Pathways to Sustainability through Alternative Marine Fuels

NSRP Meeting

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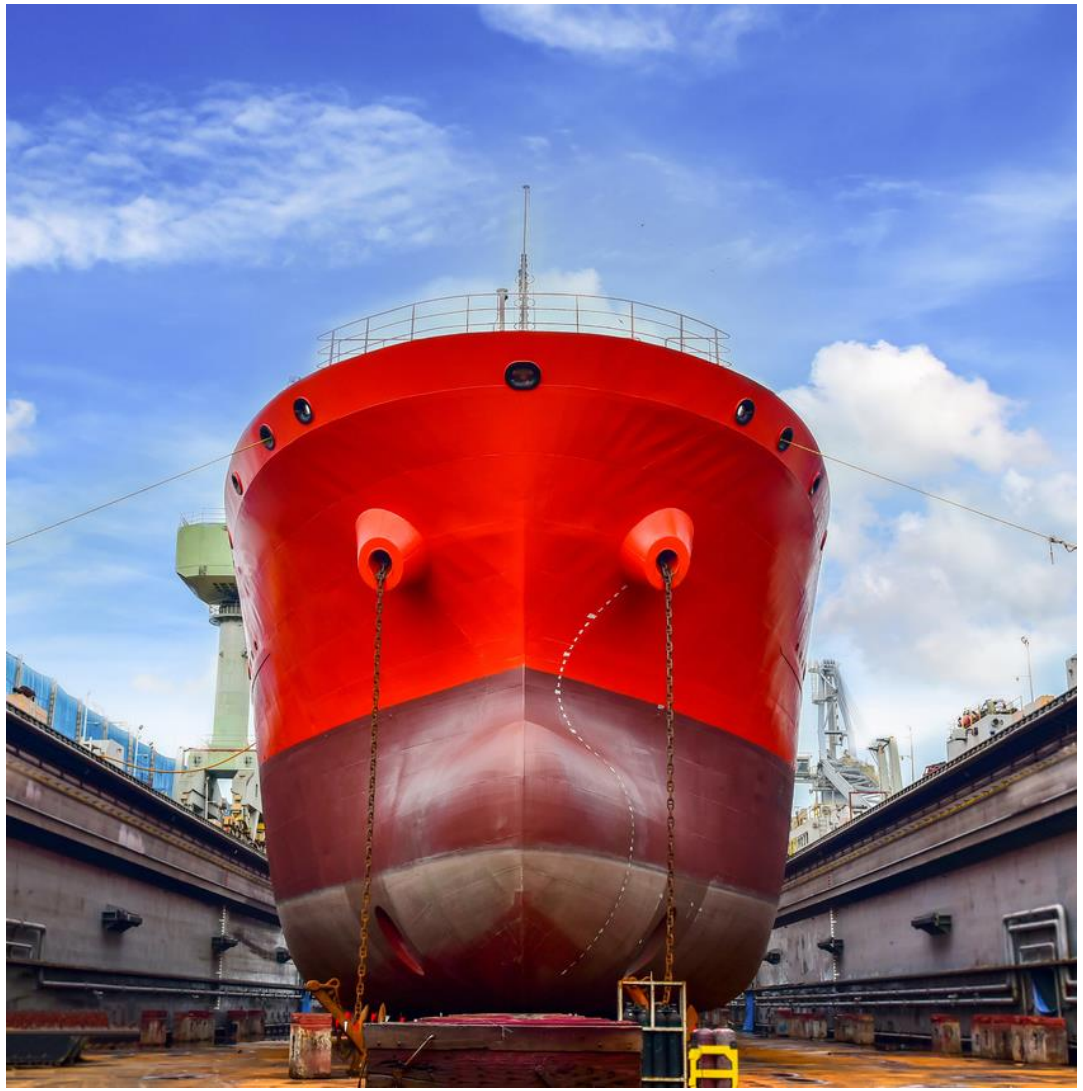
VP Technology

Agenda

- Drivers for Alternative Fuels
- Fuel Mix Outlook
- Alternative Fuel Options
  - Hydrogen
  - Ammonia
  - Methanol
  - Biofuels

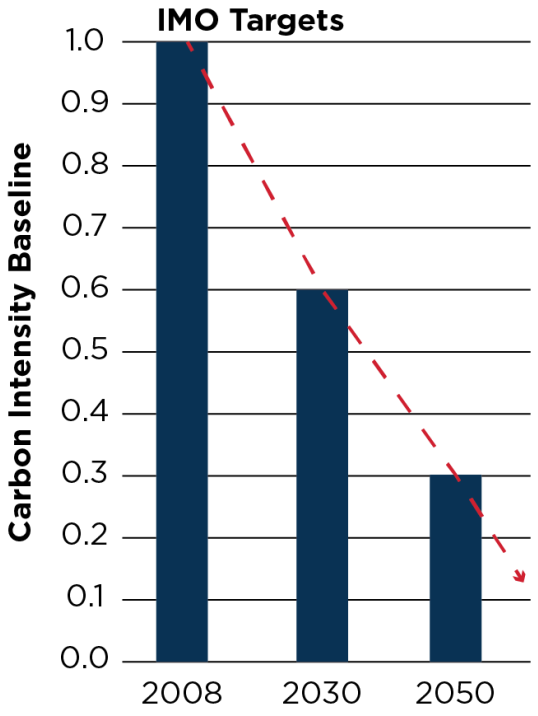


United Nations: Sustainable Development

- 2015: All member states of United Nations adopted the Agenda for Sustainable Development
  - 17 Sustainable Development Goals (SDG's)
  - Objective: shared blueprint for the planet

International Maritime Organization: GHG Strategy

- 2018: IMO adopted Initial Strategy setting ambitious goals for reduction of Greenhouse Gases
  - Reduce carbon intensity of 40% by 2030
  - Reduce carbon intensity of 70% by 2050
  - Reduce GHG emissions 50% by 2050

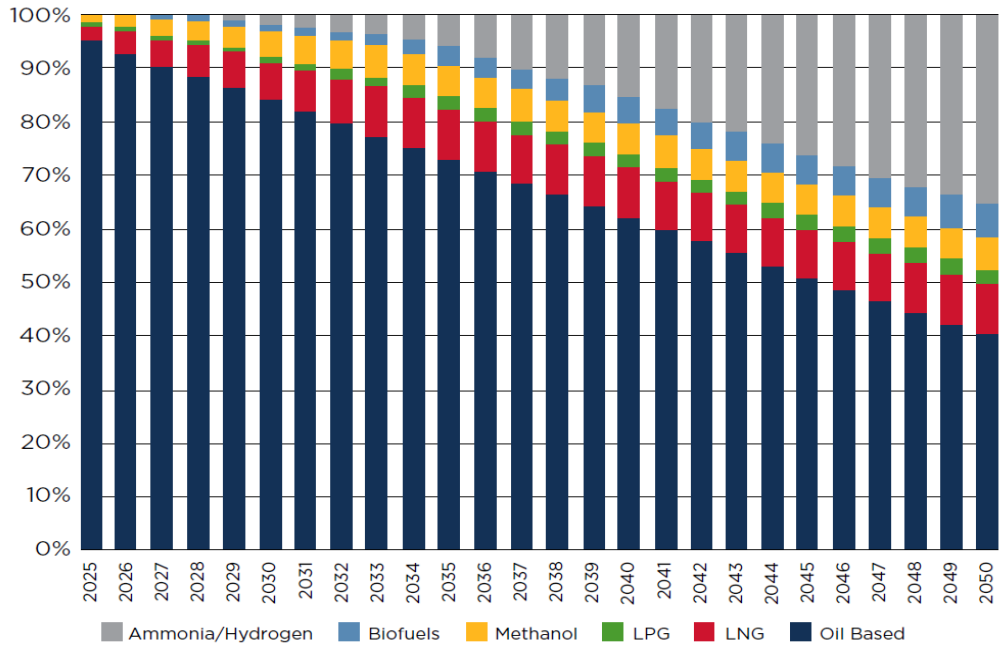


Nov 2020 (MEPC 75)	Agreed on combination of EEXI and CII EEXI framework and 4th GHG study approved
June 2021 (MEPC 76)	Develop technical guidelines for EEXI and CII Agree on CII metrics, baseline, reduction targets
(MEPC 77)	Initiation of work for adjustments on Initial IMO Strategy, based on DCS data
Summer 2021	Data for 2020 to be reported to IMO
(MEPC 78)	Phase 3: Decision step Secretariat report summarizing the 2020 data
Summer 2022	Data for 2021 to be reported to IMO
(MEPC 80)	Adoption of Revised IMO Strategy (short-, mid- and long-term measures)

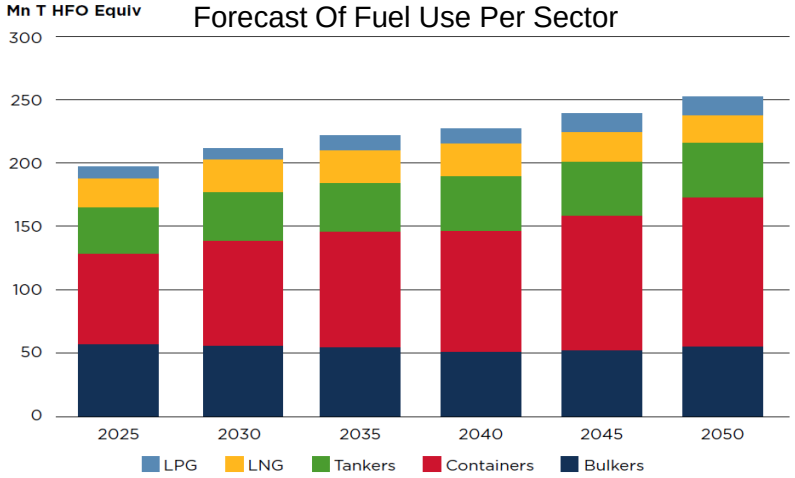
EEXI: Energy Efficiency Existing Ship Index
CII: Carbon Intensity Indicator
DCS: Data Collection System

Decarbonization Outlook

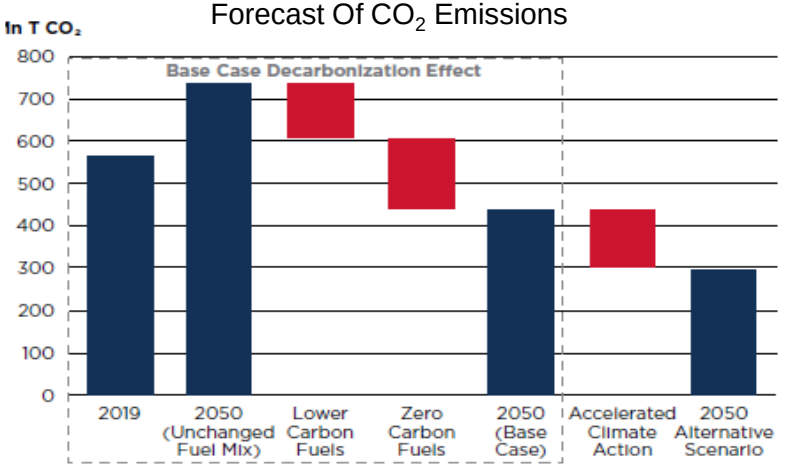
Projected Fuel Mix



Forecast Of Fuel Use Per Sector



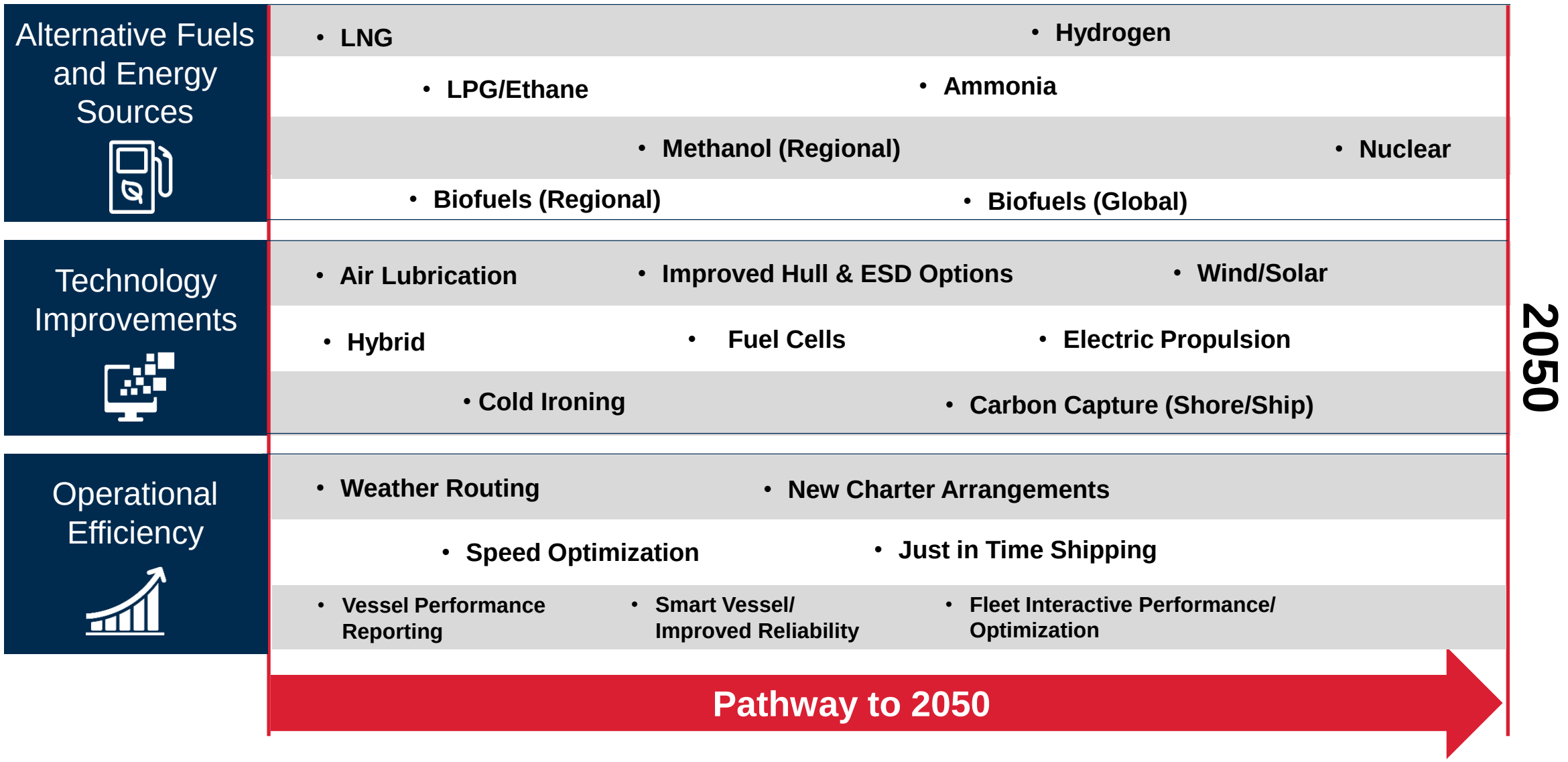
Forecast Of CO_2 Emissions



- Fuel mix projected to 2050:
  - 40% oil-based fuels
  - 35% ammonia, hydrogen
  - 25% LNG, LPG, methanol, biofuels

Sources: IEA, UNCTAD,IMO 3rd GHG study, IPCC

Decarbonization Solutions



Alternative Fuel Sources

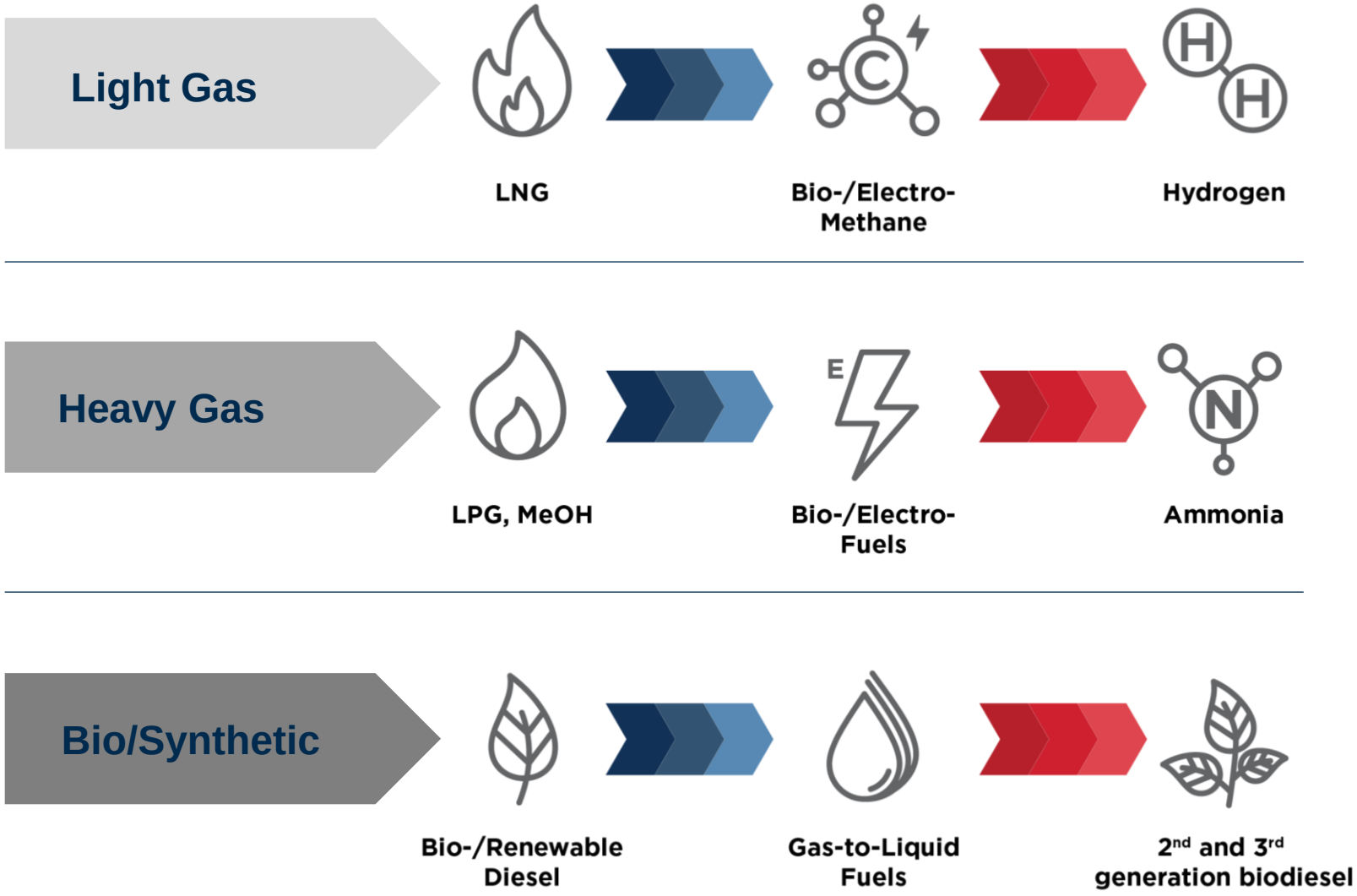
Fuel Type	Infrastructure	Security of Supply	Energy Density	CO_2	SOx	Safety
Heavy Fuel Oil						
Marine Diesel						
LNG						
LPG						
Methanol (from Methane)						
Methanol (from biomass)						
Ammonia (from methane)						
Ammonia (from renewable)						
Hydrogen (from methane)						
Hydrogen (from renewable)						
Biofuels						

Notes:

- **Infrastructure** refers to existing bunkering infrastructure or facilities that can be adapted to support bunkering (e.g. import/export terminals)
- **Security** of supply refers to the availability of sufficient global production to meet significant demand from the marine sector for bunkers
- **Energy density** refers to the volumetric energy content of the fuel and on-board storage requirements
- **CO_2 and SOx** refers to impact on emissions
- **Safety** refers to handling, storage and consumption risks

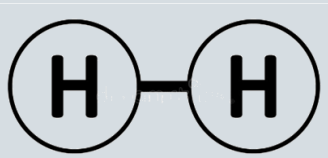
Source: ABS/MSI study

Three Fuel Pathways to the Future



Hydrogen Characteristics

- **Very small molecule**, composed of two atoms
- Colorless, odorless, tasteless, **non-toxic gas**
- Low density, **naturally buoyant**
- **Wide flammability range**
- Liquefies at -253°C (-423.4°F)
- **Can be used in a fuel cell**: outputs are heat, water, and electric power
- **High energy content by mass; low energy content by volume**
  - compressed hydrogen requires 8 x volume of marine gas oil
  - liquefied hydrogen required 4 x volume of marine gas oil

Chemical Composition	H_2
	
LHV (MJ/kg)	120
Energy Density (MJ/L)	8.5
Heat of Vaporization (kJ/kg)	1371
Autoignition Temperature (°C)	585
Liquid Density (kg/m^3)	71
Cetane Number	0
Octane Number	>130
Boiling Point (°C)	-253
Stoichiometric Air/Fuel Ratio	34:1
Adiabatic Flame Temperature at 1 Bar (°C)	2127

Hydrogen Production

Hydrogen production: fossil fuels or water

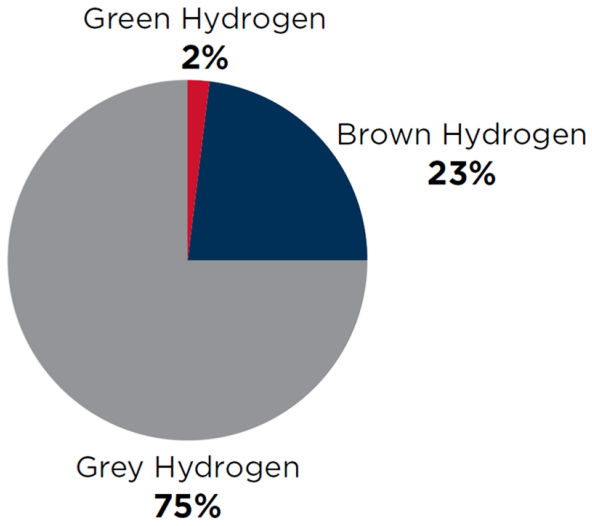
Brown Hydrogen: From processing of coal

Grey Hydrogen: From processing of natural gas

Blue Hydrogen: From processing of fossil fuels using Carbon Capture, Utilization and Storage

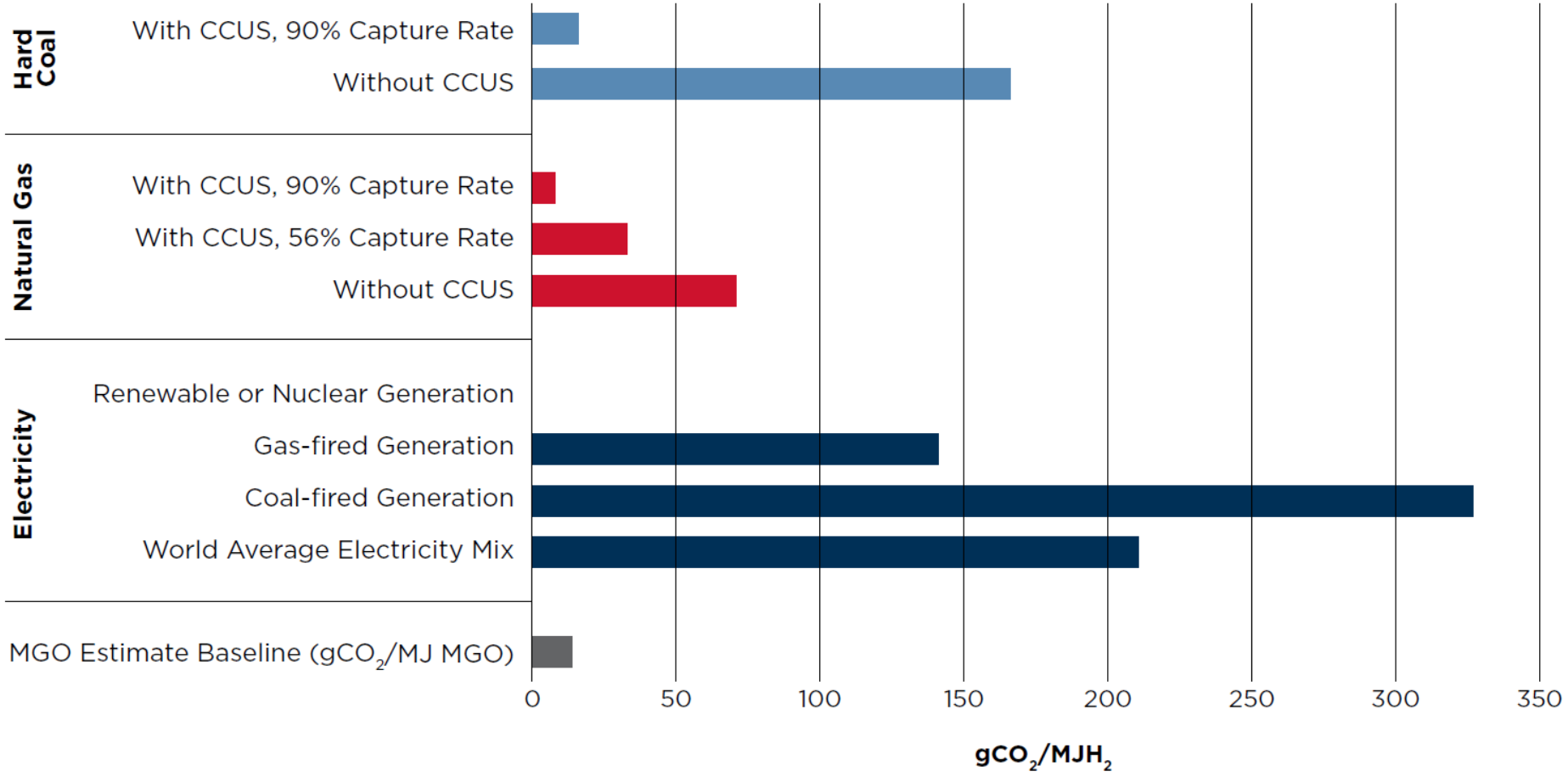
Green Hydrogen: From renewable energy sources, typically through electrolysis

Orange Hydrogen: A blend of Blue, Grey, Brown or Green hydrogen (e.g., 50/50% Grey-Green)



Source: International Energy Agency

Hydrogen Production Emissions



CCUS: Carbon Capture Utilization & Storage

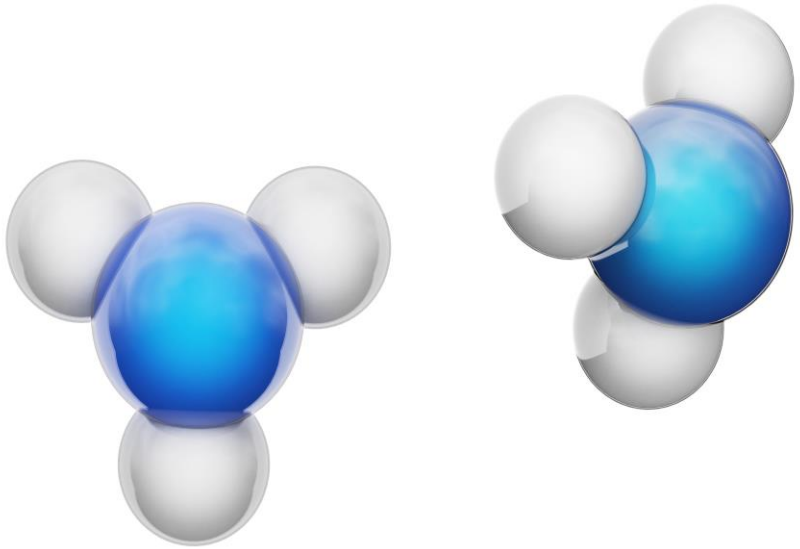
Source: International Energy Agency

Hydrogen Key Considerations

- **Wide flammability range:** special considerations should be taken to minimize the fire safety risks
- Performing a **risk assessment** is necessary for approvals
- **Experience** using hydrogen as marine fuel is growing
- Hydrogen produced from renewable sources can provide a **route to zero-emission vessels**
- **Supporting a hydrogen economy** can make it more available as a marine fuel

Ammonia Characteristics

- A colorless inorganic compound
- **Carbon- and sulphur-free and gives a clean combustion without generation of CO_2 or SO_X**
- Liquefied by compression to approximately 8 bar
- **Commonly stored at ~17 bar**, to keep in liquid phase if ambient temperature increases
- **While relatively low volumetric energy density, is higher than hydrogen; reduces tank size**



Ammonia Concerns

- **Toxicity/strong odor**
  - Restricting venting to ppm levels rather than the lower explosive limit (LEL)
  - Location of vent outlets
  - In case of Type A tank – vent from secondary barrier to be specially considered
  - Leaks/release in confined spaces
- **Gas freeing operations**
  - At quay with Nitrogen from shoreside
- **Nitrogen Oxide emissions, potent GHG**, presently unregulated
  - Prototype engine testing required to understand the issue

- Corrosive nature → use of some metals to be avoided in FGSS
- Gas freeing of fuel gas supply system (FGSS) and engine prior maintenance

Ammonia Key Considerations

- **Class and regulatory framework in place**
- **Risk assessment** is part of the approval process
- Experience and scope of dual-fuel technologies growing
- **Ammonia produced using renewable energy can provide route to zero and low carbon fuels**

Methanol Characteristics

- A clear liquid compound
- **Low flashpoint** and is **corrosive** to certain materials
- **Toxic and poisonous** to the central nervous system may cause blindness, coma and death if ingested
- **Vapor is heavier than air**
- At high vapor concentrations, methanol **can also cause asphyxiation**
- **Methanol flames are particularly hazardous**, they burn at low temperatures with a flame that is nearly invisible in daylight with no smoke

METHANOL PROPERTY	VALUE
Energy density (MJ/L)	15.7
Heat of vaporization (kJ/kg)	1098
Autoignition temperature (°C)	450
Liquid density (kg/m^3)	798
Adiabatic flame temperature at 1 bar (°C)	1980
Molecular weight (g/mol)	32.04
Melting point (°C)	-97.8
Boiling point at 1 bar (°C)	65
Critical temperature (°C)	239.4
Critical pressure (bar)	80.48
Flammable range in dry air (%)	6-36.5
Cetane number	< 5
Octane number	109
Flash point (°C)	12
Heavy Fuel Oil (HFO) equivalent volume	2.54

Methanol Advantages

- **Available worldwide and used in a variety of applications for many decades**
- Liquid at ambient temperature and pressure
- **Existing infrastructure can be repurposed**
- More efficient retrofits than LNG
- **Economical to store on board**
- **Capable of being produced from renewable sources and supported with carbon capture**

Methanol Key Considerations

- **Existing infrastructure**
- **Carbon neutral potential**
- **Class and regulatory framework for applications are in place**
- **Risk assessment** is part of the approval process
- Local applications require flag and local authority approval
- **Flames are particularly challenging**

Biofuel Characteristics

- **“Biofuels” describe any liquid or gaseous fuel derived from biomass or bio-waste**

Distillate Fuel Oils (e.g., MGO)

- Fatty Acid Methyl Ester (FAME) biodiesel
- Hydrotreated renewable diesel (e.g., hydrotreated vegetable oil, or HVO)
- Fischer-Tropsch (FT) diesel

Residual Fuel Oils (e.g., HFO)

- Straight Vegetable Oil (SVO)
- Pyrolysis bio-oil
- Hydrothermal liquefaction (HTL) bio-crude

Drop-in biofuel benefits:

- **“Drop-In” characteristics**
- **Non-toxic and biodegradable**
- **Reduced emissions profile**
- **Compatible with existing bunkering infrastructure**
- Detergent properties

Biofuels Key Considerations

- Biofuels covers a **wide variety of biomass-derived fuels**
- **Drop-in biofuel blends can improve emissions profile** for carbon dioxide, sulfur oxides, and particulate matter
- **Biofuels can use existing fuel infrastructure**
- **Biofuel produced from renewable sources can provide a route to net-zero carbon vessels**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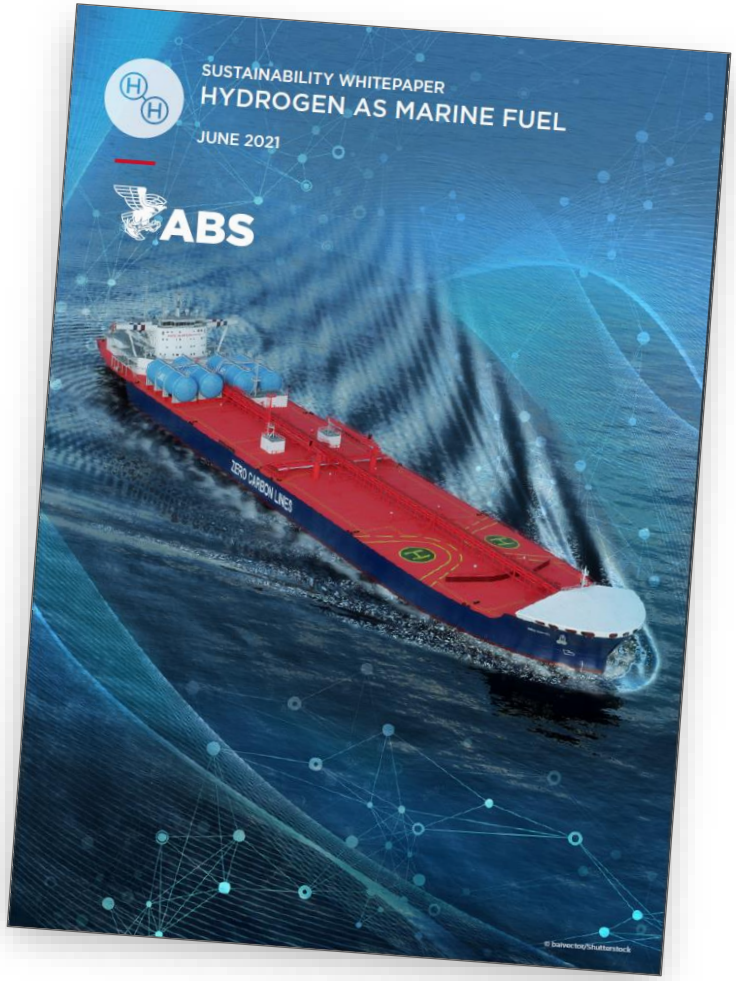
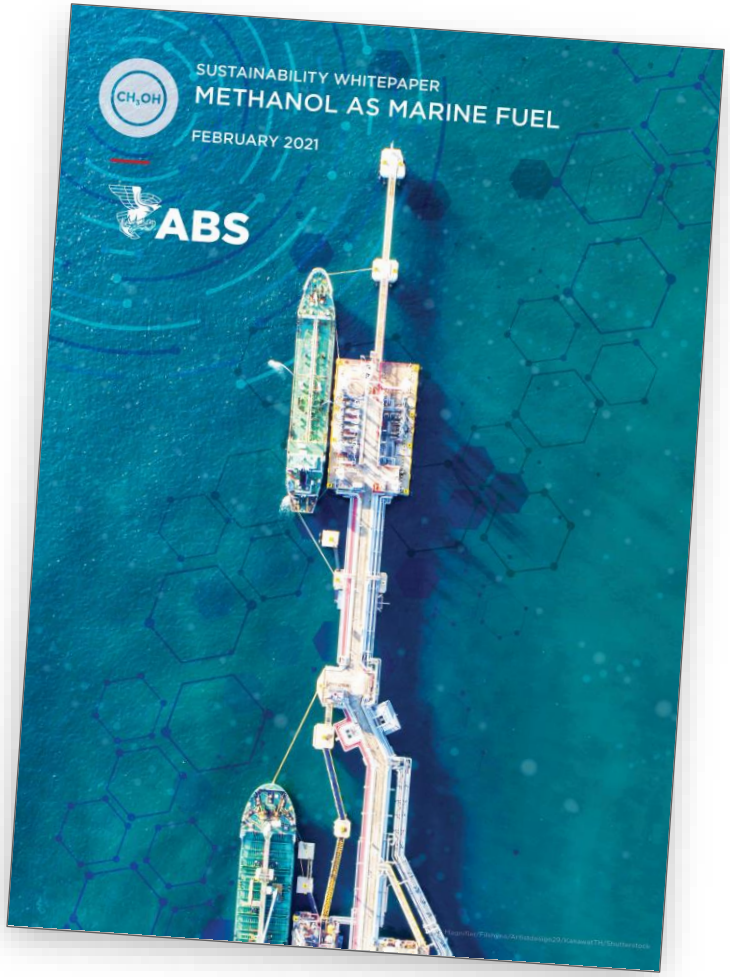
ABS Resources





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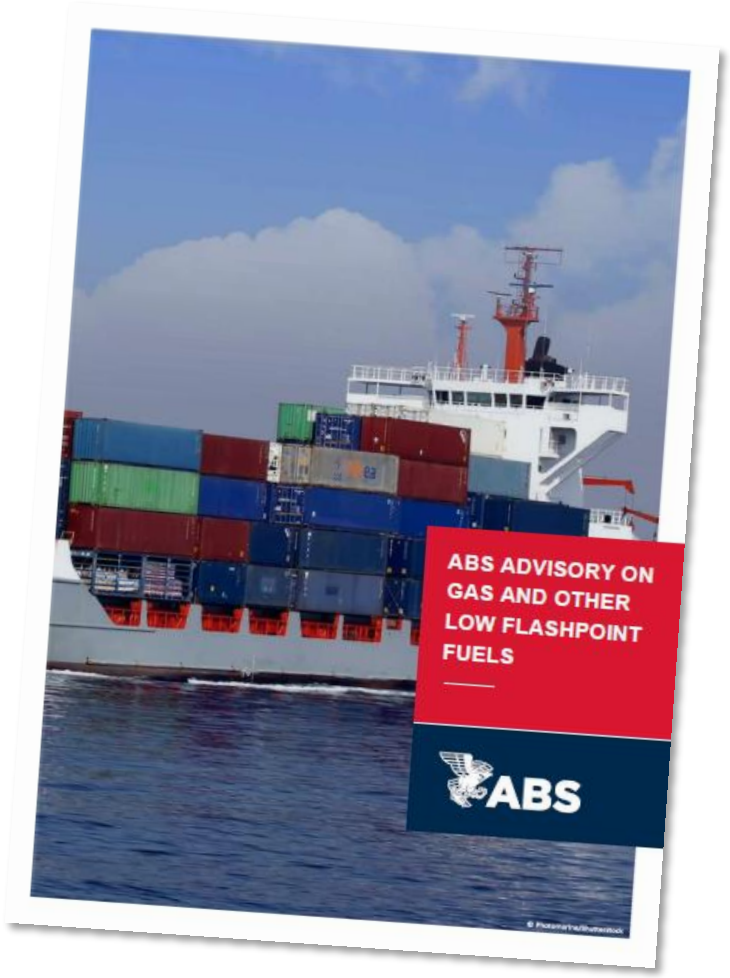

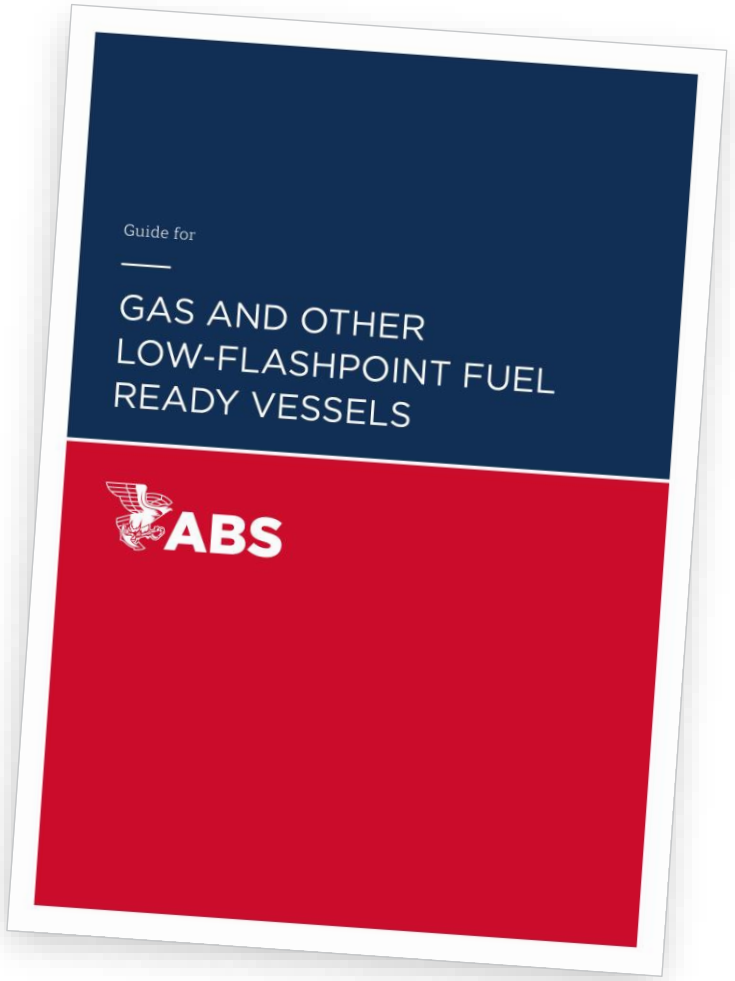

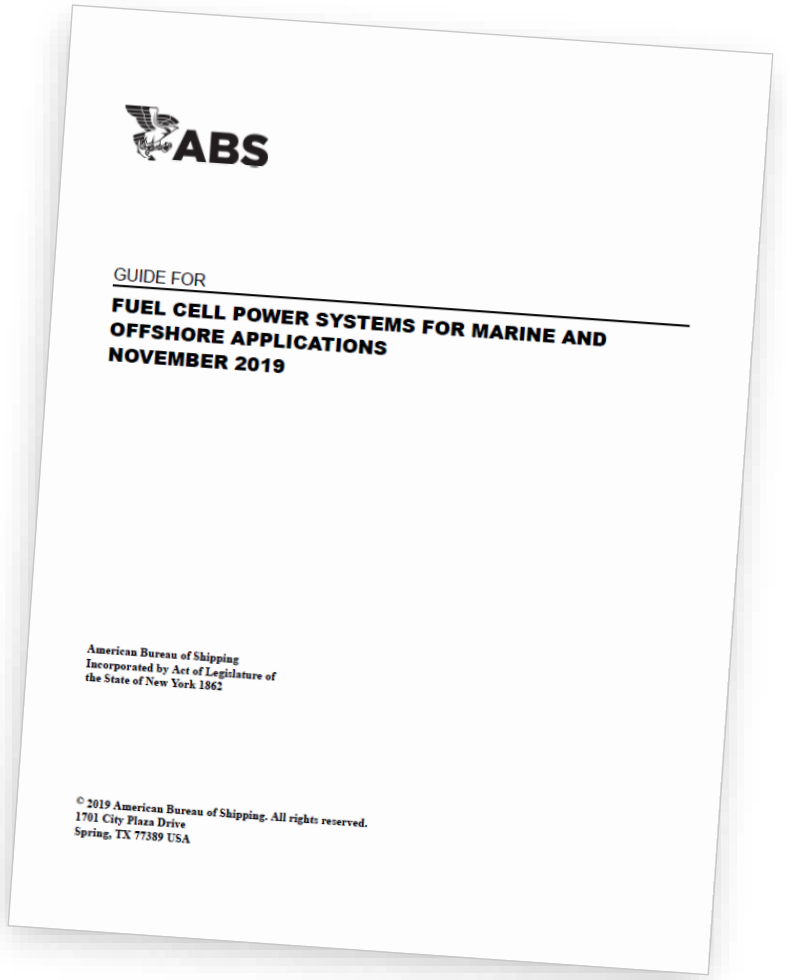

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