphere as gaseous in its natural state; ▪ Low levels of exposure through inhalation are necessary to cause medical issues; ▪ Low temperature and/or high-pressure systems are necessary to facilitate on board utilisation. **Positive Points** ▪ Accumulation in low level spaces is unlikely due to specific density being less than that of air; ▪ Exposure through dermal contact and/or oral ingestion are inapplicable.	**Negative Points** ▪ No applicable flashpoint temperature as flammable in its natural state; ▪ Very high oxygenated concentration for upper explosive limit; ▪ Moderate explosive envelope characteristics; ▪ Storage at high pressures and/ or low temperatures with closed system pressure regulated ventilation arrangements. **Positive Points** ▪ Very high auto-ignition temperature; ▪ Very high oxygenated concentration for lower explosive limit; ▪ Very high limiting Oxygen concentration for combustion.	**Negative Points** ▪ Category 1 hazard (acute) to aquatic environment; ▪ Category 2 hazard (chronic) to aquatic environment; ▪ Very high levels of solubility in seawater; ▪ Very high impact for fish, moderate impact for crustaceans. **Positive Points** ▪ Low impact for algae; ▪ Bioaccumulation within the natural environment is unlikely; ▪ Biodegradable in the environment; ▪ Specific density less than that of seawater. ▪ No additional global warming potential due to atmospheric release.	**Cargo Specific** ▪ Refrigerated and/or pressurised liquid cargo carried in bulk; ▪ Covered under the International Gas Carrier (IGC) code; ▪ Covered under the International Bulk Chemical (IBC) code; ▪ Also regulated under MARPOL Annex II - regulations for the control of pollution by noxious liquid substances in bulk; ▪ Vessel construction verification through certificate of fitness for the carriage of liquefied gases in bulk; ▪ Vessel construction verification through certificate of fitness for the carriage of dangerous chemicals in bulk; ▪ Construction standards also verified through international pollution prevention certificate for the carriage of noxious liquid substances in bulk. **Fuel Specific** ▪ Refrigerated and/or pressurised liquid cargo carried in aggregate; ▪ Not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code).	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - gas tanker endorsement; ▪ Additional training requirements beyond those applicable to other vessel types - chemical (aqueous) tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Additional training requirements not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code).

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Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Ethane	**Negative Points** ▪ Potential for creation of a deoxygenated atmosphere as gaseous in its natural state; ▪ Potential for accumulation in low level spaces due to specific density being greater than that of air; ▪ Very low levels of exposure through inhalation are necessary to cause medical issues; ▪ Very low temperature and/or high-pressure systems are necessary to facilitate on board utilisation. **Positive Points** ▪ No hazard categorisations for personnel are associated with the product; ▪ Exposure through dermal contact and/or oral ingestion are inapplicable.	**Negative Points** ▪ No applicable flashpoint temperature as flammable in its natural state; ▪ Low oxygenated concentration for lower explosive limit; ▪ Moderate limiting Oxygen concentration for combustion; ▪ Storage at high pressures and/or very low temperatures with closed system pressure regulated ventilation arrangements. **Positive Points** ▪ High auto-ignition temperature; ▪ Low oxygenated concentration for upper explosive limit; ▪ Small explosive envelope characteristics.	**Negative Points** ▪ Moderate levels of solubility in seawater; ▪ Very high impact for algae, high impact for crustaceans and fish; ▪ Additional global warming potential of six times that of Carbon Dioxide ($CO_2eq = 6 \times CO_2$) due to atmospheric release. **Positive Points** ▪ Categorised as non-hazardous to aquatic environment; ▪ Bioaccumulation within the natural environment is unlikely; ▪ Readily biodegradable in the environment; ▪ Specific density less than that of seawater.	**Cargo Specific** ▪ Refrigerated and/or pressurised liquid cargo carried in bulk; ▪ Covered under the International Gas Carrier (IGC) code; ▪ Vessel construction verification through certificate of fitness for the carriage of liquefied gases in bulk; **Fuel Specific** ▪ Refrigerated and/or pressurised liquid fuel carried in aggregate; ▪ Not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code); ▪ Similarity and copresence of Propane/Butane with Methane in Natural Gas allows for relative ease of incorporation for fuel type within the IGF Code.	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - gas tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Additional training requirements not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code); ▪ Similarity and copresence of Ethane with Methane in Natural Gas allows for relative ease of incorporation for fuel type within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code).

OPERATIONAL SAFETY AND THE ENVIRONMENT

Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Natural Gas (Methane)	**Negative Points** ▪ Potential for creation of a deoxygenated atmosphere as gaseous in its natural state; ▪ Moderate levels of exposure through inhalation are necessary to cause medical issues; ▪ Extremely low temperature systems are necessary to facilitate on board utilisation. **Positive Points** ▪ No hazard categorisations for personnel are associated with the product; ▪ Accumulation in low level spaces is unlikely due to specific density being less than that of air; ▪ Exposure through dermal contact and/or oral ingestion are inapplicable.	**Negative Points** ▪ No applicable flashpoint temperature as flammable in its natural state; ▪ Moderate oxygenated concentration for upper explosive limit; ▪ Moderate explosive envelope characteristics; ▪ Storage at extremely low temperatures with closed system pressure regulated ventilation arrangements. **Positive Points** ▪ Very high auto-ignition temperature; ▪ High oxygenated concentration for lower explosive limit; ▪ High limiting Oxygen concentration for combustion.	**Negative Points** ▪ High levels of solubility in seawater; ▪ Additional global warming potential of twenty-five times that of Carbon Dioxide ($CO_2eq = 25 \times CO_2$) due to atmospheric release. **Positive Points** ▪ Categorised as non-hazardous to aquatic environment; ▪ No impact for algae, crustaceans and fish; ▪ Bioaccumulation within the natural environment is unlikely; ▪ Readily biodegradable in the environment; ▪ Specific density less than that of seawater.	**Cargo Specific** ▪ Cryogenically refrigerated liquid cargo carried in bulk; ▪ Covered under the International Gas Carrier (IGC) code; ▪ Vessel construction verification through certificate of fitness for the carriage of liquefied gases in bulk; **Fuel Specific** ▪ Cryogenically refrigerated liquid fuel carried in aggregate; ▪ Covered under the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code).	**Cargo Specific** ▪ Additional training requirements beyond those applicable to other vessel types - gas tanker endorsement; ▪ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▪ Training requirements covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code); ▪ In accordance with the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code) additional training requirements should be commensurate with those applicable to gas tanker endorsement.

OPERATIONAL SAFETY AND THE ENVIRONMENT

Fuel Product	Hazards to Personnel	Hazards to the Vessel	Hazards to the Environment	Applicable Regulations	Training Requirements
Hydrogen	**Negative Points** ▫ Potential for creation of a deoxygenated atmosphere as gaseous in its natural state; ▫ Moderate levels of exposure through inhalation are necessary to cause medical issues; ▫ Extremely low temperature systems are necessary to facilitate on board utilisation. **Positive Points** ▫ No hazard categorisations for personnel are associated with the product; ▫ Accumulation in low level spaces is unlikely due to specific density being less than that of air; ▫ Exposure through dermal contact and/or oral ingestion are inapplicable.	**Negative Points** ▫ No applicable flashpoint temperature as flammable in its natural state; ▫ Moderate oxygenated concentration for lower explosive limit; ▫ Very high oxygenated concentration for upper explosive limit; ▫ Very low limiting Oxygen concentration for combustion. ▫ Very large explosive envelope characteristics; ▫ Storage at extremely low temperatures with closed system pressure regulated ventilation arrangements. **Positive Points** ▫ High auto-ignition temperature.	**Negative Points** ▫ High levels of solubility in seawater. **Positive Points** ▫ Categorised as non-hazardous to aquatic environment; ▫ No impact for algae, crustaceans and fish; ▫ Bioaccumulation within the natural environment is unlikely; ▫ Readily biodegradable in the environment; ▫ Specific density less than that of seawater; ▫ No additional global warming potential due to atmospheric release.	**Cargo Specific** ▫ Cryogenically refrigerated liquid cargo carried in bulk; ▫ Covered under the International Gas Carrier (IGC) code; ▫ Vessel construction verification through certificate of fitness for the carriage of liquefied gases in bulk; **Fuel Specific** ▫ Cryogenically refrigerated liquid fuel carried in aggregate; ▫ Not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code).	**Cargo Specific** ▫ Additional training requirements beyond those applicable to other vessel types - gas tanker endorsement; ▫ Additional training requirements covered within the STCW convention with certification issued through flag state administrations. **Fuel Specific** ▫ Additional training requirements not yet covered within the international code of safety for ships using gases or other low-flashpoint fuels (IGF Code).

Table Notes

Hazards to Personnel: This assessment evaluates the risk posed by the characteristics of the alternative fuel products that are relevant to the safety of operational personnel on board. In particular, scope for the products to cause a dangerous atmosphere (deoxygenation, tendency to settle within a space), the hazard categorisations, the levels of exposure and corresponding serious medical issues and the necessity for pressure/temperature systems to be used for their containment on board.

Hazards to the Vessel: This assessment considers the risk posed by the characteristics of the alternative fuel products that would be considered relevant to the safety of the vessel. In particular, the necessity for high pressure and/or low temperature systems for product containment on board. Also, flammability characteristics including flashpoint, auto-ignition temperature, lower flammability limit, upper flammability limit, limiting Oxygen concentration and the total area encompassed by the resultant explosive envelope.

Hazards to the Environment: This assessment includes characteristics of the alternative fuel products that would be considered relevant to the safety of the maritime environment. This includes the associated hazard categorisations, behavioural characteristics upon release into the environment both atmospherically and through their interaction with seawater (solubility and relative density), the levels of danger posed to marine organisms (algae, crustaceans and fish) and the persistence impact.

Applicable Regulations: This criteria considers established practices for the carriage of the majority of products as a cargo on board specialised vessels in conjunction with their relative novelty used as an alternative fuel. As such, assessment is based on the availability of relevant existing (cargo or fuel) codes and their multiplicity, or otherwise the complexity of establishing/developing a code under which the product can be safely carried as a fuel.

Training Requirements: This assessment considers current regulations that outline relevant training requirements for alternative fuel products as they are currently carried on board as cargoes or where applicable, as fuel products. The deviation from International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) is also taken into account.

Note on Hazard Categories and Characteristics[1]: Actual figures from the relevant Material Safety Data Sheets have been compared to one another, however presented in this table in a simplified format to allow for understanding by the reader.

[1] Hazard categories/characteristics are derived from the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), as managed by the United Nations (UN) and noted on respective Material Safety Data Sheets (MSDS). **Globally Harmonized System of Classification and Labelling of Chemicals | UNITAR**

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Heavy Oil	**Physical Characteristics** ▪ Semi-solid liquid with a specific density that can be comparable to and/or greater than that of seawater. **Chemical Characteristics** ▪ $C_{25}H_{32}$ (Composed of Carbon and Hydrogen in variable relative ratios) **Emission Species** ▪ Particulate Matter (PM); ▪ Unburned Hydrocarbons (HCs); ▪ Carbon Monoxide (CO); ▪ Carbon Dioxide (CO_2); ▪ Oxides of Nitrogen (NOx); ▪ Oxides of Sulphur (SOx); ▪ Water Vapour (H_2O).	**Fossil-Fuel** ▪ Crude Oil extraction followed by single stage refinery distillation; **Synthetic-Fuel** ▪ Natural Gas extraction followed by steam reformation, in combination with the Fischer-Tropsch conversion process; ▪ Coal extraction followed by liquefaction and steam reformation, in combination with the Fischer-Tropsch conversion process. **Bio-Fuel** ▪ Biomass cultivation followed by gasification, in combination with the Fischer-Tropsch conversion process. **Electro-Fuel** ▪ Electrolysis of water and direct air capture of Carbon Dioxide using renewable electricity followed by the reverse water-gas shift reaction, in combination with the Fischer-Tropsch conversion process.	**One Storage State** ▪ Liquid at elevated temperature and atmospheric pressure - requiring standard steel tank with heating mechanism (steam coils) and conventional ventilation arrangements open to atmosphere.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Gas Oil and Fischer-Tropsch Diesel; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Fatty Acid Methyl Ester and Hydrotreated Vegetable Oil; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Ethanol and Methanol; ▪ Fundamentally incompatible with the carriage and utilisation of gas fuel products, including Petroleum Gas, Dimethyl Ether, Ammonia, Ethane, Methane and Hydrogen.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Gas Oil	**Physical Characteristics** ▪ Liquid with a specific density close to but less than that of seawater. **Chemical Characteristics** ▪ $C_{14.4}H_{24.9}$ (Composed of Carbon and Hydrogen in fixed relative ratio). **Emission Species** ▪ Particulate Matter (PM); ▪ Unburned Hydrocarbons (HCs); ▪ Carbon Monoxide (CO); ▪ Carbon Dioxide (CO_2); ▪ Oxides of Nitrogen (NOx); ▪ Oxides of Sulphur (SOx); ▪ Water Vapour (H_2O).	**Fossil-Fuel** ▪ Crude Oil extraction followed by multiple stage refinery distillation. **Synthetic-Fuel** ▪ Coal extraction followed by liquefaction, in combination with multiple stage refinery distillation.	**One Storage State** ▪ Liquid at atmospheric temperature and pressure - requiring standard steel tank with conventional ventilation arrangements open to atmosphere.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Fischer-Tropsch Diesel; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Heavy Oil, Fatty Acid Methyl Ester and Hydrotreated Vegetable Oil; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Ethanol and Methanol; ▪ Fundamentally incompatible with the carriage and utilisation of gas fuel products, including Petroleum Gas, Dimethyl Ether, Ammonia, Ethane, Methane and Hydrogen.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Fatty Acid Methyl Ester (FAME)	**Physical Characteristics** ▫ Liquid with a specific density close to but less than that of seawater. **Chemical Characteristics** ▫ $C_{18.75}H_{34.55}O_2$ (Composed of Carbon, Hydrogen and Oxygen in fixed relative ratio). **Emission Species** ▫ Particulate Matter (PM); ▫ Unburned Hydrocarbons (HCs); ▫ Carbon Monoxide (CO); ▫ Carbon Dioxide (CO_2); ▫ Oxides of Nitrogen (NOx); ▫ Water Vapour (H_2O).	**Bio-Fuel** ▫ Biomass cultivation followed by pressing and extraction, in combination with the trans-esterification process.	**One Storage State** ▫ Liquid at atmospheric temperature and pressure - requiring stainless or epoxy coated steel tank with conventional ventilation arrangements open to atmosphere.	**Machinery Systems** ▫ Readily compatible with the carriage and utilisation of Gas Oil, Hydrotreated Vegetable Oil and Fischer-Tropsch Diesel; ▫ Minor adaptations required for compatibility with the carriage and utilisation of Heavy Oil; ▫ Moderate adaptations required for compatibility with the carriage and utilisation of Ethanol and Methanol; ▫ Fundamentally incompatible with the carriage and utilisation of gas fuel products, including Petroleum Gas, Dimethyl Ether, Ammonia, Ethane, Methane and Hydrogen.
Hydrotreated Vegetable Oil (HVO)	**Physical Characteristics** ▫ Liquid with a specific density close to but less than that of seawater. **Chemical Characteristics** ▫ $C_{12}H_{26}$ (Composed of Carbon and Hydrogen in fixed relative ratio). **Emission Species** ▫ Particulate Matter (PM); ▫ Unburned Hydrocarbons (HCs); ▫ Carbon Monoxide (CO); ▫ Carbon Dioxide (CO_2); ▫ Oxides of Nitrogen (NOx); ▫ Water Vapour (H_2O).	**Bio-Fuel** ▫ Biomass cultivation followed by pressing and extraction, in combination with hydro-treatment, hydrocracking and isomerisation processes.	**One Storage State** ▫ Liquid at atmospheric temperature and pressure - requiring stainless or epoxy coated steel tank with conventional ventilation arrangements open to atmosphere.	**Machinery Systems** ▫ Readily compatible with the carriage and utilisation of Gas Oil, Fatty Acid Methyl Ester and Fischer-Tropsch Diesel; ▫ Minor adaptations required for compatibility with the carriage and utilisation of Heavy Oil; ▫ Moderate adaptations required for compatibility with the carriage and utilisation of Ethanol and Methanol; ▫ Fundamentally incompatible with the carriage and utilisation of gas fuel products, including Petroleum Gas, Dimethyl Ether, Ammonia, Ethane, Methane and Hydrogen.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Fischer-Tropsch Diesel	**Physical Characteristics** ▪ Liquid with a Specific Density Close to but less than that of seawater. **Chemical Characteristics** ▪ $C_{12}H_{26}$ (Composed of Carbon and Hydrogen in fixed relative ratio). **Emission Species** ▪ Particulate Matter (PM); ▪ Unburned Hydrocarbons (HCs); ▪ Carbon Monoxide (CO); ▪ Carbon Dioxide (CO_2); ▪ Oxides of Nitrogen (NOx); ▪ Water Vapour (H_2O).	**Synthetic-Fuel** ▪ Natural Gas extraction followed by steam reformation, in combination with the Fischer-Tropsch conversion process; **Bio-Fuel** ▪ Biomass cultivation followed by gasification, in combination with the Fischer-Tropsch conversion process. **Electro-Fuel** ▪ Electrolysis of water and direct air capture of Carbon Dioxide using renewable electricity followed by the reverse water-gas shift reaction, in combination with the Fischer-Tropsch conversion process.	**One Storage State** ▪ Liquid at atmospheric temperature and pressure - requiring standard steel tank with conventional ventilation arrangements open to atmosphere.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Gas Oil; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Heavy Oil, Fatty Acid Methyl Ester and Hydrotreated Vegetable Oil; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Ethanol and Methanol; ▪ Fundamentally incompatible with the carriage and utilisation of gas fuel products, including Petroleum Gas, Dimethyl Ether, Ammonia, Ethane, Methane and Hydrogen.
Ethanol	**Physical Characteristics** ▪ Vaporising liquid with a specific density close to but less than that of seawater for its liquid phase and heavier than air for its vapours. **Chemical Characteristics** ▪ C_2H_5OH (Composed of Carbon, Hydrogen and Oxygen in fixed relative ratio). **Emission Species** ▪ Unburned Ethanol (C_2H_5OH); ▪ Carbon Monoxide (CO); ▪ Carbon Dioxide (CO_2); ▪ Oxides of Nitrogen (NOx); ▪ Water Vapour (H_2O).	**Bio-Fuel** ▪ Biomass cultivation followed by enzymatic hydrolysis (saccharification), in combination with fermentation and distillation processes.	**One Storage State** ▪ Liquid at atmospheric temperature and pressure within an inert gas atmosphere - requiring stainless or epoxy coated steel tank and inert gas generation system with pressure vacuum regulated ventilation arrangements open to atmosphere.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Methanol; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Gas Oil, Fatty Acid Methyl Ester, Hydrotreated Vegetable Oil and Fischer-Tropsch Diesel; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Heavy Oil; ▪ Fundamentally incompatible with the carriage and utilisation of gas fuel products, including Petroleum Gas, Dimethyl Ether, Ammonia, Ethane, Methane and Hydrogen.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Methanol	**Physical Characteristics** ▪ Vaporising Liquid with a specific density close to but less than that of seawater for its liquid phase and heavier than air for its vapours. **Chemical Characteristics** ▪ CH_3OH (Composed of Carbon, Hydrogen and Oxygen in fixed relative ratio). **Emission Species** ▪ Unburned Methanol (CH_3OH); ▪ Carbon Monoxide (CO); ▪ Carbon Dioxide (CO_2); ▪ Oxides of Nitrogen (NOx); ▪ Water Vapour (H_2O).	**Synthetic-Fuel** ▪ Crude Oil extraction followed by partial oxidation, in combination with the Methanol synthesis process; ▪ Natural Gas extraction followed by steam reformation, in combination with the Methanol synthesis process; ▪ Coal extraction followed by gasification, in combination with the Methanol synthesis process. **Bio-Fuel** ▪ Biomass cultivation followed by gasification, in combination with the Methanol synthesis process. **Electro-Fuel** ▪ Electrolysis of water and direct air capture of Carbon Dioxide using renewable electricity followed by the reverse water-gas shift reaction, in combination with the Methanol synthesis process.	**One Storage State** ▪ Liquid at atmospheric temperature and pressure within an inert gas atmosphere - requiring stainless or epoxy coated steel tank and inert gas generation system with pressure vacuum regulated ventilation arrangements open to atmosphere.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Ethanol; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Gas Oil, Fatty Acid Methyl Ester, Hydrotreated Vegetable Oil and Fischer-Tropsch Diesel; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Heavy Oil; ▪ Fundamentally incompatible with the carriage and utilisation of gas fuel products, including Petroleum Gas, Dimethyl Ether, Ammonia, Ethane, Methane and Hydrogen.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Petroleum Gas (Propane/ Butane)	**Physical Characteristics** ▪ Gas with a specific density greater than that of Air **Chemical Characteristics** ▪ C_3H_8/C_4H_{10} (Composed of Carbon and Hydrogen in fixed relative ratio). **Emission Species** ▪ Unburned Propane/Butane (C_3H_8/C_4H_{10}); ▪ Carbon Monoxide (CO); ▪ Carbon Dioxide (CO_2); ▪ Oxides of Nitrogen (NOx); ▪ Water Vapour (H_2O).	**Fossil-Fuel** ▪ Petroleum gas produced as a by-product of Natural Gas extraction, followed by purification and separation; **Synthetic-Fuel** ▪ Crude Oil extraction followed by partial oxidation, in combination with the Fischer-Tropsch conversion process; ▪ Natural Gas extraction followed by steam reformation, in combination with the Fischer-Tropsch conversion process; ▪ Coal extraction followed by gasification, in combination with the Fischer-Tropsch conversion process. **Bio-Fuel** ▪ Biomass cultivation followed by gasification, in combination with the Fischer-Tropsch conversion process. **Electro-Fuel** ▪ Electrolysis of water and direct air capture of Carbon Dioxide using renewable electricity followed by the reverse water-gas shift reaction, in combination with the Fischer-Tropsch conversion process.	**Three Storage States** ▪ Liquid at atmospheric temperature and elevated pressure (fully pressurised) - requiring pressurised steel tank with closed system pressure regulated ventilation arrangements; ▪ Liquid at refrigerated temperature and atmospheric pressure (fully refrigerated) - requiring insulated low temperature steel tank and reliquefication system with closed system pressure regulated ventilation arrangements; ▪ Liquid at refrigerated temperature and elevated pressure (semi pressurised/ refrigerated) - requiring insulated pressurised steel tank and reliquefication system with closed system pressure regulated ventilation arrangements.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Dimethyl Ether; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Ammonia and Ethane; ▪ Major adaptations required for compatibility with the carriage and utilisation of Methane and Hydrogen; ▪ Fundamentally incompatible with the carriage and utilisation of liquid fuel products, including Heavy Oil, Gas Oil, Fatty Acid Methyl Ester, Hydrotreated Vegetable Oil, Fischer-Tropsch Diesel, Ethanol and Methanol.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Dimethyl Ether (DME)	**Physical Characteristics** ▪ Gas with a specific density greater than that of air **Chemical Characteristics** ▪ CH_3OCH_3 (Composed of Carbon, Hydrogen and Oxygen in fixed relative ratio). **Emission Species** ▪ Unburned Dimethyl Ether (CH_3OCH_3); ▪ Carbon Monoxide (CO); ▪ Carbon Dioxide (CO_2); ▪ Oxides of Nitrogen (NOx); ▪ Water Vapour (H_2O).	**Synthetic-Fuel** ▪ Crude Oil extraction followed by partial oxidation, in combination with the Methanol synthesis process and subsequent dehydration; ▪ Natural Gas extraction followed by steam reformation, in combination with the Methanol synthesis process and subsequent dehydration; ▪ Coal extraction followed by gasification, in combination with the Methanol synthesis process and subsequent dehydration. **Bio-Fuel** ▪ Biomass cultivation followed by gasification, in combination with the Methanol synthesis process and subsequent dehydration. **Electro-Fuel** ▪ Electrolysis of water and direct air capture of Carbon Dioxide using renewable electricity followed by the reverse water-gas shift reaction, in combination with the Methanol synthesis process and subsequent dehydration.	**Three Storage States** ▪ Liquid at atmospheric temperature and elevated pressure (fully pressurised) - requiring pressurised steel tank with closed system pressure regulated ventilation arrangements; ▪ Liquid at refrigerated temperature and atmospheric pressure (fully refrigerated) - requiring insulated low temperature steel tank and reliquefication system with closed system pressure regulated ventilation arrangements; ▪ Liquid at refrigerated temperature and elevated pressure (semi pressurised/ refrigerated) - requiring insulated pressurised steel tank and reliquefication system with closed system pressure regulated ventilation arrangements.	**Machinery Systems** ▪ Minor adaptations required for compatibility with the carriage and utilisation of Petroleum Gas; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Ammonia and Ethane; ▪ Major adaptations required for compatibility with the carriage and utilisation of Methane and Hydrogen; ▪ Fundamentally incompatible with the carriage and utilisation of liquid fuel products, including Heavy Oil, Gas Oil, Fatty Acid Methyl Ester, Hydrotreated Vegetable Oil, Fischer-Tropsch Diesel, Ethanol and Methanol.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Ammonia	**Physical Characteristics** ▪ Gas with a specific density less than that of air **Chemical Characteristics** ▪ NH_3 (Composed of Nitrogen and Hydrogen in fixed relative ratio). **Emission Species** ▪ Unburned Ammonia (NH_3); ▪ Oxides of Nitrogen (NOx); ▪ Water Vapour (H_2O).	**Synthetic-Fuel** ▪ Crude Oil extraction followed by partial oxidation and air separation of Nitrogen, in combination with the water-gas shift reaction and Haber-Bosch conversion process; ▪ Natural Gas extraction followed by steam reformation and air separation of Nitrogen, in combination with the water-gas shift reaction and Haber-Bosch conversion process; ▪ Coal extraction followed by gasification and air separation of Nitrogen, in combination with the water-gas shift reaction and Haber-Bosch conversion process. **Bio-Fuel** ▪ Biomass cultivation followed by gasification and air separation of Nitrogen, in combination with the water-gas shift reaction and Haber-Bosch conversion process. **Electro-Fuel** ▪ Electrolysis of water and air separation of Nitrogen using renewable electricity followed by the Haber-Bosch conversion process.	**Three Storage States** ▪ Liquid at atmospheric temperature and elevated pressure (fully pressurised) - requiring pressurised stainless-steel tank with closed system pressure regulated ventilation arrangements; ▪ Liquid at refrigerated temperature and atmospheric pressure (fully refrigerated) - requiring insulated low temperature stainless-steel tank and reliquefication system with closed system pressure regulated ventilation arrangements; ▪ Liquid at refrigerated temperature and elevated pressure (semi pressurised/ refrigerated) - requiring insulated pressurised stainless-steel tank and reliquefication system with closed system pressure regulated ventilation arrangements.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Dimethyl Ether; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Petroleum Gas; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Ethane; ▪ Major adaptations required for compatibility with the carriage and utilisation of Methane and Hydrogen; ▪ Fundamentally incompatible with the carriage and utilisation of liquid fuel products, including Heavy Oil, Gas Oil, Fatty Acid Methyl Ester, Hydrotreated Vegetable Oil, Fischer-Tropsch Diesel, Ethanol and Methanol.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Ethane	**Physical Characteristics** ▪ Gas with a specific density greater than that of air **Chemical Characteristics** ▪ C_2H_6 (Composed of Carbon and Hydrogen in fixed relative ratio). **Emission Species** ▪ Unburned Ethane (C_2H_6); ▪ Carbon Monoxide (CO); ▪ Carbon Dioxide (CO_2); ▪ Oxides of Nitrogen (NOx); ▪ Water Vapour (H_2O).	**Fossil-Fuel** ▪ Ethane produced as a by-product of Natural Gas extraction, followed by purification and separation; **Synthetic-Fuel** ▪ Crude Oil extraction followed by partial oxidation, in combination with the Fischer-Tropsch conversion process; ▪ Natural Gas extraction followed by steam reformation, in combination with the Fischer-Tropsch conversion process; ▪ Coal extraction followed by gasification, in combination with the Fischer-Tropsch conversion process. **Bio-Fuel** ▪ Biomass cultivation followed by gasification, in combination with the Fischer-Tropsch conversion process. **Electro-Fuel** ▪ Electrolysis of water and direct air capture of Carbon Dioxide using renewable electricity followed by the reverse water-gas shift reaction, in combination with the Fischer-Tropsch conversion process.	**Three Storage States** ▪ Liquid at atmospheric temperature and elevated pressure (fully pressurised) - requiring pressurised steel tank with closed system pressure regulated ventilation arrangements; ▪ Liquid at cryogenic temperature and atmospheric pressure (fully refrigerated) - requiring highly insulated low temperature steel tank and reliquefication system with closed system pressure regulated ventilation arrangements; ▪ Liquid at refrigerated temperature and elevated pressure (semi pressurised/ refrigerated) - requiring insulated pressurised steel tank and reliquefication system with closed system pressure regulated ventilation arrangements.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Petroleum Gas; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Dimethyl Ether; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Ammonia; ▪ Major adaptations required for compatibility with the carriage and utilisation of Methane and Hydrogen; ▪ Fundamentally incompatible with the carriage and utilisation of liquid fuel products, including Heavy Oil, Gas Oil, Fatty Acid Methyl Ester, Hydrotreated Vegetable Oil, Fischer-Tropsch Diesel, Ethanol and Methanol.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Natural Gas (Methane)	**Physical Characteristics** ▪ Gas with a specific density less than that of air **Chemical Characteristics** ▪ CH_4 (Composed of Carbon and Hydrogen in fixed relative ratio). **Emission Species** ▪ Unburned Methane (CH_4); ▪ Carbon Monoxide (CO); ▪ Carbon Dioxide (CO_2); ▪ Oxides of Nitrogen (NOx); ▪ Water Vapour (H_2O).	**Fossil-Fuel** ▪ Natural Gas extraction followed by purification; **Synthetic-Fuel** ▪ Crude Oil extraction followed by hydro-gasification, in combination with the methanation (sabatier) conversion process; ▪ Coal extraction followed by hydro-gasification, in combination with the methanation (sabatier) conversion process. **Bio-Fuel** ▪ Biomass cultivation followed by hydro-gasification, in combination with the methanation (sabatier) conversion process. **Electro-Fuel** ▪ Electrolysis of water and direct air capture of Carbon Dioxide using renewable electricity followed by the reverse water-gas shift reaction, in combination with the methanation (sabatier) conversion process.	**Two Storage States** ▪ Liquid at cryogenic temperature and atmospheric pressure (fully refrigerated) - requiring highly insulated low temperature steel tank and reliquefication system with closed system pressure regulated ventilation arrangements; ▪ Liquid at cryogenic temperature and elevated pressure (semi pressurised/ refrigerated) - requiring highly insulated pressurised steel tank and reliquefication system with closed system pressure regulated ventilation arrangements.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Ethane; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Petroleum Gas and Dimethyl Ether; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Ammonia; ▪ Major adaptations required for compatibility with the carriage and utilisation of Hydrogen; ▪ Fundamentally incompatible with the carriage and utilisation of liquid fuel products, including Heavy Oil, Gas Oil, Fatty Acid Methyl Ester, Hydrotreated Vegetable Oil, Fischer-Tropsch Diesel, Ethanol and Methanol.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Fuel Product	Fuel Characteristics	Production Methods	Carriage States	Possible Interchangeability
Hydrogen	**Physical Characteristics** ▪ Gas with a specific density less than that of air **Chemical Characteristics** ▪ H_2 (Composed of Hydrogen). **Emission Species** ▪ Unburned Hydrogen (H_2); ▪ Oxides of Nitrogen (NOx); ▪ Water Vapour (H_2O).	**Synthetic-Fuel** ▪ Crude Oil extraction followed by partial oxidation, in combination with the water-gas shift reaction; ▪ Natural Gas extraction followed by steam reformation, in combination with the water-gas shift reaction; ▪ Coal extraction followed by gasification, in combination with the water-gas shift reaction. **Bio-Fuel** ▪ Biomass cultivation followed by gasification, in combination with the water-gas shift reaction. **Electro-Fuel** ▪ Electrolysis of water using renewable electricity.	**Two Storage States** ▪ Liquid at cryogenic temperature and atmospheric pressure (fully refrigerated) - requiring highly insulated low temperature steel tank and reliquefication system with closed system pressure regulated ventilation arrangements; ▪ Liquid at cryogenic temperature and elevated pressure (semi pressurised/ refrigerated) - requiring highly insulated pressurised steel tank and reliquefication system with closed system pressure regulated ventilation arrangements.	**Machinery Systems** ▪ Readily compatible with the carriage and utilisation of Methane; ▪ Minor adaptations required for compatibility with the carriage and utilisation of Petroleum Gas, Dimethyl Ether and Ethane; ▪ Moderate adaptations required for compatibility with the carriage and utilisation of Ammonia; ▪ Fundamentally incompatible with the carriage and utilisation of liquid fuel products, including Heavy Oil, Gas Oil, Fatty Acid Methyl Ester, Hydrotreated Vegetable Oil, Fischer-Tropsch Diesel, Ethanol and Methanol.

CHARACTERISTICS OF OPERATIONAL UTILISATION

Table Notes

Fuel Characteristics: This assessment considers the physical and chemical characteristics for the individual alternatives, i.e., their natural state and elemental composition, from which their respective emission profile as a fuel can be gauged. The comparison between the alternatives in this instance is undertaken with respect to the number of emission species resulting from the use of the individual fuel products relative to one another and on board a vessel with comparable power and propulsion machinery.

Production Methods: This criteria included assessment of the production methods available for the individual fuel alternatives. This is limited to the conversion processes and corresponding technologies that may be considered as well established or at an advanced stage of development. These characteristics are subsequently assessed by way of the number of potential methods for production of the final product, whether these be as a fossil-, synthetic-, bio- or electro-fuel variant, with those possessing increased feedstock possibilities being considered preferential to those with limited scope.

Carriage States: With regard for current cargo carriage requirements and practices, consideration is given to the various ways that the alternatives may be stored on board the vessel for use as a fuel. Storage methods have been considered with respect for the system complexity necessary to enable the carriage of the individual fuel products on board.

Possible Interchangeability: This assessment considers the practical implications associated with alteration of the vessel to accommodate the alternative fuel product and the degree to which adaptations to the storage system and propulsion technology would be necessary. This is assessed in terms of the degree of adaptions necessary for an existing vessel to successfully adopt the alternative fuel e.g. direct compatibility (none or minor adaptations), indirect compatibility (moderate or major adaptations) or incompatibility (extensive adaptations warranting newbuild).

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Heavy Oil	**Fossil-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation. **Synthetic-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Energy intensity of further conversion processes in in production; ▪ Ecological impacts associated with further alteration to the natural environment; ▪ Environmental contamination stemming from conversion processes and/or transportation of dissimilar products.	**Fuel Product** ▪ Current levels of production equate to 567.7 million tonnes of Heavy Oil on an annual basis; ▪ Internationally traded product in a well-established commercial market, forming part of general oil and gas commodities; ▪ Global transportation networks with a total capacity distributed between 7,444 operational vessels (oil tankers); ▪ Standardised bunkering facilities available for supply of Heavy Oil within approximately 400 ports globally. **Fossil-Fuel** ▪ Crude Oil feedstock reserves of 3,057,250 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Crude Oil production equate to approximately 52,070 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 59 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Crude Oil resources available for production within approximately 31.8% of nations.	**Fuel Product** ▪ World fleet size currently using Heavy Oil as a fuel product equates to nearly 80,000 vessels; ▪ World fleet size currently capable of using Heavy Oil as a fuel product equates to nearly 80,000 vessels; ▪ Feasibility of retrofit for existing vessels incapable of using Heavy Oil as a fuel product is good; ▪ Number of vessels requiring retrofit to enable operations using Heavy Oil is minimal; ▪ Vessel range or capacity (volumetric) can be increased by a factor of 1.01 due to adoption of Heavy Oil as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be decreased by a factor of 0.91 due to adoption of Heavy Oil as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for Heavy Oil within approximately 400 ports worldwide; ▪ Upgrades required to existing bunkering infrastructure within approximately 100 additional ports to achieve worldwide distribution of Heavy Oil; ▪ Alterations to bunkering infrastructure required for Heavy Oil capability are minor.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Heavy Oil (Continued)	**Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation. **Electro-Fuel** ▪ Energy intensity and material requirements associated with increasing renewable electricity capacity; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation.	**Synthetic-Fuel** ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource; ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations. **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle.	

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Heavy Oil (Continued)		**Electro-Fuel** ▪ Renewable energy feedstock reserves of 2,993,889 terra watt-hours available globally on an annual basis; ▪ Current levels of renewable energy production equate to approximately 7,027 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable with overall capacity only limited by annual availability; ▪ Global distribution of renewable energy resources available for production within 100% of nations.	
Gas Oil	**Fossil-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation. **Synthetic-Fuel** ▪ All points of relevance to fossil-fuel, in addition to the following; ▪ Energy intensity of further conversion processes in production; ▪ Ecological impacts associated with further alteration to the natural environment; ▪ Environmental contamination stemming from conversion processes and/or transportation of dissimilar products.	**Fuel Product** ▪ Current levels of production equate to 4,730.6 million tonnes of Gas Oil on an annual basis; ▪ Internationally traded product in a well-established commercial market, forming part of general oil and gas commodities; ▪ Global transportation networks with a total capacity distributed between 4,451 operational vessels (product tankers); ▪ Standardised bunkering facilities available for supply of Gas Oil within approximately 500 ports globally. **Fossil-Fuel** ▪ Crude Oil feedstock reserves of 3,057,250 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Crude Oil production equate to approximately 52,070 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 59 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Crude Oil resources available for production within approximately 31.8% of nations.	**Fuel Product** ▪ World fleet size currently using Gas Oil as a fuel product equates to approximately 80,000 vessels; ▪ World fleet size currently capable of using Gas Oil as a fuel product equates to approximately 80,000 vessels; ▪ Feasibility of retrofit for existing vessels incapable of using Gas Oil as a fuel product is very good; ▪ No existing vessels require retrofit to enable operations using Gas Oil; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.99 due to adoption of Gas Oil as a fuel product (Heavy Oil reference); ▪ Vessel range or capacity (gravimetric) can be increased by a factor of 1.09 due to adoption of Gas Oil as a fuel product (Heavy Oil reference); ▪ Current bunkering capability exists for Gas Oil within approximately 500 ports worldwide; ▪ No upgrades required to existing bunkering infrastructure within any additional ports to achieve worldwide distribution of Gas Oil; ▪ Alterations to bunkering infrastructure required for Gas Oil capability are negligible.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Gas Oil (Continued)		**Synthetic-Fuel** ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource; ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations.	

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Fatty Acid Methyl Ester (FAME)	**Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment.	**Fuel Product** ▪ Current levels of production equate to 1.7 million tonnes of Fatty Acid Methyl Ester on an annual basis; ▪ Internationally traded product in a well-established commercial market, forming part of general oil and gas commodities; ▪ Global transportation networks with a total capacity distributed between 1,283 operational vessels (chemical tankers); ▪ Standardised bunkering facilities available for supply of Fatty Acid Methyl Ester within approximately 500 ports globally. **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle.	**Fuel Product** ▪ World fleet size currently using FAME as a constituent component of the fuel product equates to approximately 80,000 vessels; ▪ World fleet size currently capable of using FAME as a constituent component of the fuel product equates to approximately 80,000 vessels; ▪ Feasibility of retrofit for existing vessels incapable of using FAME or its closest equivalent as a fuel product is very good; ▪ Number of vessels requiring retrofit to enable operations using FAME is negligible; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.88 due to adoption of FAME as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be decreased by a factor of 0.88 due to adoption of FAME as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for FAME within approximately 500 ports worldwide; ▪ No upgrades required to existing bunkering infrastructure within any additional ports to achieve worldwide distribution of FAME; ▪ Alterations to bunkering infrastructure required for FAME capability are negligible.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Hydrotreated Vegetable Oil (HVO)	**Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment.	**Fuel Product** ▪ Current levels of production equate to 5.5 million tonnes of Hydrotreated Vegetable Oil on an annual basis; ▪ Internationally traded product in a well-established commercial market, forming part of general oil and gas commodities; ▪ Global transportation networks with a total capacity distributed between 1,283 operational vessels (chemical tankers); ▪ Standardised bunkering facilities available for supply of Hydrotreated Vegetable Oil within approximately 500 ports globally. **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle.	**Fuel Product** ▪ There are currently no vessels within the world fleet using HVO as a fuel product due to its commercial unavailability; ▪ World fleet size currently capable of using HVO as a fuel product equates to nearly 80,000 vessels; ▪ Feasibility of retrofit for existing vessels incapable of using HVO as a fuel product is good; ▪ Number of vessels requiring retrofit to enable operations using HVO is minimal; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.91 due to adoption of HVO as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be increased by a factor of 1.03 due to adoption of HVO as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for HVO within approximately 400 ports worldwide; ▪ Upgrades required to existing bunkering infrastructure within approximately 100 additional ports to achieve worldwide distribution of HVO; ▪ Alterations to bunkering infrastructure required for HVO capability are minor.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Fischer-Tropsch Diesel	**Synthetic-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Energy intensity of further conversion processes in in production; ▪ Ecological impacts associated with further alteration to the natural environment; ▪ Environmental contamination stemming from conversion processes and/or transportation of dissimilar products.	**Fuel Product** ▪ Current levels of production equate to 5.6 million tonnes of Fischer-Tropsch Diesel on an annual basis; ▪ Internationally traded product in a well-established commercial market, forming part of general oil and gas commodities; ▪ Global transportation networks with a total capacity distributed between 4,451 operational vessels (product tankers); ▪ Standardised bunkering facilities available for supply of Fischer-Tropsch Diesel within approximately 500 ports globally. **Synthetic-Fuel** ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource; ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations.	**Fuel Product** ▪ There are currently no vessels within the world fleet using FT-Diesel as a fuel product due to its commercial unavailability; ▪ World fleet size currently capable of using FT-Diesel as a fuel product equates to approximately 80,000 vessels; ▪ Feasibility of retrofit for existing vessels incapable of using FT-Diesel as a fuel product is very good; ▪ No existing vessels require retrofit to enable operations using FT-Diesel; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.97 due to adoption of FT-Diesel as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be increased by a factor of 1.01 due to adoption of FT-Diesel as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for FT-Diesel within approximately 500 ports worldwide; ▪ No upgrades required to existing bunkering infrastructure within any additional ports to achieve worldwide distribution of FT-Diesel; ▪ Alterations to bunkering infrastructure required for FT-Diesel capability are negligible.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Fischer-Tropsch Diesel (Continued)	**Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation. **Electro-Fuel** ▪ Energy intensity and material requirements associated with increasing renewable electricity capacity; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation.	**Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle. **Electro-Fuel** ▪ Renewable energy feedstock reserves of 2,993,889 terra watt-hours available globally on an annual basis; ▪ Current levels of renewable energy production equate to approximately 7,027 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable with overall capacity only limited by annual availability; ▪ Global distribution of renewable energy resources available for production within 100% of nations.	

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Ethanol	**Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment.	**Fuel Product** ▪ Current levels of production equate to 110.3 million tonnes of Ethanol on an annual basis; ▪ Internationally traded product in an established market of chemical commodities; ▪ Global transportation networks with a total capacity distributed between 1,283 operational vessels (chemical tankers); ▪ Standardised bunkering facilities available for supply of Ethanol within approximately 100 ports globally. **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle.	**Fuel Product** ▪ World fleet size currently using Ethanol or its closest equivalent as a fuel product equates to approximately 12 vessels; ▪ There are currently no vessels within the world fleet that are capable of using Ethanol as a fuel product without some form of retrofitting; ▪ Feasibility of retrofit for existing vessels incapable of using Ethanol as a fuel product is moderate; ▪ All existing vessels require some degree of retrofit to enable operations using Ethanol or its closest equivalent; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.56 due to adoption of Ethanol as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be decreased by a factor of 0.62 due to adoption of Ethanol as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for Ethanol or its closest equivalent within approximately 100 ports worldwide; ▪ Upgrades required to existing bunkering infrastructure within approximately 400 additional ports to achieve worldwide distribution of Ethanol; ▪ Alterations to bunkering infrastructure required for Ethanol capability, or its closest equivalent, are moderate.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Methanol	**Synthetic-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Energy intensity of further conversion processes in in production; ▪ Ecological impacts associated with further alteration to the natural environment. **Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment.	**Fuel Product** ▪ Current levels of production equate to 148 million tonnes of Methanol on an annual basis; ▪ Internationally traded product in an established market of chemical commodities; ▪ Global transportation networks with a total capacity distributed between 1,283 operational vessels (chemical tankers); ▪ Standardised bunkering facilities available for supply of Methanol within approximately 100 ports globally. **Synthetic-Fuel** ▪ Crude Oil feedstock reserves of 3,057,250 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Crude Oil production equate to approximately 52,070 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 59 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Crude Oil resources available for production within approximately 31.8% of nations. ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource; ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource;	**Fuel Product** ▪ World fleet size currently using Methanol or its closest equivalent as a fuel product equates to approximately 12 vessels; ▪ There are currently no vessels within the world fleet that are capable of using Methanol as a fuel product without some form of retrofitting; ▪ Feasibility of retrofit for existing vessels incapable of using Methanol as a fuel product is moderate; ▪ All existing vessels require some degree of retrofit to enable operations using Methanol or its closest equivalent; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.42 due to adoption of Methanol as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be decreased by a factor of 0.47 due to adoption of Methanol as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for Methanol or its closest equivalent within approximately 100 ports worldwide; ▪ Upgrades required to existing bunkering infrastructure within approximately 400 additional ports to achieve worldwide distribution of Methanol; ▪ Alterations to bunkering infrastructure required for Methanol capability, or its closest equivalent, are moderate.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Methanol (Continued)	**Electro-Fuel** ▪ Energy intensity and material requirements associated with increasing renewable electricity capacity; ▪ Ecological impacts associated with alteration to the natural environment.	**Synthetic-Fuel** (Continued) ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations. **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle. **Electro-Fuel** ▪ Renewable energy feedstock reserves of 2,993,889 terra watt-hours available globally on an annual basis; ▪ Current levels of renewable energy production equate to approximately 7,027 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable with overall capacity only limited by annual availability; ▪ Global distribution of renewable energy resources available for production within 100% of nations.	

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Petroleum Gas (Propane/ Butane)	**Fossil-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment. **Synthetic-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Energy intensity of further conversion processes in production; ▪ Ecological impacts associated with further alteration to the natural environment.	**Fuel Product** ▪ Current levels of production equate to 325 million tonnes of Petroleum Gas on an annual basis; ▪ Internationally traded product in a well-established commercial market, forming part of general oil and gas commodities; ▪ Global transportation networks with a total capacity distributed between 1,508 operational vessels (LPG carriers); ▪ Standardised bunkering facilities available for supply of Petroleum Gas within approximately 221 ports globally. **Fossil-Fuel** ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations. **Synthetic-Fuel** ▪ Crude Oil feedstock reserves of 3,057,250 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Crude Oil production equate to approximately 52,070 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 59 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Crude Oil resources available for production within approximately 31.8% of nations.	**Fuel Product** ▪ World fleet size currently using Petroleum Gas or its closest equivalents as a fuel product equates to approximately 12 vessels; ▪ There are currently no vessels within the world fleet that are capable of using Petroleum Gas as a fuel product without some form of retrofitting; ▪ Feasibility of retrofit for existing vessels incapable of using Petroleum Gas as a fuel product is poor; ▪ All existing vessels require some degree of retrofit to enable operations using Petroleum Gas or its closest equivalents; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.70 due to adoption of Petroleum Gas as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be increased by a factor of 1.06 due to adoption of Petroleum Gas as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for Petroleum Gas or its closest equivalents within approximately 221 ports worldwide; ▪ Upgrades required to existing bunkering infrastructure within approximately 279 additional ports to achieve worldwide distribution of Petroleum Gas; ▪ Alterations to bunkering infrastructure required for Petroleum Gas capability, or its closest equivalents, are major.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Petroleum Gas (Propane/ Butane) (Continued)	**Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment. **Electro-Fuel** ▪ Energy intensity and material requirements associated with increasing renewable electricity capacity; ▪ Ecological impacts associated with alteration to the natural environment.	**Synthetic-Fuel** (Continued) ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource; ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle. **Electro-Fuel** ▪ Renewable energy feedstock reserves of 2,993,889 terra watt-hours available globally on an annual basis; ▪ Current levels of renewable energy production equate to approximately 7,027 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable with overall capacity only limited by annual availability; ▪ Global distribution of renewable energy resources available for production within 100% of nations.	

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Dimethyl Ether (DME)	**Synthetic-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Energy intensity of further conversion processes in in production; ▪ Ecological impacts associated with further alteration to the natural environment; ▪ Environmental contamination stemming from conversion processes and/or transportation of dissimilar products; ▪ Additional Carbon capture and storage to offset increased global warming potential of 1xco_2. **Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement;	**Fuel Product** ▪ Current levels of production equate to 10 million tonnes of Dimethyl Ether on an annual basis; ▪ Internationally traded in a market currently being established for chemical and fuel product commodities; ▪ Global transportation networks with a total capacity distributed between 1,508 operational vessels (lpg carriers); ▪ Standardised bunkering facilities available for supply of Dimethyl Ether within approximately 341 ports globally. **Synthetic-Fuel** ▪ Crude Oil feedstock reserves of 3,057,250 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Crude Oil production equate to approximately 52,070 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 59 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Crude Oil resources available for production within approximately 31.8% of nations. ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource; ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource;	**Fuel Product** ▪ There are currently no vessels within the world fleet using DME as a fuel product due to its commercial unavailability; ▪ There are currently no vessels within the world fleet that are capable of using DME as a fuel product without some form of retrofitting; ▪ Feasibility of retrofit for existing vessels incapable of using DME as a fuel product is poor; ▪ All existing vessels require some degree of retrofit to enable operations using DME or its closest equivalents; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.56 due to adoption of DME as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be decreased by a factor of 0.68 due to adoption of DME as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for DME or its closest equivalents within approximately 341 ports worldwide; ▪ Upgrades required to existing bunkering infrastructure within approximately 159 additional ports to achieve worldwide distribution of DME; ▪ Alterations to bunkering infrastructure required for DME capability, or its closest equivalents, are major.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Dimethyl Ether (DME) (Continued)	**Bio-Fuel** (Continued) ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Additional Carbon capture and storage to offset increased global warming potential of $1xCO_2$. **Electro-Fuel** ▪ Energy intensity and material requirements associated with increasing renewable electricity capacity; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Additional Carbon capture and storage to offset increased global warming potential of $1xCO_2$.	**Synthetic-Fuel** (Continued) ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations. **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle. **Electro-Fuel** ▪ Renewable energy feedstock reserves of 2,993,889 terra watt-hours available globally on an annual basis; ▪ Current levels of renewable energy production equate to approximately 7,027 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable with overall capacity only limited by annual availability; ▪ Global distribution of renewable energy resources available for production within 100% of nations.	

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Ammonia	**Synthetic-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Energy intensity of further conversion processes in production; ▪ Ecological impacts associated with further alteration to the natural environment; ▪ Environmental contamination stemming from conversion processes and/or transportation of dissimilar products. **Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access;	**Fuel Product** ▪ Current levels of production equate to 235.3 million tonnes of Ammonia on an annual basis; ▪ Internationally traded in an established market of chemical commodities; ▪ Global transportation networks with a total capacity distributed between 1,508 operational vessels (LPG carriers); ▪ Standardised bunkering facilities available for supply of Ammonia within approximately 341 ports globally. **Synthetic-Fuel** ▪ Crude Oil feedstock reserves of 3,057,250 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Crude Oil production equate to approximately 52,070 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 59 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Crude Oil resources available for production within approximately 31.8% of nations. ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource; ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining.	**Fuel Product** ▪ There are currently no vessels within the world fleet using Ammonia as a fuel product due to its commercial unavailability; ▪ There are currently no vessels within the world fleet that are capable of using Ammonia as a fuel product without some form of retrofitting; ▪ Feasibility of retrofit for existing vessels incapable of using Ammonia as a fuel product is poor; ▪ All existing vessels require some degree of retrofit to enable operations using Ammonia or its closest equivalents; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.34 due to adoption of Ammonia as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be decreased by a factor of 0.44 due to adoption of Ammonia as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for Ammonia or its closest equivalents within approximately 341 ports worldwide; ▪ Upgrades required to existing bunkering infrastructure within approximately 159 additional ports to achieve worldwide distribution of Ammonia; ▪ Alterations to bunkering infrastructure required for Ammonia capability, or its closest equivalents, are major.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Ammonia (Continued)	**Bio-Fuel** (Continued) ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation. **Electro-Fuel** ▪ Energy intensity and material requirements associated with increasing renewable electricity capacity; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation.	**Synthetic-Fuel** (Continued) ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations. **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle. **Electro-Fuel** ▪ Renewable energy feedstock reserves of 2,993,889 terra watt-hours available globally on an annual basis; ▪ Current levels of renewable energy production equate to approximately 7,027 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable with overall capacity only limited by annual availability; ▪ Global distribution of renewable energy resources available for production within 100% of nations.	

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Ethane	**Fossil-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Additional Carbon capture and storage to offset increased global warming potential of 6xCO_2. **Synthetic-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Energy intensity of further conversion processes in in production; ▪ Ecological impacts associated with further alteration to the natural environment; ▪ Additional Carbon capture and storage to offset increased global warming potential of 6xCO_2.	**Fuel Product** ▪ Current levels of production equate to 50.8 million tonnes of Ethane on an annual basis; ▪ Domestically traded as no international market has been established at present; ▪ Global transportation networks with a total capacity distributed between 29 operational vessels (LEC vessels); ▪ Standardised bunkering facilities available for supply of Ethane within approximately 96 ports globally. **Fossil-Fuel** ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations. **Synthetic-Fuel** ▪ Crude Oil feedstock reserves of 3,057,250 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Crude Oil production equate to approximately 52,070 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 59 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Crude Oil resources available for production within approximately 31.8% of nations.	**Fuel Product** ▪ World fleet size currently using Ethane or its closest equivalents as a fuel product equates to approximately 8 vessels; ▪ World fleet size currently capable of using Ethane as a fuel product equates to approximately 400 vessels; ▪ Feasibility of retrofit for existing vessels incapable of using Ethane as a fuel product is poor; ▪ Nearly all existing vessels require some degree of retrofit to enable operations using Ethane or its closest equivalents; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.68 due to adoption of Ethane as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be increased by a factor of 1.11 due to adoption of Ethane as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for Ethane or its closest equivalents within approximately 96 ports worldwide; ▪ Upgrades required to existing bunkering infrastructure within approximately 404 additional ports to achieve worldwide distribution of Ethane; ▪ Alterations to bunkering infrastructure required for Ethane capability, or its closest equivalents, are major.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Ethane (Continued)	**Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Additional Carbon capture and storage to offset increased global warming potential of $6xCO_2$. **Electro-Fuel** ▪ Energy intensity and material requirements associated with increasing renewable electricity capacity; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Additional Carbon capture and storage to offset increased global warming potential of $6xCO_2$.	**Synthetic-Fuel** (Continued) ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource; ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle. **Electro-Fuel** ▪ Renewable energy feedstock reserves of 2,993,889 terra watt-hours available globally on an annual basis; ▪ Current levels of renewable energy production equate to approximately 7,027 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable with overall capacity only limited by annual availability; ▪ Global distribution of renewable energy resources available for production within 100% of nations.	

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Natural Gas (Methane)	**Fossil-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Additional Carbon capture and storage to offset increased global warming potential of 25xCO_2. **Synthetic-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Energy intensity of further conversion processes in in production; ▪ Ecological impacts associated with further alteration to the natural environment; ▪ Additional Carbon capture and storage to offset increased global warming potential of 25xCO_2.	**Fuel Product** ▪ Current levels of production equate to 2,952.1 million tonnes of Natural Gas on an annual basis; ▪ Internationally traded product in a well-established commercial market, forming part of general oil and gas commodities; ▪ Global transportation networks with a total capacity distributed between 538 operational vessels (LNG carriers); ▪ Standardised bunkering facilities available for supply of Natural Gas within approximately 96 ports globally. **Fossil-Fuel** ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations. **Synthetic-Fuel** ▪ Crude Oil feedstock reserves of 3,057,250 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Crude Oil production equate to approximately 52,070 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 59 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Crude Oil resources available for production within approximately 31.8% of nations.	**Fuel Product** ▪ World fleet size currently using Methane as a fuel product equates to approximately 400 vessels; ▪ There are currently no vessels within the world fleet that are capable of using Methane as a fuel product without some form of retrofitting; ▪ Feasibility of retrofit for existing vessels incapable of using Methane as a fuel product is very poor; ▪ Nearly all existing vessels require some degree of retrofit to enable operations using Methane or its closest equivalents; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.55 due to adoption of Methane as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be increased by a factor of 1.14 due to adoption of Methane as a fuel product (Gas Oil reference); ▪ Current bunkering capability exists for Methane within approximately 96 ports worldwide; ▪ Upgrades required to existing bunkering infrastructure within approximately 404 additional ports to achieve worldwide distribution of Methane; ▪ Alterations to bunkering infrastructure required for Methane capability are extensive.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Natural Gas (Methane) (Continued)	**Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Additional Carbon capture and storage to offset increased global warming potential of 25xCO_2. **Electro-Fuel** ▪ Energy intensity and material requirements associated with increasing renewable electricity capacity; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Additional Carbon capture and storage to offset increased global warming potential of 25xCO_2.	**Synthetic-Fuel** (Continued) ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource; ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; **Bio-Fuel** ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle. **Electro-Fuel** ▪ Renewable energy feedstock reserves of 2,993,889 terra watt-hours available globally on an annual basis; ▪ Current levels of renewable energy production equate to approximately 7,027 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable with overall capacity only limited by annual availability; ▪ Global distribution of renewable energy resources available for production within 100% of nations.	

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Hydrogen	**Synthetic-Fuel** ▪ Continued use of fossil-based feedstocks and associated emissions; ▪ Requirement for high levels of Carbon capture and storage for abatement; ▪ Energy intensity of source material extraction and production processes; ▪ Ecological impacts associated with alteration to the natural environment; ▪ Environmental contamination stemming from production and/or transportation; ▪ Energy intensity of further conversion processes in in production; ▪ Ecological impacts associated with further alteration to the natural environment. **Bio-Fuel** ▪ Limitations on the availability of land with suitable characteristics for cultivation; ▪ Creation of competition with food production through the use of energy crops; ▪ Requirement for high levels of land use changes, incentivising further deforestation; ▪ Increased pollution through higher levels of production and use (run-off) of fertilisers; ▪ Requirement for high levels of water consumption, imposing limitations on availability and access; ▪ Requirement for low levels of Carbon capture and storage for abatement; ▪ Energy intensity of biomass cultivation and subsequent production processes; ▪ Ecological impacts associated with alteration to the natural environment.	**Fuel Product** ▪ Current levels of production equate to 73.9 million tonnes of Hydrogen on an annual basis; ▪ Commercially available as a final product, with no international trading market established at present; ▪ No existing global transportation networks with a number of vessels currently undergoing construction (H_2 carriers); ▪ No standardised bunkering facilities available for supply of Hydrogen within any ports globally. **Synthetic-Fuel** ▪ Natural Gas feedstock reserves of 64,964,744 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Natural Gas production equate to approximately 39,893 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 1,628 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Natural Gas resources available for production within approximately 32.8% of nations. ▪ Crude Oil feedstock reserves of 3,057,250 terra watt-hours remaining globally of a finite resource; ▪ Current levels of Crude Oil production equate to approximately 52,070 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 59 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of Crude Oil resources available for production within approximately 31.8% of nations. ▪ Coal feedstock reserves of 5,350,000 terra watt-hours remaining globally of a finite resource;	**Fuel Product** ▪ There are currently no vessels within the world fleet using Hydrogen as a fuel product due to its commercial unavailability; ▪ There are currently no vessels within the world fleet that are capable of using Hydrogen as a fuel product without some form of retrofitting; ▪ Feasibility of retrofit for existing vessels incapable of using Hydrogen as a fuel product is very poor; ▪ All existing vessels require some degree of retrofit to enable operations using Hydrogen; ▪ Vessel range or capacity (volumetric) can be decreased by a factor of 0.23 due to adoption of Hydrogen as a fuel product (Gas Oil reference); ▪ Vessel range or capacity (gravimetric) can be increased by a factor of 2.80 due to adoption of Hydrogen as a fuel product (Gas Oil reference); ▪ There are currently no ports with existing bunkering capability for Hydrogen at the worldwide scale ▪ Upgrades required to existing bunkering infrastructure within approximately 500 additional ports to achieve worldwide distribution of Hydrogen; ▪ Alterations to bunkering infrastructure required for Hydrogen capability are extensive.

CHARACTERISTICS OF FUEL PRODUCTION

Fuel Product	Sustainability Issues	Fuel Availability	Adoption Trends
Hydrogen (Continued)	**Electro-Fuel** ▪ Energy intensity and material requirements associated with increasing renewable electricity capacity; ▪ Ecological impacts associated with alteration to the natural environment.	**Synthetic-Fuel** (Continued) ▪ Current levels of coal production equate to approximately 46,549 terra watt-hours on an annual basis; ▪ Timeframe to depletion of 115 years given current levels of production and reserves that are known to be remaining. ▪ Global distribution of coal resources available for production within approximately 23.6% of nations; ▪ Bio-Fuel ▪ Biomass feedstock reserves of 333,333 terra watt-hours available globally of a restricted resource; ▪ Current levels of biomass production equate to approximately 1,143 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable but overall capacity restricted in accordance with land availability; ▪ Global distribution of biomass resources available for production within 100% of nations in principle. ▪ Electro-Fuel ▪ Renewable energy feedstock reserves of 2,993,889 terra watt-hours available globally on an annual basis; ▪ Current levels of renewable energy production equate to approximately 7,027 terra watt-hours on an annual basis; ▪ Timeframe to depletion inapplicable with overall capacity only limited by annual availability; ▪ Global distribution of renewable energy resources available for production within 100% of nations.	

CHARACTERISTICS OF FUEL PRODUCTION

Table Notes

Sustainability Issues: This assessment considers the wider environmental and/or societal implications associated with the excavation/production/cultivation of the various feedstocks required for the production of the alternative fuels, i.e., as a fossil-, synthetic-, bio- or electro-fuel. In this instance, these characteristics are measured in terms of the number of sustainability issues associated with the fuel products, including the various production methods available for each alternative, and taking into account multiple feedstocks that may be adopted.

Fuel Availability: This assessment takes into account the current levels of production for the alternative fuel, market maturity for international trade as a commodity, the number of vessels available that are capable of transportation of it and the distribution of ports at a global scale with compatible bunkering facilities. Additionally characteristics specific to the feedstock used in the production of the alternative fuels and includes their remaining reserves, the longevity characteristics of the resources and their management, geopolitical accessibility, geophysical location, global distribution, propensity for utilisation, annual production quantities, trends and predicted timescale to exhaustion.

Adoption Trends: This assessment considers the relevance of current adoption trends being witnessed within the maritime industry for the individual fuel products being evaluated and trialled by first movers that are establishing initial transition trajectories. This includes the number of vessels currently using the individual fuel product and those that are capable of transitioning without significant adaptations to existing systems and machinery. Also, the feasibility of vessel retrofitting to enable use of the alternative and the number of vessels that would necessitate such measures, the volume and mass effects on the range and capacity of a vessel intending to transition, the number of ports on a global scale that have existing bunkering capability and those requiring upgrade, in addition to their relative complexity of adoption.

CONTACT DETAILS

If you would like to provide feedback about this Loss Prevention resource, please contact:

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