E-METHANOL

Introduction

Methanol is, like ammonia, a global commodity and shipped worldwide, with global production levels around 100 million tonnes per year. It has widespread use in the chemical and pharmaceutical industries as a precursor feedstock for various products, such as synthetic hydrocarbons. It can also be used directly as a fuel or easily converted into a range of other fuels, such as dimethyl ether and petrol/gasoline. Whilst it is currently predominantly produced from syngas, derived from fossil feedstock through steam methane reforming or coal gasification, it can readily be synthesised sustainably by combining low carbon hydrogen and captured CO_2.

E-methanol is in many ways a special case of an E-fuel, utilising the same concepts of Power-to-Liquid, creating valuable products from renewable and sustainable feedstocks, often utilising renewable electricity. E-methanol however differs from generic E-fuels as it can be synthesised directly by combining CO_2 and H_2, without the need to reduce CO_2 and produce syngas, simplifying the overall process. Additionally, as there is no need to employ Fischer-Tropsch to produce e-methanol or to convert e-methanol to SAF, the backend of the process is much simplified, reducing process complexity and cost. These considerations merit a separate treatment of E-methanol

E-methanol is currently considered a promising sustainable energy vector and fuel to de-fossilise hard to-abate sectors, with international shipping a market that is being targeted in particular.

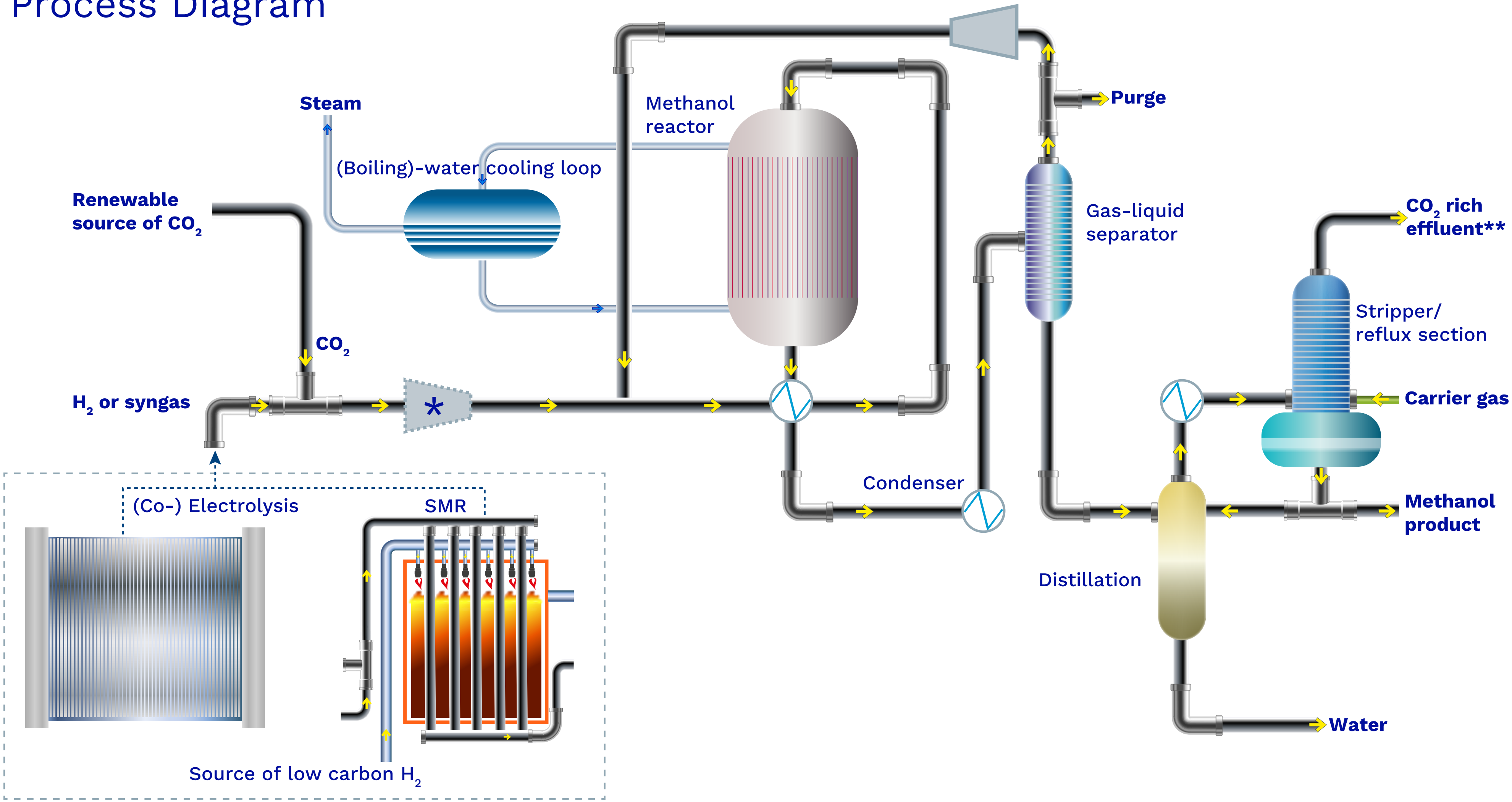
E-methanol production

Methanol is currently predominantly produced from syngas through steam methane reforming or coal gasification using fossil feedstocks. However, it can readily be synthesised sustainably by combining low carbon hydrogen and a renewable source of carbon, such as captured CO_2. Indeed, such a plant has been in operation in Iceland since 2012 (George Olah Renewable Methanol Plant), producing 5,500 tonnes/year of so-called E-methanol. Methanol synthesis is an exothermic reaction, so any reaction heat generated during this step can be utilised to lower overall process energy consumption. Thermal integration with high temperature electrolysis would be of particular interest as it would allow for a significant reduction in electricity consumption.

Utilising CO_2 directly, instead of CO as is currently the case, offers some opportunities for process simplification, reducing cost and improving process efficiency.

E-methanol production

Process Diagram



* Compression may not be required depending on feedstock pressures

**This stream could be recycled into methanol reactor

E-methanol production – feedstock

Hydrogen supply

Whilst the E in E-methanol generally refers to electrolytically produced hydrogen, more generally other sources of low carbon hydrogen could be considered, such as SMR using biomethane, although scale is important for E-methanol to be a viable commodity or hydrogen carrier. Low carbon production routes to hydrogen are described in other fact sheets. Hydrogen can either be produced onsite as part of the overall process, or externally supplied, although security of a continual supply is essential to optimally run the E-methanol production process, so pipeline connection and buffer storage would be preferred. Onsite production offers the potential for extensive process integration, reducing overall energy consumption and making the process economically more competitive with fossil based production.

Carbon supply

E-methanol synthesis requires a sustainable source of carbon and the most straightforward source would be CO_2 captured from a process that produces streams rich in this gas. Although many processes currently generate such streams, such as thermochemical power plants or industrial processes such as steel and cement making, the carbon emitted in these processes is predominantly fossil-derived. For E-methanol to be truly sustainable, a renewable source is necessary over the long term. Potential biogenic sources of CO_2 are anaerobic digestion and fermentation processes, or CO_2 captured from biomass power plants. Carbon capture can be achieved in a number of ways. Amine absorption is widely used although Pressure Swing Adsorption and membrane separation are viable alternatives. These processes are discussed in other fact sheets. Co-location again offers opportunities of process integration and as discussed for the hydrogen feedstock, continuity of supply is key, so pressurised storage and/or a pipeline connection would be key to achieve this.

E-methanol Production - Feedstock Sub-components
Hydrogen and carbon dioxide storage or buffer tanks
Compressors
High pressure stainless steel pipework (AISI 316L or 304L)
Gauges and pressure control system
Manifolding systems
Temperature control and sensing
Mass flow control
Actuatued shut off valves
Non-return valves
Isolation valves
Quick release couplers or similar for external supply interfacing
Flexible braided stainless steel tubes for hydrogen transfer (AISI 316 / 316 L)

Methanol synthesis – CO_2 hydrogenation

Methanol reactor

In the most straightforward scenario, E-methanol synthesis is achieved by combining hydrogen and CO_2 in a fixed bed reactor, operating at elevated temperature and pressure, typically 200 - 300°C and several tens of bar, up to 100 bar. The reaction conditions are chosen to provide a balance between kinetics and thermodynamic equilibrium. Depending on reactor configuration and the chosen catalysts, single pass conversions can be limited and a recycle loop is typically deployed to achieve acceptable overall production rates. Reactors with integrated heat exchange can limit temperature rises as a result of the reaction heat and can thus improve single pass yield, although at the cost of increased capital expenditure. Similarly, research and development work is ongoing to find more suitable catalysts for CO_2 hydrogenation, as currently E-methanol simply utilises $Cu/ZnO/Al_2O_3$ based materials which are optimised for traditional syngas feedstock.

Alternative synthesis schemes are possible, for instance co-electrolysing water and CO_2 to produce syngas and subsequently converting this to methanol in the traditional thermo-catalytic process. Co-electrolysis has been proven on small scale and although this route is not as mature as CO_2 hydrogenation, it benefits from utilising the existing methanol synthesis infrastructure and technology, without need for modifications. Similarly, SMR using biomethane produces syngas directly, which could be utilised as feedstock for methanol synthesis.

Thermal management

Traditional methanol synthesis uses CO/H_2 or syngas as feedstock. The heat generated during synthesis in this scenario is significantly higher than when CO_2 is used directly. E-methanol synthesis therefore presents an opportunity for simpler reactor design, avoiding the need of Boiling Water Reactors and using simpler tube-cooled reactors instead, lowering capital cost. Reduced heat generation also lowers the potential for catalyst deactivation due to sintering.

Methanol separation and purification

Reaction mixtures leaving the methanol synthesis reactor typically pass through a number of heat exchangers and are flashed to separate gaseous and liquid fractions. The liquid fraction or crude methanol, mostly a mixture of water and methanol, is separated using a combination of distillation and CO_2 stripping, yielding a purified stream of E-methanol. The gas mixture from the flash, mostly CO_2 and H_2 with smaller amounts of CO and product, is recirculated to the inlet of the methanol reactor after recompression.

E-methanol production from CO_2 feedstock offers further opportunities for process simplification when compared to conventional methanol synthesis from syngas. The production of trace impurities, such as acetone, esters and ketones is greatly reduced, allowing for a much simplified purification section post synthesis.

Balance of Plant

Thermal integration and recovery are key in the e-methanol production plant to optimise process efficiency. Heat exchangers are critical for thermal integration, whereas any high temperature steam could be utilised to drive centrifugal compressors to pressurise feedstock. As with any other chemical process, careful control is required for each process step to operate within acceptable process parameters and at optimum efficiency. See other fact sheets for further detail, e.g. SMR / ATR

Process safety

Process safety is integrated with process control. Pressure relief and shutdown valves are linked to pressure and temperature monitoring. Burst valves can be also installed in case of critical pressure increases, avoiding catastrophic damage to equipment or even explosions. Sudden drops in gas (differential) pressure may indicate a major leak from e.g. equipment failure, loose connections. Gas monitoring equipment allows for gas leak detection, and linked to process control system allows for process shutdown if this is the case.

Periodic maintenance and inspections, both invasive and non-invasive carried out to spot defects and replace process critical equipment.

Methanol as a feedstock for Sustainable Aviation Fuel (SAF)

Sustainable/Synthetic Aviation Fuels are designed to provide a lower emission replacement to conventional jet fuel (aviation currently accounts for 2.5% global CO_2 emissions). SAF is a "drop-in" fuel which means it can be a direct replacement for conventional aviation fuel (CAF). This allows for ease of adoption both at airports and in use by aircraft. This is particularly important given rising demand for global connectivity and that conventionally-fuelled aircraft are likely to operate until at least 2070s.

SAF is now mandated/supported globally. In the UK there is now the SAF mandate in place (meaning that 10% of UK jet fuel must be SAF by 2030) and there is the UK SAF Revenue Certainty Mechanism which is set to be implemented from 2026 onwards.

SAF production methods fall into two broad categories; biofuel production methods (HEFA-derived and alcohol to jet) and synthetic fuels. Synthetic fuels in particular rely on significant volumes of hydrogen, providing a possible opportunity for domestic demand for green hydrogen (alongside locally sourced biogenic carbon).

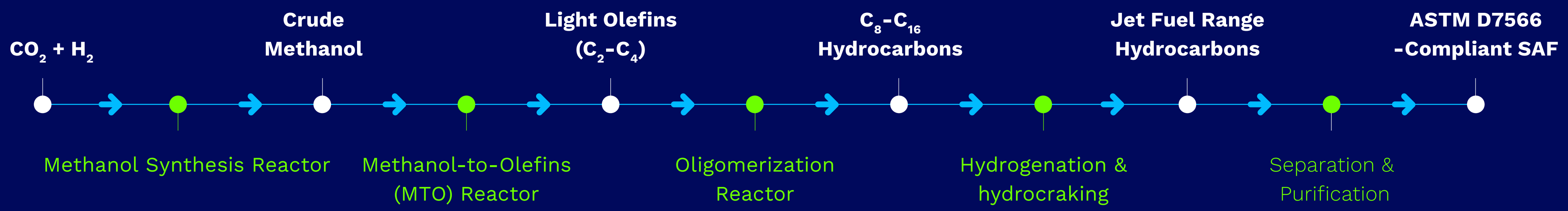
One SAF production method under development (under the synthetic fuel/power-to-liquid production category) is methanol-to-jet (MtJ). Companies like ExxonMobil, Topsoe and Johnson Matthey/Honeywell are all working on Methanol-to-Jet production methods. It is a pathway which is expected to be approved before 2030 by ASTM as a certified method for SAF production.*

Project Willow (Grangemouth) considers MtJ to be a viable pathway to producing SAF at Grangemouth, identified as one of 9 key project areas to be taken forward within a Grangemouth biorefinery.

The Methanol-to-Jet (MtJ) pathway is an emerging route for producing Sustainable Aviation Fuel (SAF) using renewable methanol as a feedstock. It offers a promising alternative to traditional Fischer-Tropsch or HEFA processes, especially when methanol is derived from green hydrogen and captured CO_2 [note, the final SAF product must achieve a minimum GHG emissions reduction of 40% relative to a fossil fuel comparator of 89gCO2e/MJ to comply with the UK SAF mandate]. Following its production, methanol is converted to hydrocarbons via a two-step process.

1. **Methanol-to-Olefins (MTO)**: Converts methanol to light olefins (ethylene, propylene)
2. **Olefins-to-Jet (OTJ): Oligomerization**, hydrogenation, and hydrocracking to produce jet-range hydrocarbons

It requires catalysts including Zeolites (e.g., ZSM-5) for MTO and metal-based catalysts for hydrogenation.



*World Economic Forum publication

E-methanol storage

Methanol is attractive due to its liquid state at ambient conditions and thus high energy density. Storage of methanol is therefore relatively straightforward, with handling comparable to many flammable liquid hydrocarbons in use today, such as petrol, keeping many of the safety guidance in place. Excessive temperature (and thus exposure to direct sunlight) must be avoided due to methanol's relatively high vapour pressure. Pressure relief devices must be installed. Temperature monitoring and control may be required if there is risk of reaching excessive temperature beyond design parameters. There are some methanol specific considerations as compared to hydrocarbons. It is a polar solvent and can therefore cause corrosion in metal containers. It has a much broader flammability range than for instance petrol, which needs to be taken into account. Outdoor storage in a well-ventilated area is preferred. Earthing is essential to avoid static sources of ignition.

Medium scale storage is typically in horizontal cylindrical tanks with fixed dimensions, constructed from either carbon steel or 300 series stainless steel. Fill rate should not exceed 80% to allow for liquid expansion with temperature. Tanks should be earthed/bonded. External coatings can be applied to protect against elements. The use of most polymers should be avoided due to long term material degradation. Rubbers on the other hand, e.g. nitrile and EPDM, are suitable for use in seals and washers.

Large scale storage is typically in vertical cylindrical tanks with floating roofs, allowing for pressure differentials and minimising large volumes of flammable vapour.

E-methanol Transport

Transport of methanol is primarily by shipping, rail and road

Methanol, shipping code UN 1230, is a Class 3 flammable liquid under UN regulations and comes under packing group II (medium risk)

The safety of transporting methanol is regulated by the respective regulations of the mode of transport, i.e.

- Shipping – IMDG (The International Maritime Dangerous Goods code)
- Rail – RID (Regulations concerning the International Carriage of Dangerous Goods by Rail)
- Road – ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road)

Safety precautions are broadly similar to those for stationary storage. Road transport typically utilises portable ISO tanks.

Methanol Synthesis, Separation and Purification

Sub-component	Material(s)	Specs
Specialist catalysts and support materials	"Typically copper/zinc-oxide (Cu/ZnO) based, supported on Aluminium Oxide (Al_2O_3). Alternative support materials are Cerium Oxide (CeO_2), Zirconium oxide (ZrO_2), or Lanthanum (III) oxide (La_2O_3). Molybdenum disulfide (MoS_2) based catalysts also considered"	
Reactor		Fixed bed adiabatic reactor or multi-tubular reactor
Reactor vessel	Low-carbon chromium steel	
	Chromium-Molybdenum (Mo-Cr) low carbon alloys	
Gas or boiled water cooled reactors	Low carbon steel boiler vessel	ASME Boiler and Pressure Vessel Code (BPVC) for the design, construction, and inspection of boilers and pressure vessels
For Distillation		
Multiple stage distillation column	Carbon steel	
Reflux condenser and boiler	Carbon steel	
For Stripper		
Multiple perforated plate type with spargers for liquid phase dispensing	Stainless steel	Appropriate for operating conditions
Suitable carrier gas	Nitrogen, hydrogen	Appropriate for operating conditions
Suitable stripping fluid	Monoethanolamine (MEA) or Methyldiethanolamine (MDEA)	
Reflux drum	Stainless steel	Appropriate for operating conditions

Balance of Plant Components

Heat exchangers	Compression fittings
Compressors (Centrifugal or reciprocating depending on feedstock)	Pressure control systems
Blowers	Electrical supplies to componentry
Liquid/water pumps	Electrical heating elements
Pressure gauges	Electrical signalling
Pressure transducers (Multiple pressure range - including vacuum for Vacuum Pressure Swing Adsorption)	Electrical switchboard and electronics cabinet
Back pressure regulators	Electrical safety and interlocks
Thermocouples/thermistors	Steel construction frames and gantries
Mass flow controllers (Coriolis or ultrasonic or thermal conductivity based)	Stairways, handrails and safety barriers
Solenoid control valves	Concrete foundations and plinths
Multidirectional valves and no-return valves	Earthings and drainage
Ball valves	Steel skids
Pressure relief valves	Stationary & mobile gas detection
Burst valves	Warning signs (Illuminated, traffic light and yellow flashing lights)
Stainless steel pipework (ASTM 316/304)	General signage

E-Methanol Storage

Sub-component
Filling and drain valves
Vapour venting and pressure relief valves
Liquid level gauge
Liquid transfer pumps
Thermostat and cooling (optional)
Earthing connections
Pipework

Transport

Tanks
Fire fighting equipment (Alcohol-resistant aqueous film-forming foam)
Pipework
Manifolding

For all metallic components a mild carbon steel or austenitic series 300 stainless steel would normally be used e.g. ASME S235 or stainless 304. Many grades are available, and the choice is often one of economics vs. longevity.

External corrosion protection in the form of coatings and/or cathodic protection (excl. galvanised steel) may be required in particularly corrosive environments, e.g. offshore or coastal storage (e.g. port terminals and shipping).

For sealing materials within any of these components, a synthetic rubber, e.g. Ethylene Propylene Diene Monomer (EPDM) or Nitrile Butadiene Rubber (NBR) would normally be used.

Core Process Units & Engineering Components for SAF Production from Methanol

Unit Operation	Key Equipment	Engineering Considerations
Methanol Feed System	- Storage tanks - Pumps - Preheaters	- Corrosion-resistant materials - Temperature control for vaporization
Methanol-to-Olefins (MTO) Reactor	- Fixed-bed reactor - Zeolite catalyst (e.g., ZSM-5)	- High-temperature operation (~400–500°C) - Coke management and regeneration systems
Olefin Oligomerization	- Reactor with SAPO-11 or Ni-based catalyst	- Pressure control for chain growth - Product distribution tuning
Hydrogenation & Hydrocracking	- Trickle-bed reactor - NiMo or CoMo catalysts	- High-pressure hydrogen feed - Heat exchangers for exothermic control
Separation & Fractionation	- Distillation columns - Knock-out drums - Reboilers and condensers	- Jet fuel cut-point control - Removal of light gases and aromatics
Utilities & Ancillaries	- Hydrogen supply system - Cooling water and steam systems - Flare and safety systems	- Integration with renewable H_2 - Heat recovery and energy efficiency

Additional Engineering Design Features

Catalyst Handling Systems: For loading, unloading, and in-situ regeneration

Instrumentation & Control: Advanced process control (APC) for temperature, pressure, and flow optimization

Modular Skid Design: For distributed or small-scale SAF production

Environmental Controls: Emissions monitoring, flare gas recovery, and wastewater treatment

Organisation	Standard	Details	Date of Publication
Codes of Practice (1/2)			
International Maritime Organization	International Maritime Dangerous Goods (IMDG)	The IMDG Code was developed as an international code for the maritime transport of dangerous goods in packaged form, in order to enhance and harmonise the safe carriage of dangerous goods and to prevent pollution to the environment. The Code sets out in detail the requirements applicable to each individual substance, material or article, covering matters such as packing, container traffic and stowage, with particular reference to the segregation of incompatible substances.	Introduced in 1965 and made mandatory under the umbrella of SOLAS Convention from January 1st 2004
Convention concerning International Carriage by Rail	International Carriage of Dangerous Goods by Rail	Outlines specific requirements for packaging, labeling, documentation, and handling of dangerous goods during international rail transport. Its purpose is to prevent accidents and minimise the consequences of any incidents involving dangerous goods during rail transport.	Applicable from January 1st 2023

Organisation	Standard	Details	Date of Publication
Codes of Practice (2/2)			
United Nations Economic Commission for Europe (UNECE)	European Agreement concerning the International Carriage of Dangerous Goods by Road	The agreement itself is brief and straightforward, and its most relevant article is article 2. This section states that except certain hazardous materials, hazardous materials may, in general, be transported internationally in wheeled vehicles, provided that two sets of conditions be met: 1. Annex A regulates the merchandise involved, notably their packaging and labels. 2. Annex B regulates the construction, equipment, and use of vehicles for the transport of hazardous materials.	Applicable from January 1st 2023
United Nations (UN) identification number for methanol	UN 1230 Flammable Liquid Placard	Hazard Class 3 placards meet the requirements of 49 CFR 172.500 for domestic and international shipments of hazardous materials by highway, rail and water.	

Organisation	Standard	Details	Date of Publication
Guidance Documents (1/2)			
Health and Safety Executive	HSG176 Storage of flammable liquids in tanks	This guidance applies to above and below ground fixed bulk storage tanks. It applies to premises where flammable liquids are stored in individual tanks or groups of tanks. It may also be applied to portable or skid-mounted vessels with capacities in excess of 1000 litres. It gives guidance on the design, construction, operation and maintenance of installation used for the storage of flammable liquids in fixed and transportable tanks operating at or near atmospheric pressure.	Published 2015
	HSG51 Storage of flammable liquids in containers	This guidance is for those responsible for the safe storage of flammable liquids in containers at the workplace. It applies to storage of flammable liquids in containers up to 1000 litres capacity. It explains the fire and explosion hazards associated with flammable liquids and will help you determine how to control the risks in your workplace.	Published 2015

Organisation	Standard	Details	Date of Publication
Guidance Documents (2/2)			
	HSG140 Safe use and handling of flammable liquids	This guidance is for those responsible for the safe use and handling of flammable liquids in all general work activities, small-scale chemical processing and spraying processes. It explains the fire and explosion hazards associated with flammable liquids and will help you determine how to control the risks in your workplace.	Published 2015
Marine Safety Forum	The carriage of methanol in bulk onboard offshore vessels	Provides guidance on the safe loading, carriage, and discharge of methanol by offshore support vessels	First edition 2020
Directives			
Health and Safety Executive	ATEX - 2014/34/EU	Two EU directives which describe the minium safety requiements for workplaces and exxquipment used in explosive atmoshperes - ATEX Workplace Directive and the ATEX Equipment Directive	Published in 2014 and applicable from 2016
Health and Safety Executive	Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)	Require employers to control the risks to safety from fire, explosions and substances corrosive to metal	Published 2002

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