



SUMMARY OF RESULTS

STUDY ON BIODIESEL-BUNKER FUEL BLENDS AS MARINE POLLUTANTS

PRACTICAL CONSIDERATIONS FOR RESPONDERS

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1. Executive overview

This document is based on the study “Blends of Biodiesels with Conventional Marine Bunker Fuels as Marine Pollutants and the Response Measures for their Accidental Releases” (ISBN: 978-92-95229-45-7), commissioned by the European Maritime Safety Agency (EMSA) and carried out by the World Maritime University (WMU) and Cedre. It has been developed to provide practical guidance for responders by translating the study’s findings into operationally relevant information.

The maritime sector is progressively transitioning towards alternative fuels in response to international and European commitments to reduce greenhouse gas emissions. Within this context, biodiesel-based fuels, including Fatty Acid Methyl Ester (FAME) and Hydrotreated Vegetable Oil (HVO), are increasingly being used in blends with conventional marine fuels such as Marine Gas Oil (MGO) and Very Low Sulphur Fuel Oil (VLSFO). Whilst their use is expanding, knowledge regarding their behaviour as marine pollutants and the implications for spill response remain more limited than for traditional fuels.

The purpose of this document is to support competent authorities, operators, and spill response organisations by providing clear and operational insights into the behaviour of potential spills of biodiesel–marine fuel blends in the marine environment. It outlines key considerations related to detection, monitoring, and recovery, and clarifies how existing response strategies and capabilities can be effectively applied in practice.

2. Marine fuels: physicochemical properties

The ISO 8217 norm refers to the specifications of marine fuels. In the edition released in 2024, blends of conventional bunker fuel, i.e. Low Sulphur Fuel Oil (LSFO), Ultra Low Sulphur Fuel Oil (ULSFO), and High Sulphur Fuel Oil (HSFO), with biodiesel are now possible up to 100%. Due to this regulatory change, new fuels are entering the marine fuel market. Until now, the fate and impact of biodiesel and marine fuel oil blends in the case of accidental spills have not been the subject of specific studies.

2.1 Biodiesel properties

ISO 8217 indicates that two biodiesels (FAME and paraffinic diesel) are used in blends with marine fuels. Based on experience from the automotive industry, FAME, HVO, and Fischer-Tropsch diesel are believed to have the greatest potential for application in marine diesel engines.

Table 1. Description of the main biodiesel types and operational characteristics.

Biodiesel type	Production source	Key characteristics	Operational implications (spill response)
FAME (Fatty Acid Methyl Ester)	Vegetable oils, animal fats, waste greases	Contains oxygen; slightly higher density and viscosity; lower stability	Faster weathering and oxidation; may enhance natural dispersion; can reduce recovery efficiency
HVO (Hydrotreated Vegetable Oil)	Hydrogenated oils, fats, algae	Paraffinic, oxygen-free; stable; good cold flow properties	Behaviour close to diesel; predictable spreading and evaporation; easier to manage in response
FT (Fischer–Tropsch Diesel)	Biomass, natural gas, coal (via syngas)	Synthetic, high purity; low density and viscosity	Highly diesel-like behaviour; efficient spreading; generally favourable for recovery operations

Table 2. Physicochemical properties of diesel and biodiesels (FAME, HVO, and FT) according to international standards (EN 590, EN 14214, ASTM D6751, and EN 15940).

Property	Diesel		Biodiesel					
			FAME				HVO	
	EN 590	EN 590	EN 14214		ASTM D6751		FTEN 15940	
	Min	Max	Min	Max	Min	Max	Min	Max
Cetane number	51		51		47		70	
Density @ 15 °C (kg m ⁻³)	820	845	860	900			765	800
Flash-point (°C)	< 55		101				55.1	
Viscosity @ 40 °C (mm ² s ⁻¹)	2.0	4.5	3.5	5	1.9	6	2	4.5
Lubricity (µm, HFRR)		460						400
Aromatics (% m m ⁻¹)		8						1.1
Sulphur content (mg kg ⁻¹)		10						5
Carbon residue on 10 % distillate (% m m ⁻¹)		0.30						0.1
Fatty-acid methyl ester content (% m m ⁻¹)		7	96.5					
Sulphated ash (% m m ⁻¹)		0.01		0.02				0.001
Water content (% m m ⁻¹)		200		0.05				0.02
Total contamination (mg kg ⁻¹)				24				24
Oxidation stability @ 110 °C (h)		25	8		3		25	
Acid value (mg KOH g ⁻¹)				0.5	0.5			0.01
Cloud point (°C)		+3 Summer -5 winter						-10 Summer -32 winter
Appearance @ 25 °C	Clear and bright; free from visible sediment						Clear and bright	

(Note: HVO and FT biodiesels specifications refer to the same standard EN 15490)

Biodiesels such as FAME, HVO, and Fischer–Tropsch (FT) fuels exhibit physicochemical properties within a relatively similar range, despite differences in feedstock and production processes. Typically, density values range from approximately 0.72 (FT fuels) to 0.87 (FAMEs), while viscosity varies from around 2 mm²/s (FT fuels) up to 4.9 mm²/s (FAMEs). These variations reflect compositional differences but overall indicate comparable fluid behaviour across biodiesel types.

Key conclusions for responders:

- **FAME blends:** more reactive and less stable. They may disperse faster and be harder to recover.
- **HVO / FT blends:** behave like conventional diesel. They are more predictable and manageable.

2.2 Conventional marine fuel properties

■ Marine fuel classification: ISO standards

Marine fuels are classified according to ISO 8217, which defines specifications, testing methods, and acceptable properties such as density, viscosity, sulphur content, flash point, and pour point. The 2024 edition incorporates biofuels, allowing FAME blends up to 100% (B100), supporting the maritime sector's transition to renewable energy while ensuring engine performance and reliability.

Building on this framework, marine fuels can be grouped into a limited number of categories based on their composition and behaviour. For operational purposes, a simplified classification is more useful than detailed specifications, as it highlights the key properties influencing spill behaviour and response effectiveness. The table below provides an overview of the main fuel types, their characteristics, and their practical implications for response operations.

Table 3. Simplified classification of marine fuels for operational use (ISO 8217).

Category	Fuel type / Grade	Key characteristics
Residual marine fuels (RM) (HFO)	ULSFO	Sulphur content < 0.1%
	VLSFO	Sulphur content < 0.5%
	HSFO	Sulphur content > 0.5%
	RF (FAME blends)	Residual fuels blended with FAME; viscosity limits specified
Distillate marine fuels (DM)	DMA / DMZ	Clear, yellow fuels with minimal viscosity differences
	DFA / DFZ	Bio-distillates containing FAME up to 100%
	DMX	Lighter fuel with low cloud point; requires special storage
	DMB / DFB	Heavier distillates, including bio variants
Common operational terms	MGO (Marine Gas Oil)	Covers lighter DM grades (DMA, DFA, DMZ, DFZ)
	MDO (Marine Diesel Oil)	Covers heavier distillates (DMB, DFB)

Key conclusions for responders:

- Residual fuel oils exhibit a much wider variability in physicochemical properties than distillate fuels, particularly in terms of viscosity, density, and pour point. As a result, fuels classified under the same category — especially VLSFO — may behave very differently in spill scenarios and should not be treated as a uniform product. VLSFOs combine relatively low viscosity with a highly variable pour point, meaning that each spill may present distinct handling and response challenges.
- Marine distillates show much more consistent properties across grades. This leads to more predictable behaviour at sea and generally similar slick dynamics during spills. The main observable difference during aerial surveillance may be slick colour, which can vary due to the use of dyes mandated by national regulations (e.g. fishing gasoil appearing blue, red, or green depending on the country).

2.3 Properties of biodiesel blends with conventional marine fuel oil

■ Identification of most “popular” biodiesel blends with marine fuel oil

The properties of biodiesel–marine fuel blends depend on the type of biodiesel (e.g., FAME), the nature of the base fuel (distillate or residual), and the blending ratio. These parameters directly influence key behaviours such as viscosity, stability, and dispersion in the event of a spill.

To identify the most representative blends currently used in the maritime sector, market data from major bunkering hubs (notably Rotterdam and Singapore) were analysed. These data show that VLSFOs have dominated fuel sales in recent years, reflecting regulatory requirements on sulphur emissions. In parallel, the increasing use of scrubbers has contributed to a partial recovery in HSFO consumption.

Regarding biodiesel integration, VLSFO is currently the primary base fuel used for blending, due to its widespread availability and compatibility with existing marine engines.

Bunkering trials conducted between 2022 and 2024 indicate that industry practices are converging towards a limited number of blend types, particularly involving UCOME (Used Cooking Oil Methyl Ester) as the biodiesel component.

Table 4. Main biodiesel–marine fuel blends identified.

Blend type	Base fuel	Biodiesel type	Biodiesel content	Key characteristics
Blend #1	VLSFO (residual)	UCOME (FAME)	~24%	Moderate viscosity, potential for emulsification, increased variability
Blend #2	MGO (distillate)	UCOME (FAME)	~30%	Low viscosity, high dispersion potential, more predictable behaviour

These blends represent the current operational reality of biodiesel use in marine fuels. From a response perspective, they illustrate two distinct behavioural patterns:

- **Residual-based blends (e.g., VLSFO + FAME)** tend to retain some persistence while showing increased variability compared to conventional fuels.
- **Distillate-based blends (e.g., MGO + FAME)** are generally more fluid and dispersive, leading to faster spreading and reduced recovery potential.

Key conclusions for responders:

- A limited number of blend types dominate current usage, with behaviour largely driven by the base fuel (residual vs distillate) and the biodiesel proportion.
- Spill behaviour is primarily driven by the base fuel type while biodiesel content modifies properties such as viscosity, persistence and dispersibility.

■ Evolution of marine fuel oil properties blended with biodiesel.

Available scientific data on biodiesel–marine fuel blends remain limited, as most studies focus either on conventional marine fuels or on biodiesel alone. The literature review identified only one relevant study addressing these blends, analysing the evolution of physicochemical properties of biodiesel mixed with VLSFO over a biodiesel range of 5% to 30%.

The results show clear and consistent trends in key parameters, particularly viscosity and pour point, which are critical for predicting spill behaviour and selecting response strategies.

Table 5. Evolution of key properties with increasing biodiesel content (VLSFO blends).

Properties	Pure VLSFO (B0)	Blend (up to B30)	Trend	Operational implication
Pour point	~0°C	Down to -25°C	Strong decrease	Increased fluidity and spreading
Viscosity (@50°C)	~510 cSt	~70 cSt	Significant decrease	Easier pumping, recovery, and dispersion
Physical state	Semi-solid	Liquid	Transition	Improved response options

The reduction in viscosity and pour point with increasing biodiesel content significantly alters the behaviour of the fuel. While pure VLSFO may behave as a semi-solid product that is difficult to handle and recover, higher biodiesel blends (e.g., B30) behave more like liquid fuels with improved flow properties.

From a response perspective, this transition is critical:

- **Pure or low-blend VLSFO:** shows limited recovery efficiency due to high viscosity
- **Higher biodiesel blends (e.g., B30):** more amenable to mechanical recovery and potentially chemical dispersion

These findings highlight that even moderate biodiesel addition can substantially change spill behaviour and expand the range of applicable response techniques.

Key conclusions for responders:

- Increasing biodiesel content makes conventional fuels less persistent directly improving response effectiveness.
- The improved flow properties of biodiesel blends may also increase the applicability of response techniques such as chemical dispersion, subject to operational and regulatory constraints.
- Even moderate biodiesel addition can significantly modify spill behaviour and should be considered when selecting response strategies and equipment.

2.4 Behaviour of biodiesel blends with conventional bunker fuels in case of accidental spill

The weathering of biodiesel blends with marine fuels involves multiple simultaneous processes (e.g., evaporation, dispersion, emulsification), driven by environmental conditions and the fuel's initial properties.

■ Approaches to Assess Fate and Behaviour

1. **Initial Physicochemical Properties:** Key parameters such as density (buoyancy), viscosity (spreading), and distillation range (evaporation) provide a first estimate of behaviour and can be used in modelling tools (e.g., ADIOS 2).
2. **Laboratory Protocols:** Provide controlled and reproducible conditions to simulate key weathering processes such as evaporation (via distillation) and emulsification (e.g., Mackay method). They allow comparison between products and generation of input data for modelling. However, they cannot fully reproduce real spill conditions, as interactions between processes (e.g., evaporation, dispersion, emulsification) are not captured simultaneously.
3. **Pilot-Scale Experiments:** Provide the most realistic assessment by reproducing environmental conditions (wind, waves, currents), allowing simultaneous processes and monitoring over time.

■ Physicochemical characterisation

Key properties such as viscosity, density, and pour point are critical for predicting oil slick behaviour and planning response strategies. For biodiesel blends (5–50% FAME) with marine fuels:

- **Density:** Slight decrease with FAME addition; buoyancy largely unaffected.
- **Viscosity:** Significant decrease; promotes faster spreading.
- **Pour Point:** Drops for blends $\geq 30\%$ FAME, increasing flow at lower temperatures.
- **Biodegradability:** Increases with FAME content, especially above 30%, enhancing natural breakdown.

Implications for response:

- Faster spreading requires prompt mechanical recovery.

- Lower viscosity and pour point affect chemical dispersion windows.

Existing response strategies remain applicable with minor adjustments.

■ Fate and behaviour of alternative fuels in the marine environment under different weather conditions: Oil weathering study at pilot scale

Weathering tests were conducted in Cedre’s hydraulic canal (Polludrome®) over 7 days to simulate open sea conditions and monitor the early kinetics of oil slick changes after a spill.

■ Evolution of the physicochemical properties of the B30 FAME/ VLSFO

Figure 1 presents the evolution of the B30 FAME/VLSFO slick during the weathering test at pilot scale. Initially, the blend is a liquid black product which spread rapidly to cover the surface of the Polludrome®. After a few hours of weathering, the oil slick is fragmented into large lumps/ patches distributed over the surface of the tank surface. The water column gradually becomes turbid and takes on a yellowish tint. After 2 days of weathering, viscous brown patches of oil are observed at the water surface of the tank. During agitation period, a submersion of small patches of oil is observed in the water column.

Figure 1. Evolution of the B30 FAME/VLSFO appearance according to the weathering duration.

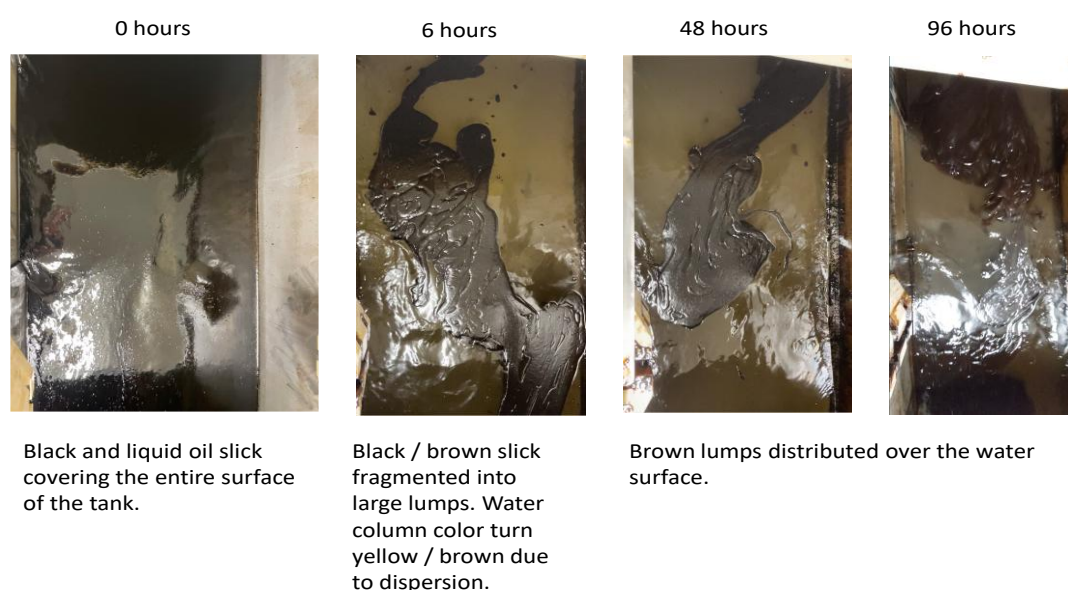


Table 6. Key physicochemical and behavioural properties of B30 FAME/VLSFO during weathering.

Properties	Observation / Evolution	Implications for spill response
Viscosity	156 → 3830 mPa·s in 24h; 6360 mPa·s at 7 days	Rapid initial increase affects spreading and mechanical recovery; recovery more challenging with dense emulsions
Emulsification	Water content ~85% in 6h; emulsions highly stable	Urgent containment required; dense emulsions may submerge
Emulsion stability	Emulsions become highly stable shortly after formation and remain stable throughout weathering.	Natural water separation is limited, increasing persistence and complicating storage, transfer, and recovery operations
Density	Increases rapidly, stabilizes ~1.001	Slick may sink under agitation; influences choice of recovery techniques

Summary of Results of the Study on Biodiesel–Bunker Fuel Blends as Marine Pollutants Practical Considerations for Responders

Flash Point	~100°C	In situ burning not viable
Evaporation	Negligible	Evaporation does not significantly reduce fuel mass; slick persists
Natural dispersion	Limited, stabilises ~190 mg/L	Natural dispersion contributes little; mechanical recovery remains key
Chemical dispersibility	Effective only at viscosity ≤ 3000 mPa·s (~8h)	Dispersant use window is limited; rapid action required
Mechanical recovery (oleophilic skimmers)	Adhesion to skimmers improves over time (830 → 2875 g/m ² in 6h)	Skimmers are effective, but efficiency depends on conditions and timing
Biodegradability	~36% degraded after 28 days: FAME highly degradable, VLSFO less	Part of the fuel persists; mechanical recovery still necessary
Ecotoxicity (<i>Aliivibrio fischeri</i>)	Low toxicity (luminescence inhibition 43–49%)	Environmental impact limited; response should focus on containment and recovery

■ Evolution of the physicochemical properties of the B30 HVO/ VLSFO

Figure 2 presents the evolution of the B30 HVO/ VLSFO slick during the weathering test at pilot scale. Initially, the blend is a liquid black product which spreads to cover the surface of the Polludrome®. After 6 hours of weathering, the slick thickness increases and forms large lumps / patches of oil distributed over the surface of the Polludrome®. After 24 hours, the lumps break to form black balls that progressively turn brown. After one week of weathering, the B30 HVO/VLSFO slick is observed as an accumulation of floating brown balls (5 to 10 cm diameters). Due to agitation, these balls can submerge at a maximum of 20 cm depth, but they resurface rapidly.

Figure 2. Evolution of the B30 HVO/ VLSFO appearance according to the weathering duration.

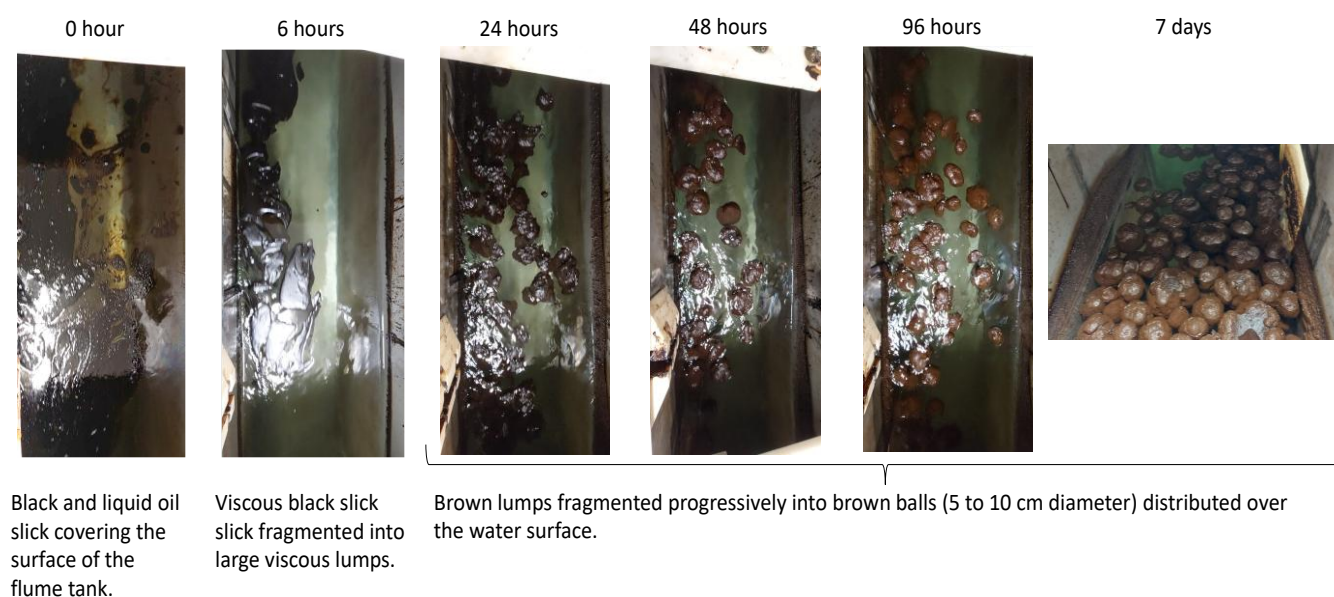


Table 7. Key physicochemical and behavioural properties of B30 HVO/LSFO during weathering.

Properties	Observation / Evolution	Implications for spill response
Viscosity	200 → 19,000 mPa·s in 24h; linear increase to 80,000 mPa·s at 7 days	Rapid thickening affects spreading and mechanical recovery; high viscosity after 1 week requires specialised handling
Emulsification	Water content ~90% within 6h; explains viscosity increase	Rapid formation of dense emulsions; urgent containment needed
Emulsion stability	Stability ratio ≥0.8 throughout test	Emulsions are very stable; slick may remain cohesive, affecting recovery
Density	Increases rapidly to ~1.003 within 12h; allows partial submersion up to 20 cm	Slick may partially sink under agitation; impacts skimming techniques
Flash Point	~100°C	In situ burning not viable
Evaporation	Negligible (lab and pilot scale)	Minimal natural loss; slick persists
Natural dispersion	None observed; water samples confirmed absence of micro-droplets	Slick does not naturally disperse; active recovery required
Chemical dispersibility	Not dispersible (IFP tests)	Chemical dispersants ineffective; mechanical recovery preferred
Mechanical recovery (oleophilic skimmers)	Adhesion to oleophilic surfaces rises from 1,245 → 13,000 g/m ² in 24h; ball formation observed	Skimmers effective; nets may complement recovery due to ball formations
Biodegradability	~32% biodegraded after 28 days; 1% evaporated; ~67% persists	Partial natural degradation; majority remains; containment and recovery critical
Ecotoxicity (<i>Aliivibrio fischeri</i>)	Low toxicity; luminescence inhibition: 43% (seawater), 54% (culture medium)	Limited environmental impact; standard response strategies sufficient

■ Evolution of the physicochemical properties of the B30 FAME/ MGO

MGO used to produce the B30 FAME/ MGO presents a blue colour. This colour is due to the presence of 1-4 di-*n*-aminoanthraquinone, a chemical compound used as a tracer to differentiate non-road diesel to road-taxed diesel. This colour might change according to State regulations (red, yellow, green, or black).

The main evolution of B30 FAME/MGO slick observed during the weathering test are presented in Figure 3. The pictures were taken under agitated conditions, and 15 minutes after agitation had stopped for the sampling phase.

Observations made during Polludrome® tests show that the B30 FAME/ MGO spreads rapidly after oil release. After 4 hours of agitation, a natural dispersion was observed as a whitish plume in the water column. As soon as the agitation was stopped, a phenomenon of recoalescence of the dispersed microdroplets occurred and a blue slick formation was observed on the water surface. From 1 day to 3 days, the same observations were made:

- A complete natural dispersion during agitation phase; and
- A recoalescence of oil droplets and formation of a yellow slick at the water surface. The colour change was due to an oxidation of the blue tracer when exposed to solar radiation.

After 78 hours of weathering, due to the complete natural dispersion, it was not possible to collect sufficient oil samples at water surface even after a settling time. Consequently, no results are presented beyond this period of weathering.

Figure 3. Evolution of the B30 FAME/ MGO appearance according to the weathering duration.



This evolution of the B30 FAME/MGO blend is very similar to the evolution of MGO studied earlier at Cedre. The main difference lies in the time before the natural dispersion is observed, namely:

- After 48 hours of weathering, for the MGO alone; and
- Few hours after the oil release, for the blend of MGO with 30% of FAME.

This difference suggests an effect of FAME addition on the natural dispersion of an oil.

Table 8. Key physicochemical properties and weathering behaviour of B30 FAME/MGO.

Variable	Observations / Values	Implications / Notes
Viscosity	3 → 9 mPa.s	Very low; minimal impact on spreading
Emulsification	Whitish foam observed at water surface; emulsion unstable	No significant effect on recoverable volume
Emulsion stability	Emulsions are unstable and rapidly separate.	Minimal impact on recovery operations
Density	0.846 → 0.871 (78h)	Below seawater (1.025); no sinking expected
Flash point	70°C (>60°C threshold)	In situ burning not suitable
Evaporation	~22% total (rapid in first 8h)	Partial loss of light fractions
Natural dispersion	Water column shows whitish coloration; oil concentration peaks 1500 mg/L (24h), drops to 750 mg/L (170h); FAME and MGO both dispersed	FAME addition enhances early dispersion
Chemical dispersibility	Fresh blend: 87%	Blend considered dispersible; further testing unnecessary due to natural dispersion
Mechanical recovery (oleophilic skimmers)	Adhesion decreases 150 → 75 g/m ² (78h)	Low adhesion due to low viscosity and water droplets
Biodegradability	Max 68% biodegraded; 22% evaporated	~10% persists after natural degradation
Ecotoxicity (<i>Aliivibrio fischeri</i>)	Seawater: 43% inhibition; culture medium: 54% inhibition; PAHs low	Low ecotoxic impact; robust repeatability

2.5 Overview of characterisation of physicochemical properties and weathering of blends of biodiesel with conventional marine bunker fuel

- Regarding the physicochemical properties of blends of biodiesel with conventional marine fuel, laboratory analyses and weathering experiments were conducted to characterise these new fuels and to assess at pilot scale their behaviour in case of accidental spill. The main results are summarised in Table 9.

Table 9. Effect of biodiesel blending on marine fuel properties and behaviour.

		FAME (30%)		HVO (30%)
		VLSFO (70%)	MGO (70%)	VLSFO (70%)
Properties	Viscosity	↓	=	=
	Density	↓	=	↓
	Pour point	↓	↑	↓
	Flash point	=	↑	=
Behaviour	Spreading	↑	=	↑
	Buoyancy	↑	=	↑
	Evaporation	=	↓	=
	Emulsification			
	Natural dispersion	↑	=	-
	Biodegradability	↑	↑	↑
	Ecotoxicity			

- Regarding the oil spill response technique, it can be stated that the addition of FAME to MGO will not influence the Oil Spill Response (OSR) strategies. In case of a spill in agitated conditions, a natural dispersion will occur few hours after the spill. Consequently, it is highly probable that the response time will be too long for successful OSR deployment. In case of an oil spill in calm conditions (harbour area), the natural dispersion will occur, but this phenomenon will be more progressive. For these conditions, and depending on the oil volume, a mechanical recovery (skimmer) or use of sorbent (boom, pad) can be considered as an effective strategy before natural dispersion occurs.
- When blended with HVO, the viscosity of VLSFO is lower than the VLSFO alone. After 7 days of weathering, the blend viscosity was in the same range as the 7-days weathered VLSFO tested during the IMAROS 2 project. Consequently, it can be stated that HVO blending has no effect on viscosity of the weathered VLSFO and on mechanical recovery efficiency.
- When blended with FAME, the VLSFO became easier to recover by using skimmers due to a significant decrease in both viscosity and pour point values. This effect of FAME addition to a viscous oil to increase the efficiency of the mechanical recovery technique has already been considered in previous oil spills. Indeed, during the Erika spill (France, 1999), a product called Diester (FAME produced from rapeseed oil) was injected in the wreck to facilitate the pumping operations of the HVO.

3. Response measures, technology, and equipment analysis

3.1 Response measures analysis

3.1.1 In-situ burning as a response measure for biodiesel–marine fuel blends.

In-situ burning (ISB) is a response technique based on the controlled combustion of oil vapours directly on the water surface. For ignition and sustained combustion, three conditions are required: sufficient fuel vapours, oxygen, and heat. Operationally, ISB involves containing the slick with a fire-resistant boom, increasing its thickness, and igniting

it using dedicated igniters. However, the technique generates significant atmospheric emissions (soot, CO₂, SO₂, NO_x) and produces burn residues that are difficult to recover and may persist in the environment. Due to these environmental and regulatory constraints, ISB is rarely included in contingency plans in many countries.

The effectiveness of ISB strongly depends on physicochemical properties. The oil must float (density < 1.025), have an API gravity generally above 20°, a suitable flash point and vapour pressure to ensure controlled ignition, limited water content (emulsification below ~25%), and sufficient slick thickness (typically >2–5 mm). ISB is most effective shortly after a spill, before the occurrence of significant weathering, evaporation of light fractions, emulsification, or natural dispersion.

Previous experimental work under the IMAROS project showed that VLSFOs present poor ignitability and very low burning efficiencies (≤15%), even when ignition time was extended or enhanced igniters were used. These results already indicate serious operational limitations for the application of ISB to VLSFO spills under real conditions.

Regarding the three biodiesel blends studied (B30 FAME/VLSFO, B30 HVO/VLSFO, and B30 FAME/MGO), ISB is considered not applicable due to their physicochemical characteristics, notably high flash points, and low content of light volatile compounds. In addition, B30 FAME/VLSFO and B30 HVO/VLSFO consist predominantly of VLSFO, for which ISB has already demonstrated limited effectiveness. Weathering further reduces applicability: density increases close to 1.000 may cause partial submergence depending on water salinity; B30 HVO/VLSFO may fragment into tar-ball emulsions, preventing effective containment and ignition; and weathered B30 FAME/MGO may naturally disperse under rough sea conditions, precluding sustained burning.

Overall, both intrinsic fuel properties and weathering behaviour indicate that ISB is not a viable response option for spills involving these biodiesel–marine fuel blends.

3.1.2 Chemical dispersion as a response measure for biodiesel–marine fuel blends

Chemical dispersion involves the application of dispersants — mixtures of solvents and surfactants — to enhance the natural breakup of oil slicks into small droplets that become suspended in the water column. By reducing interfacial tension, dispersants limit water-in-oil emulsification (“chocolate mousse”) and promote primary dispersion through wave action, followed by secondary dispersion via currents and turbulence. Dispersants can be applied from vessels or aircraft using calibrated spray systems designed to deliver droplets of appropriate size.

However, this technique transfers oil from the surface to the water column, potentially affecting benthic ecosystems if concentrations are high. For this reason, dispersant use is generally restricted to offshore areas and subject to regulatory approval.

The effectiveness of chemical dispersion depends primarily on physicochemical properties. The oil must float (density < 1.025). Viscosity is the key parameter:

- < 500 cSt: easily dispersible
- 500–5,000 cSt: usually dispersible
- 5,000–10,000 cSt: uncertain efficiency
- 10,000 cSt: not dispersible

Dispersion is also limited by high pour points (especially for waxy oils), excessive slick thickness, and weathering. As evaporation and emulsification increase viscosity, dispersibility decreases, creating a limited time window of opportunity for effective application. Previous testing on LSFO showed that some fresh products may be dispersible, but weathering significantly reduces efficiency, making this option operationally constrained.

Regarding the three biodiesel blends studied, applicability varies:

- **B30 FAME/VLSFO:** Fresh product is dispersible. However, rapid emulsification increases viscosity, reducing efficiency over time. After 8 hours, it is only potentially dispersible; after 2 days, it is no longer dispersible. The operational window of opportunity is therefore short and critical.

- **B30 HVO/VLSFO:** Not dispersible due to high viscosity.
- **B30 FAME/MGO:** Shows high dispersibility ($\approx 82\%$ in IFP tests*). Nevertheless, treatment is generally unnecessary because the product disperses naturally.

Overall, chemical dispersion may be applicable only in specific and time-limited conditions for certain biodiesel–marine fuel blends. Weathering behaviour, viscosity evolution, and natural dispersibility are decisive factors limiting its practical use as a response measure.

*IFP (Institut Français du Pétrole) dispersibility tests measure the effectiveness of chemical dispersants under controlled laboratory conditions. Results are expressed as the percentage of oil dispersed after treatment.

3.1.3 Containment and recovery as a response measure for biodiesel–marine fuel blends

Containment and mechanical recovery aim to physically remove floating pollutants from the water surface using booms, skimmers, pumps, and temporary storage systems. This response option is generally most effective when the slick is thick, cohesive, and intercepted early, before fragmentation or natural dispersion occurs. Booms are deployed to concentrate the oil, while skimmers (mechanical or oleophilic) selectively recover it and transfer it to storage using integrated or external pumps. System performance depends on environmental conditions (currents < 2 knots, waves < 1 m), coordination between vessels, and oil properties.

Effectiveness is strongly influenced by physicochemical characteristics. The product must float (density < 1.025). Viscosity plays a key role: extremely viscous oils ($> 100,000$ cSt) may hinder pumping and transfer, while very thin films (< 0.1 – 0.2 mm) cannot be effectively contained or skimmed. High pour points may cause the oil to behave semi-solid at ambient temperatures, requiring heating systems. Sticky oils may require technical adaptations such as annular water injection (AWI) to improve pumping efficiency. Weathering can also induce “short” behaviour, where oil fails to flow properly into the skimmer, reducing recovery efficiency and sometimes requiring dynamic recovery systems.

For the biodiesel–marine fuel blends studied, containment and recovery remain technically applicable, but with operational considerations:

- **Fresh B30 FAME/VLSFO and B30 HVO/VLSFO:** Combined containment and mechanical recovery systems operated dynamically are appropriate. Weir skimmers are generally more suitable than brush skimmers, particularly for thicker layers. Disc or drum skimmers (preferably grooved) may offer a good balance between selectivity and flow rate, especially when storage capacity is limited.
- **Weathered B30 FAME/VLSFO:** Increased viscosity may improve performance of oleophilic skimmers, but the general recovery strategy remains similar to the fresh product.
- **Weathered B30 HVO/VLSFO:** Fragmentation into tar-ball emulsions complicates recovery. Open weir skimmers without waste screens, combined with side-sweep or fast-current containment systems, are more appropriate. Heating systems and AWI may assist when viscosity, stickiness, or pour point create pumping difficulties.
- **Weathered B30 FAME/MGO:** Rapid spreading reduces recovery feasibility. In calm waters and early containment conditions, mechanical skimmers (weir, drum, or disc) may be effective, while brush skimmers are not recommended due to low flow rates. In rough or open-sea conditions, natural dispersion may render recovery impracticable.

Overall, containment and mechanical recovery represent the most broadly applicable response option for these biodiesel–marine fuel blends. However, efficiency is highly dependent on early intervention, sea state, slick cohesion, and the evolution of viscosity, emulsification, and fragmentation.

3.1.4 Surface nets and trawls as a response measure for biodiesel–marine fuel blends

Surface nets and trawls are mechanical recovery systems specifically designed for highly viscous, emulsified, or semi-solid floating pollutants, such as heavy fuel oils, tar balls, or burn residues. Unlike conventional skimming, trawling operates by concentrating and filtering thickened slicks using a two-part system: a forward concentration section (the “trawl”) and a cod-end that collects the recovered material. These systems require one or two towing vessels and are typically deployed when oil has become too viscous for efficient pumping or skimming.

The applicability of trawling depends primarily on oil properties. The pollutant must float (density < 1.025) and remain cohesive at the surface. Viscosity is the decisive parameter: literature indicates that effective trawling generally requires viscosities above 100,000–400,000 cSt. Below this range, trawling may be ineffective or even counterproductive, potentially fragmenting the slick into smaller pellets. Emulsification and evaporation of light fractions, which increase viscosity, are typically favourable for this technique. A pour point close to ambient temperature may also facilitate recovery by giving the product semi-solid characteristics.

Operational experience from major accidents (e.g., highly weathered HFOs) confirms that trawling becomes relevant only after substantial weathering and viscosity increase. It is therefore considered a late-stage response option for persistent, thickened slicks.

For the biodiesel–marine fuel blends studied (B30 FAME/VLSFO, B30 HVO/VLSFO, and B30 FAME/MGO), surface nets and trawls are generally not applicable due to insufficient viscosity (<100,000 cSt), even after weathering. However, in the specific case of weathered B30 HVO/VLSFO, the formation of emulsified tar balls, the increase in viscosity, and a relatively elevated pour point ($\approx 18^{\circ}\text{C}$) suggest that trawling cannot be entirely excluded. Additional testing would be required to confirm whether operational viscosity thresholds could be reached under real spill conditions.

Overall, surface nets and trawls are not considered a primary response option for these biodiesel–marine fuel blends, except potentially under advanced weathering conditions involving significant emulsification and fragmentation.

3.1.5 Use of sorbents as a response measure for biodiesel–marine fuel blends

Sorbents are materials designed to recover floating oil from the water surface by adsorption or absorption. They can be classified as universal sorbents, which absorb both polar and non-polar substances but tend to sink, and hydrophobic sorbents, which target non-polar pollutants and remain buoyant, making them suitable for marine use. Sorbents are available in various forms, including booms, sheets, rolls, pillows, pompoms (mops), and loose bulk materials. Some are single use, while others can be wrung out and reused. Specially designed viscous-oil sorbents, such as pompoms, enhance surface contact for thick or tacky oils.

Effectiveness of sorbents depends primarily on oil properties. The oil must float (density < 1.025), and while pour point is not restrictive, viscosity and weathering strongly influence performance. Low-viscosity oils (e.g., diesel) are rapidly sorbed but may easily release from the sorbent, whereas highly viscous oils (e.g., HFOs) adhere to the surface without full absorption, reducing sorbent capacity. The pollutant must also remain at the surface and not disperse naturally.

3.2 Recovery tests of biodiesel blend with conventional marine fuel

Within the framework of the EMSA project, Cedre conducted recovery tests on fresh and emulsified B30 FAME/VLSFO blend.

To assess the efficiency of the oleophilic recovery and the mechanical recovery, two skimmers were tested:

- An oleophilic skimmer: TDS 118 G from ELASTEC; and

- A mechanical weir skimmer: Foilex Mini from FOILEX.

For each test, recovery was tested on fresh and on emulsified B30 to evaluate the influence of viscosity and emulsification on the recovery efficiency (study of slick movement, recovery rate, and selectivity). Tests were performed at Cedre in a controlled environment: the slick thickness, the selectivity, the recovery rate as well as the water content of the oil (due to the emulsification) were measured before or during the tests.

Three parameters are measured/observed to estimate the performance of a skimmer:

- **The movement of the slick** is observed qualitatively by operators (movement or fragmentation of the slick by the skimmer)
- **The oil recovery flow rate** is measured based on the volume recovered and selectivity; and
- **Selectivity**, which corresponds to the volume collected minus the variation in water content and free water, is determined after 20 minutes of settling (in accordance with standard NF T71 500) using samples taken at the outlet of the discharge hose, taking two parameters into account:
 - The amount of free water in each sample to determine the percentage of oil (emulsified or not) recovered; and
 - The change in the percentage of water in the oil, which corresponds to the emulsification of the oil by quantifying the variation in water content between the inlet and outlet of the recovery system.

■ Movement of the slick

○ *Elastec skimmer tests*

During the tests with the Elastec oleophilic skimmer, a marked attraction of the slick is first observed over an arc of approximately 180° on the front of the skimmer. This attraction was visible with both fresh and emulsified oil.

However, after a few minutes, a significant slowdown in attraction is observed. This is due to the presence of a thin film of water a few centimetres wide between the oleophilic drums and the edge of the oil slick. Simply stirring the water manually is enough to make the slick “stick” to the drums again, but as soon as the stirring stops, the film of water reappears, thus impairing the proper functioning of this skimmer with this type of oil under static conditions.

○ *Foilex skimmer tests*

During the tests with the Foilex Mini skimmer on fresh product, the attraction of the slick is clearly visible over 360° and the three floats do not interfere with the flow of the pollutant towards the recovery device. The edge of the weir does not appear to impede the flow of the oil into the device. Visual observation shows very good attraction of the oil, but also attraction of the water present beneath the oil.

During the tests with emulsified oil, given the higher viscosity of this product, the edge of the weir acts as a barrier to the flow of the pollutant into the device. It is therefore necessary to increase the pump flow rate to immerse the weir edge more deeply in the water. As a result, on one hand, the emulsified oil is effectively sucked into the device, on the other hand, more water is also sucked in simultaneously. Under these conditions, the surface current generated by the suction of water and oil causes the slick to be clearly attracted 360° around the skimmer, even though the three floats locally disrupt the flow.

■ Recovery flow rate and selectivity

○ *Elastec skimmer tests*

The grooved drums of the Elastec oleophilic skimmer are intrinsically capable of collecting B30 FAME/VLSFO, whether fresh or emulsified. Thus, when the pollutant is in direct contact with the drums, a flow rate of 3.3 m³/h is measured for fresh product (test # 1) and 5.4 m³/h for emulsified one (test #4). Under these conditions, selectivity is

excellent (>98%). However, it is important to weigh these results against the rapid separation between drums and slick due to the rapid formation of a thin film of water under the static conditions of the test. As a result, the flow rate of the oleophilic skimmer drops to zero if there is no agitation of the water surface, allowing the oil slick to come into contact with the drums again.

○ Foilex Mini skimmer tests

The Foilex Mini can recover B30 FAME/VLSFO in the static conditions of the tests but will also collect a lot of free water same time. Test #2 with fresh B30 FAME/VLSFO shows a recovery flow rate of 16 m³/h and a poor selectivity of 27%. Test #3 with emulsified B30 FAME/VLSFO shows a flow rate of 18.3 m³/h and a medium selectivity of 50%.

Figure 4. Elastec TDS 118 G skimmer during emulsified B30 recovery (test #4), ©Cedre.



Figure 5. Foilex Mini skimmer during fresh B30 recovery (test #2), ©Cedre.



■ Summary of tests results.

During the tests, it appears that after a short period of satisfactory operation with excellent selectivity, Elastec TDS 118 G skimmer was quickly unable to recover oil due to the formation of a thin film of water between the drums and the oil slick. As the drums were then not in direct contact with the oil, the flow rate dramatically dropped down in this case. A simple stirring of the water manually is enough to make the slick “stick” to the drums again, but as soon as the stirring stops, the film of water reappears, thus impairing the proper functioning of this skimmer with this type of oil under static conditions. It is then necessary to use this type of skimmer in dynamic conditions to recover B30 FAME/VLSFO, to feed the skimmer with oil and avoid the formation of an “oil gap” in front of the drums.

Foilex Mini weir skimmer did not suffer from the problem of “oil gap” during the tests and managed to recover at a global flow rate ranging between 16 and 18.3 m³/h depending on the type of oil. A hypothesis is that due to low selectivity of this skimmer, it drags sufficient water to create a dynamic movement on the surface avoiding generation of a static water film between the weir and B30 FAME/VLSFO slick. However, the large amount of free water implies the necessity of settling storage tanks on site (if technically feasible) to evacuate the free water and concentrate oil into tanks.

Table 10 summarises the results of the skimmer tests.

Table 10. Summary of recovery tests with Foilex Mini and Elastec TDS 118G results for fresh and emulsified B30 FAME/VLSFO.

	Test #1	Test #2	Test #3	Test #4
Skimmer	Elastec TDS 118 G	Foilex Mini	Foilex Mini	Elastec TDS 118 G
Oil type	B30 FAME/VLSFO fresh		B30 FAME/VLSFO emulsified	
Viscosity	1 980 cSt @20°C		4 830 cSt @ 22°C	
Density	0.921		0.979	
Water content	-		79 %	
Initial thickness	≈ 2 cm		≈ 8 cm	

Global recovery flow rate	3.3 m ³ /h (if oil is in contact with drums) *	16 m ³ /h	18.3 m ³ /h	5.4 m ³ /h (if oil is in contact with drums) *
Selectivity	>98 %	27 %	50 %	>98 %
Oil flow rate	≈ 3.2 m ³ /h (if oil is in contact with drums)	4.3 m ³ /h	9.2 m ³ /h	≈ 5.3 m ³ /h (if oil is in contact with drums)

*Note: For tests #1 and #3, flow rate results are measured when the oil is in contact with oleophilic drums. After a few minutes, a thin film of water appears between the oleophilic drums and the edge of the oil slick in static conditions. The flow rate then decreases sharply to null.

4. Recommendations and best practices

4.1 Current state of response measures to accidental spills of biodiesel-blend fuels

Experience with spills of biodiesel blends (FAME or HVO mixed with marine fuels) is limited, creating a knowledge and technical training gap. Laboratory studies show:

- Biodiesel blends behave similarly to conventional diesel: they float on water, spread forming surface slicks.
- Distinct properties: lower evaporation, higher biodegradability (≈4× faster than diesel), and lower acute toxicity (≈5× less than petroleum diesel).

Challenges for responders:

- Biodiesel is colourless or subtle, making slicks harder to detect visually.
- High pour point in cold water can form waxy clumps or semi-solid slicks, requiring adapted recovery equipment.
- Faster biodegradation may allow passive cleanup sooner than with crude oil.

Current oil spill response techniques — booms, skimmers, containment — are largely applicable, treating biodiesel blends similarly to diesel or fuel oil of comparable viscosity. However, real-world validation is limited, and comprehensive, biodiesel-specific response protocols are not yet fully developed.

Key conclusions: preparedness relies on extrapolation from conventional oil spills, with adjustments for the unique properties of biodiesel blends.

Table 11. Effect on oil spill response efficiency.

		FAME (30%)		HVO (30%)
		VLSFO (70%)	MGO (70%)	VLSFO (70%)
Oil spill response efficiency	Recovery:			
	-Mechanical	↑	=	=
	-Sorbent (fresh oil)	↑	=	↑
	Chemical dispersion	Not dispersible	=	Not dispersible
In Situ Burning		Not flammable		

4.2 Recommendations for response techniques and technology development

Contingency plans and legal frameworks need updating to reflect the uptake of alternative fuels. National and regional oil spill response plans should include biodiesel blends, with sufficient stockpiles of equipment and funding for such incidents. Legal frameworks may require amendment, such as clarifying that biofuels are included in the definition of “oil” under the Bunkers Convention. Implementing these measures ensures effective response to accidental releases and closes accountability gaps.

Overall, response strategies for biodiesel blends rely on adapting existing oil spill techniques. Mechanical recovery remains the cornerstone, with emphasis on dynamic skimming and managing higher water content. Containment booms and onboard resources like sorbents remain effective if deployed quickly. Detection technologies gain importance due to the subtle appearance of these fuels. While specialised methods like dispersants or burning are secondary, continuous innovation, equipment adaptation, and testing should ensure that response technology keeps pace with the evolving fuel landscape.

■ Detection and monitoring

After a spill, effective monitoring is essential for guiding response operations. Remote sensing techniques, including SLAR, FLIR, infrared, and ultraviolet scanners, allow detection from a distance and can operate in low-visibility or night conditions. However, the weathering of biodiesel–marine fuel blends, such as B30 HVO/VLSFO, can complicate detection due to fragmentation of slicks, formation of brown balls, or temporary submersion. Further experimentation is needed to understand how weathered products behave and how remote sensing efficiency is affected. Mathematical modelling can help predict slick drift by integrating metocean data, observational inputs, and spill characteristics, although model outputs should be validated with field data. Additionally, physicochemical measurements of density, viscosity, and pour point remain critical for operational planning and selecting suitable response techniques, and their applicability to biodiesel blends has been demonstrated in lab studies. Further work is needed to confirm correlations between these measurements and real-world recovery or dispersant performance.

■ Containment and recovery

Containment booms remain essential for corralling spilled biodiesel blends, which can spread rapidly due to low viscosity. In agitated waters, emulsification may increase blend density, reduce buoyancy, and partially submerge the fuel under booms. Mechanical recovery using skimmers is effective but may require adaptations: weir-type skimmers can recover biodiesel blends but often include high water content, while rotating drum skimmers may show low recovery due to water films preventing adhesion. Recommendations include using on-board or portable settling tanks, oil-water separators, or integrated boom-and-skimmer systems, and developing skimmers with dynamic modes to manage semi-solid oils. In cold conditions, biodiesel blends may solidify or become more viscous, for which trawl nets or screens (e.g., DESMI Oil Trawl) can capture floating chunks. Protocols for using nets and trawls for high-viscosity or semi-solid oils are advised.

■ Dispersants and emerging agents

Chemical dispersants are generally ineffective on biodiesel blends with residual fuels, as slicks thicken rapidly and resist dispersion. Dispersant application is only feasible within the first hours after a spill, while the oil is still fresh. Overall, their use is not recommended, although the biodiesel fraction naturally disperses into the water column with low ecotoxicity. In certain sensitive areas, dispersion may be considered under a Spill Impact Mitigation Assessment (SIMA). “Green” dispersants with low environmental toxicity and better performance are emerging, but further R&D and field testing are needed before widespread use.

■ In-situ burning

In-situ burning (ISB) is generally unsuitable for biodiesel blends due to high flash points, low volatility, and potential semi-solid viscosity, especially in blends with residual fuels like VLSFO. Only in specific, light, and ideal conditions might ISB be feasible, requiring pre-heating and calm waters, but it should not be a primary response method. Mechanical recovery and chemical containment remain the main strategies.

4.3 Best practices for handling and responding to biodiesel blend spills.

In summary, effective response to biodiesel blend spills relies on prevention, rapid and coordinated action, proper use of standard spill response tools, and leveraging the natural biodegradability of biodiesel. Integrating these practices into emergency plans and ensuring crews and responders are trained with mock spills are essential to manage B20/B30 or higher blends effectively.

■ Preventive measures onboard

The most effective strategy for managing biodiesel blend spills is prevention. Operators should clean tanks and lines before switching fuels, check material compatibility, control water and moisture, and avoid uncontrolled blending. Standardised bunkering procedures, including proper hose connections, slow flow, communication, and emergency drills, should be followed, with spill containment gear ready. Although biodiesel blends have higher flash points, they can still cause slips or pollution if spilled.

■ Shipboard spill response

If a spill occurs onboard, crews should act immediately following the ship's SOPEP (Shipboard Oil Pollution Emergency Plan), which is mandatory for vessels above specified tonnage under MARPOL Annex I. SOPEP outlines procedures, contact points, and onboard equipment for spill response. Crew training is critical, as many may be unfamiliar with biodiesel properties; regular drills build confidence. On-deck response begins with stopping the source, containing the spill using absorbents and booms, sealing drains, and storing collected fuel for proper disposal. Biodiesel's lower flammability reduces fire risk but slips and environmental contamination remain concerns. Prompt communication with coastal authorities or MRCC ensures early coordination of external response.

■ Initial response to spills at sea

In the marine environment, conventional oil spill strategies apply. Rapid deployment of containment booms is key, as biodiesel blends can spread quickly. Because biodiesel is lighter in colour, responders may underestimate slick thickness and should take a cautious approach by deploying additional booms and skimmers. Mechanical skimmers should be used in advancing mode or with agitation to maximise recovery. For blends that are viscous or partially solidified, nets, snare adsorbents, or warm water may aid recovery in contained areas. Combined containment recovery systems are particularly effective for fresh biodiesel blend spills. All standard oil spill equipment — booms, skimmers, pumps, and storage barges — remains applicable.

■ Use of dispersants

Chemical dispersants can be considered only with authority approval and after environmental trade-off assessment (NEBA), typically for offshore or hard-to-contain spills. Given biodiesel's low toxicity and natural biodegradability, mechanical recovery and natural attenuation are usually preferred over dispersant applications.

■ Shoreline cleanup

If spills reach shorelines, conventional cleanup methods such as sorbent booms, low-pressure washing, and manual debris removal apply. Biodiesel blends tend to adhere less persistently than heavy oils and biodegrade faster, but thick residues or viscous accumulations should still be removed to protect habitats. Ports and marinas should maintain ready stocks of absorbent materials to manage confined water spills efficiently.

■ Concluding response and after-spill monitoring

After the bulk of a spill is removed, ongoing monitoring is recommended to detect any residual impacts.

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