Global Centre for
MARITIME DECARBONISATION

Drop-in biofuels: A framework for quality, quantity, and GHG abatement assurance

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Adopting drop-in biofuels is not without challenges

Interlinked + multifaceted barriers span the entire value chain

Sustainability | Inconsistent criteria across schemes

Feedstocks | Supply constraints and competing end-use

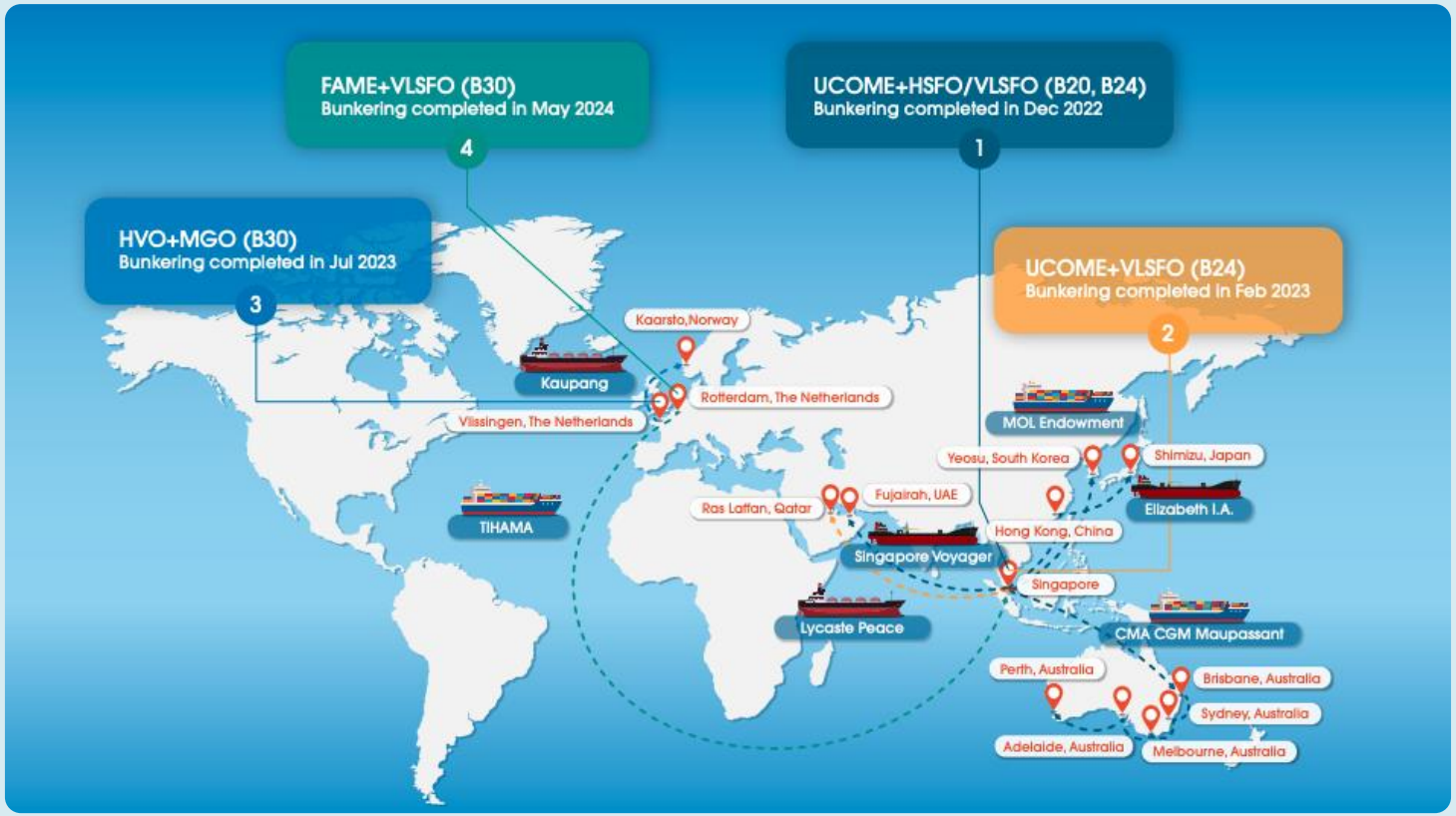
Quantity | No standardised verification thresholds for bio-components in fuel blends

Quality | Chemical stability and compatibility with fossil components are unclear

Traceability | Difficulty in tracing feedstock origin

Strong partnerships with stakeholders across the value chain enabled pilots

13,400 MT of biofuel blends traced and bunkered at ports in Asia and Europe



CAO: Crude Algae Oil
FAME: Fatty Acid Methyl Ester
HVO: Hydrotreated Vegetable Oil
HSFO: High Sulphur Fuel Oil

MGO: Marine Gas Oil
VLSFO: Very Low Sulphur Fuel Oil
UCOME: Used Cooking Oil Methyl Ester

Project partners

ANGELICOUSSIS GROUP
AngloAmerican
Astomos Energy
Authentix The Authority in Authentication
BHP
BCG
BunkerTrace
Chevron
CMA CGM
CONTROLUNION
EASTERN PACIFIC SHIPPING
GoodFuels BETTER WORLD
Hapag-Lloyd
IDS Group
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ONE OCEAN NETWORK EXPRESS
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Saybolt MEMBER OF THE SAYBOLT GROUP
Stena Bulk
SWIRE BULK
TotalEnergies
VPS
VISWA GROUP

Key assurance pillars for drop-in biofuels

To bolster user confidence + accelerate uptake

Drop-in biofuels

Quality

Ensure fuel quality and reliability

+ Environmental and operational stability
+ Compatibility with conventional marine fuels

GHG abatement

Verify genuine benefits to the environment

+ Sustainability criteria/ accurate GHG accounting
+ Traceability

Quantity

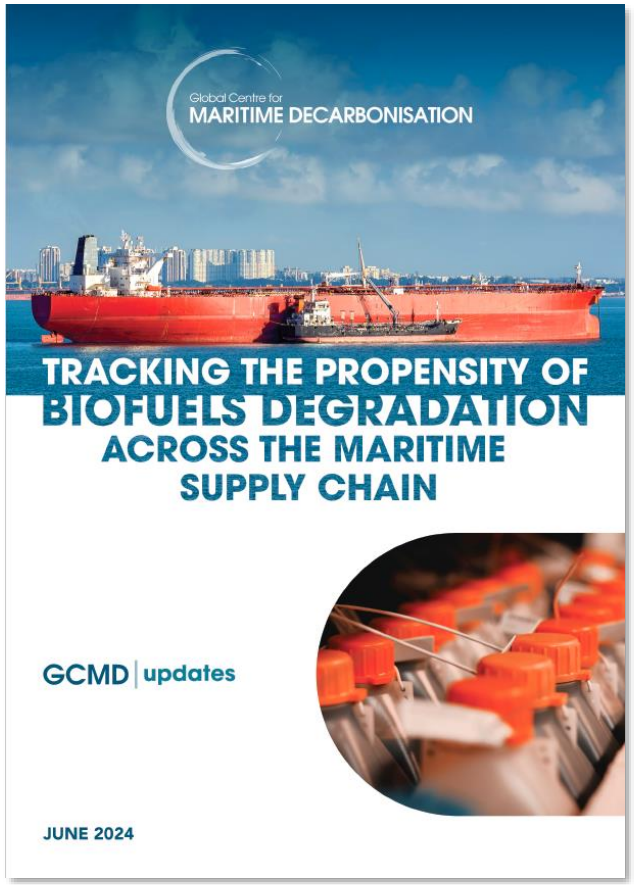
Accurately measure what was delivered

+ Bio-component fraction in fuel blends
+ Documented in BDN

Quality | Stability of FAME-based biofuels

FAME quality tracked over five months under commercial operating conditions

No significant degradation of FAME arising from the three mechanisms



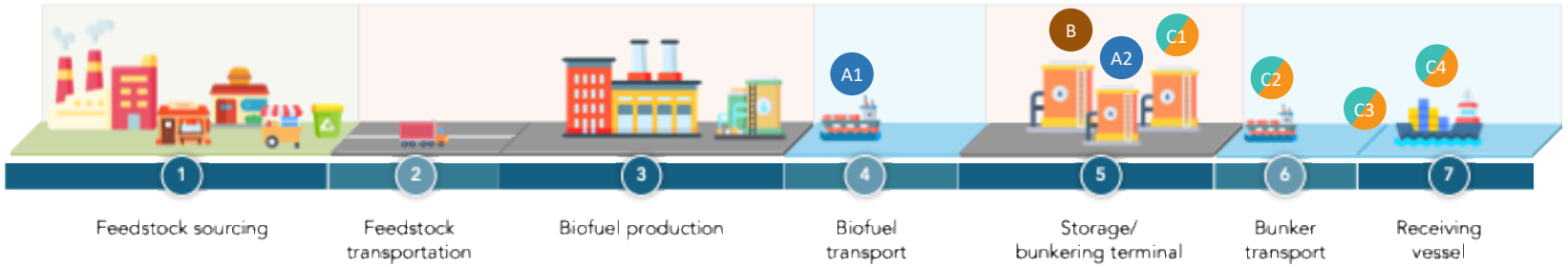
Ways in which biodiesel degradation and formation of by-products can affect fuel quality:

Mechanism	Undesirable by-products	Impact on fuel systems	Relevant fuel properties
Autoxidation *Free radical reactions* FA	○ *Free radicals* ○ *Formic and acetic acids* ○ *High-molecular weight product / sediments*	○ *Hardness and swelling of o-rings and gaskets* ○ *Corrosion of parts* ○ *Clogging of filters, pipes, etc.*	○ *Peroxide value* ○ *Acid value* ○ *Viscosity*
Hydrolytic oxidation *Reaction with water* Water	○ *Free fatty acids* ○ *Alcohols*	○ *Corrosion of parts* ○ *Safety*	○ *Free fatty acid content and acid value* ○ *Methanol content*
Microbial growth Interface	○ *Slime* ○ *Acids*	○ *Clogging of filters, pipes, etc.* ○ *Pit corrosion in fuel tanks*	○ *Viscosity* ○ *Microbial contamination*

Photo-oxidation and thermal decomposition are not significant under commercial storage and use conditions.

Quality | Stability of FAME-based biofuels

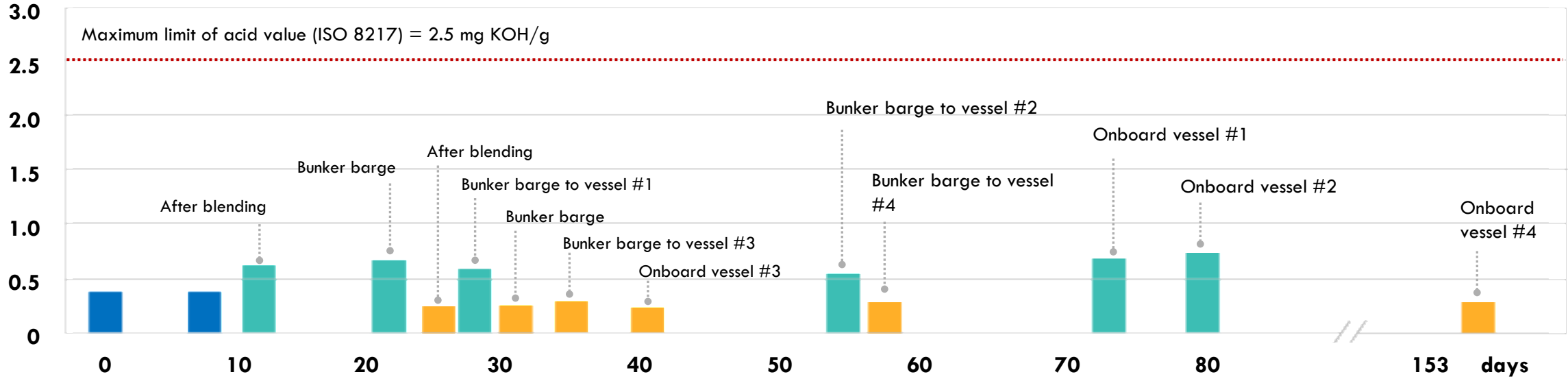
No significant degradation observed over five months—supporting use without additional handling concerns



A Neat FAME
B VLSFO/ HSFO
C FAME + VLSFO (B24)
C FAME + HSFO (B20)

Acid value (mg KOH/g)

Acid value: VLSFO = 0.6 mg KOH/g, HSFO = 0.27 mg KOH/g

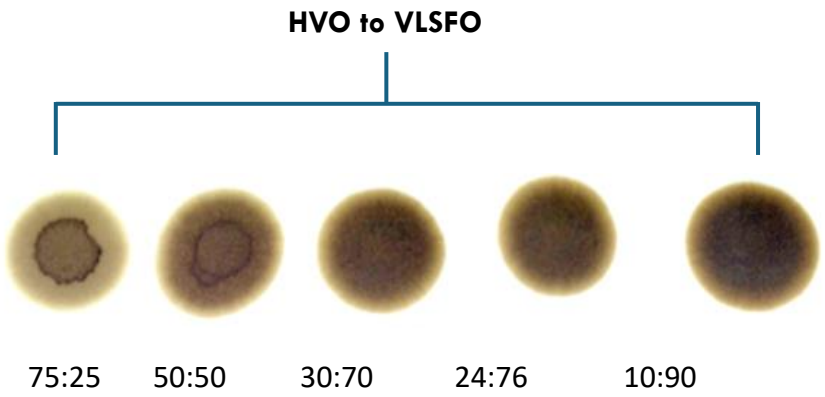


Source: GCMD

Quality | Compatibility of HVO blends

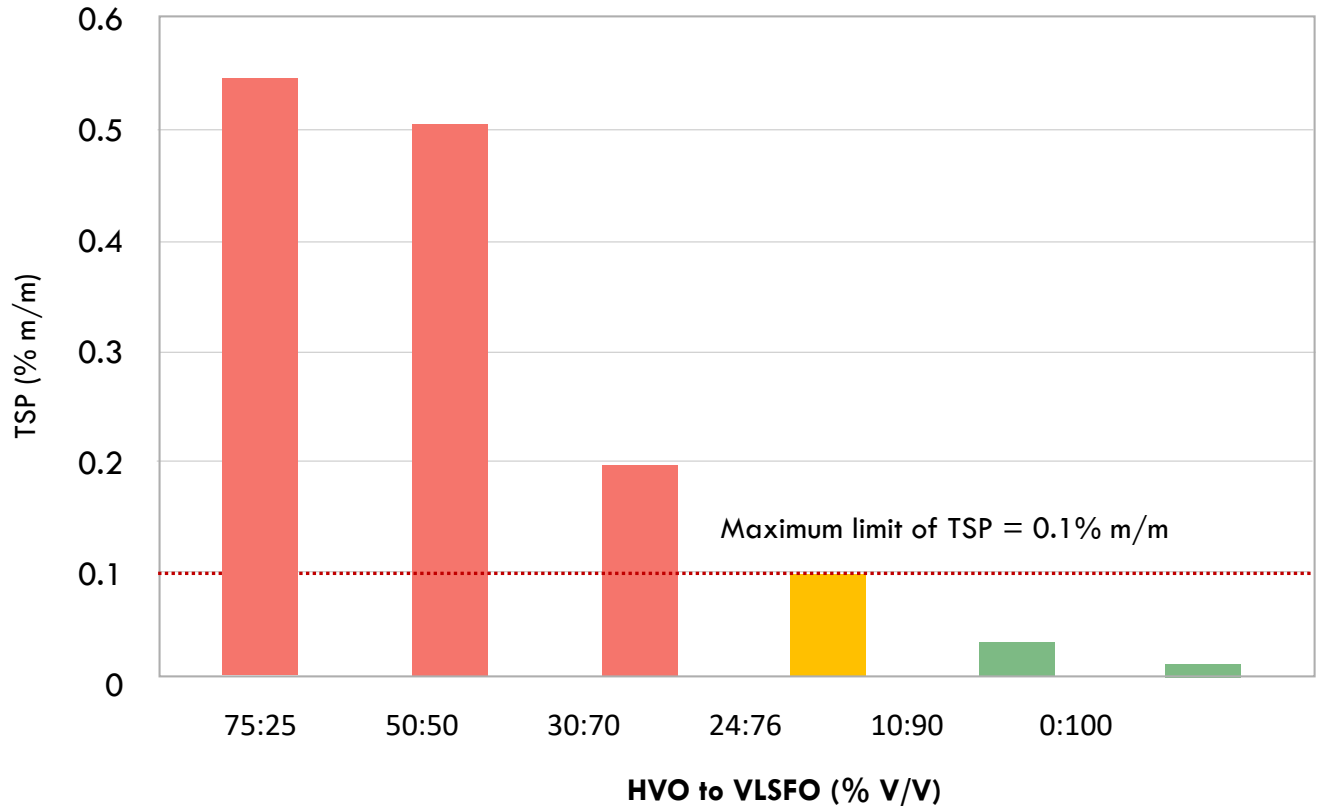
Compatibility depends on fuel type and blend ratio

Spot test



+ **Paraffinic hydrocarbons in HVO** reduce asphaltene solvency in VLSFO.
+ This triggers **asphaltene precipitation** and increases total sediment potential.

Total sediment potential



Quality | Impact of continuous biofuels use on vessel operations

Four bunkerings of **1,000 MT** *each in two onboard storage tanks over* **six months**

In operando sample monitoring + post-trial inspection revealed no major issues

Engine inspection with OEM and classification societies

Engine performance

Main engine: **No significant issues detected**

+ Comparable to VLSFO at maximum continuous rating

Generator engines: **No significant degradation in performance**

Fuel delivery system

Fuel and lube oil samples: **No anomalies**

Purifier efficiency & filter change frequency: **Unchanged**

Fuel quality

Under long-term stowage (6 months)

ISO 8217 tests: **Within specs**

Project specifications

Vessel type	RORO car carrier
Vessel route	Southeast Asia
Biofuel blend	B24 (UCOME + VLSFO)
Vol. bunkered	4,000 MT
Fuel + lube oil sampling	Before + after each bunkering
Monitoring hours	+ Main engine: **2,947 hours** + Generator engine: **1,813 hours** + Fuel oil purifier: **> 3,000 hours**

Project partners

GHG abatement | Sustainability criteria for biofuels

Harmonised criteria and consistent GHG accounting are essential to enable practical biofuel deployment.

Policies and schemes	1 Feedstocks coverage	2 GHG emissions threshold	3 Environmental criteria[b]						4 Socio-economic criteria[c]			
			1	2	3	4	5	6	1	2	3	4
1. Renewable Energy Directive I	EC, W	✓		✓	✓							
2. Renewable Energy Directive II	All	✓	✓	✓	✓			✓				
3. Renewable Energy Directive III	All	✓	✓	✓	✓			✓				
4. International Sustainability and Carbon Certificate (ISCC)	All	✓	✓	✓	✓	✓			✓	✓	✓	
5. Better Biomass	All	✓		✓	✓	✓	✓		✓	✓	✓	✓
6. Roundtable on Sustainable Biomaterials (RSB)	All	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
7. EPA Renewable Fuel Standard	All	✓	✓	✓	✓		✓					
8. Sustainable Aviation Fuels (SAF)	All	✓		✓	✓	✓	✓	✓			✓	
9. Sustainable certification for marine fuel	On-going development											

Adopted from Mai-Moulin, *et al.*, 2021.

1 **Feedstock:** All = all types of feedstock; EC = energy crops; and W = waste and residues

2 **GHG emissions threshold:** vary across regulatory framework and certification schemes

3 **Environmental criteria:** 1 sustainable forest management; 2 carbon stock prevention; 3 high biodiversity protection; 4 protection of water resources, air and soil; 5 indirect land use change; and 6 land use, land use change and forestry

4 **Socio-economic criteria:** 1 work rights; 2 land right; 3 food price and security; and 4 resource efficiency

GHG abatement | Traceability

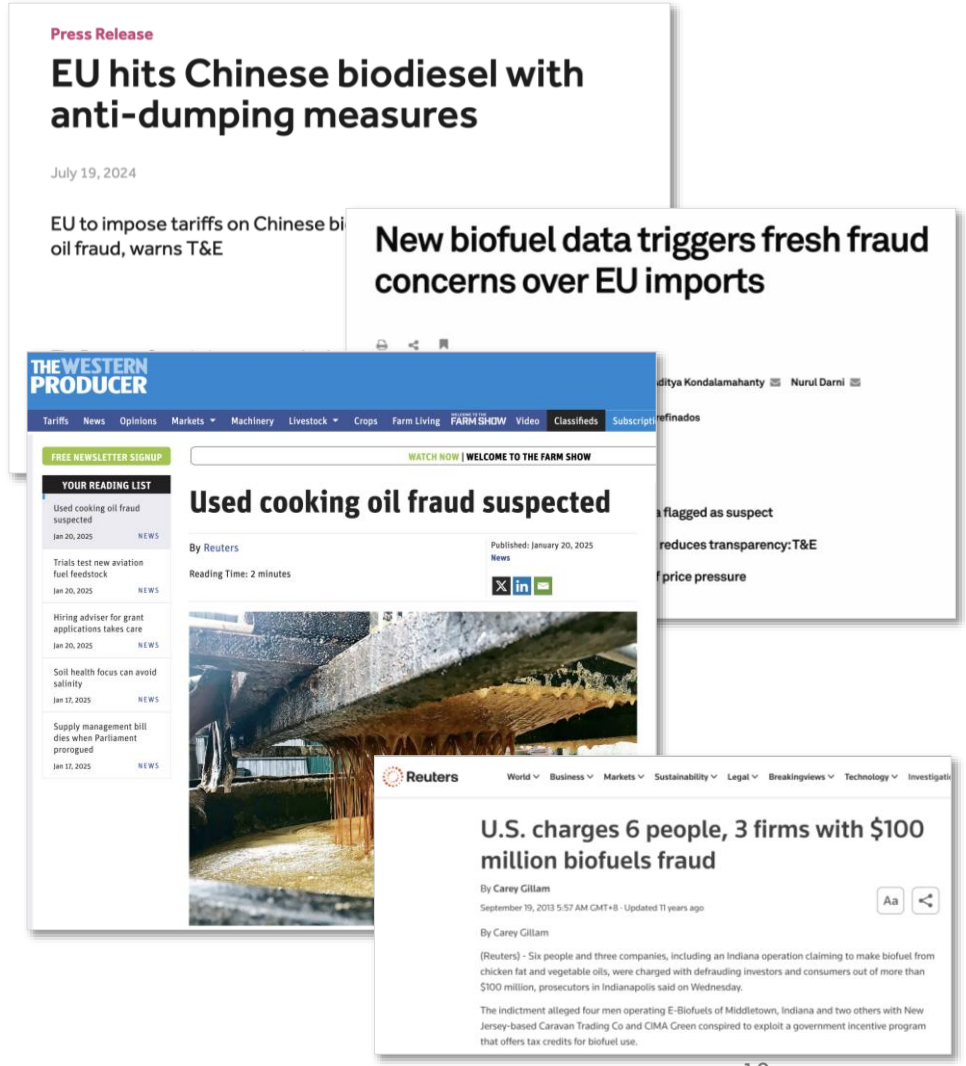
Concerns over fraudulent practices are rising, particularly on the mislabelling of feedstocks

> *Europe is completely over reliant on **unverifiable used cooking oil** from distant countries, like China. Restrictions on imports from China are a step in the right direction, however, anti-dumping tariffs alone won't be enough to tackle UCO fraud. Without a complete overhaul of the certification process, the EU will continue to play out a game of whack-a-mole as fraudsters from other countries will simply fill the gap. The EU needs to stop incentivising unverifiable, imported waste oils and **move away from an industry-led verification system** towards more stringent regulation."*
>
> *Transport & Environment*

> *A surge in **used cooking oil exports** from Asia in recent years have involved **unrealistically high volumes** relative to the amount of cooking oil used and recovered in the region.*
>
> The U.S. Environmental Protection Agency

> *The increase could be indicative of **a spike in fraudulent UCO claims**. What instantly jumps out of the data is that **a third** of the used cooking oil **is undoubtedly fake** – most likely sourced directly from **virgin palm oil**.*
>
> *EU Government Affairs*

> *They were among 17 companies in nine countries that investigators say purchased **cheap soy biofuels mislabelled as expensive UCO-based fuel** from the Bosnian company, Sistem Ecologica LLC.*
>
> *Organized Crime and Corruption Reporting Project (OCCRP)*



GHG abatement | Traceability

GCMD explored rapid, on-demand verification that complements existing sustainability schemes to detect fraud

Conducted fuel tracing to:

1. Confirm country of origin
2. Detect adulteration
3. Confirm biofuel percentage in marine fuel

Techniques	Physical Tracers	Fingerprinting	Lock and seal system	Automatic identification systems	Standard methods
Function	1 + 2 + 3	2	1 + 2*	1 + 2*	3
Description	+ Dose in neat biofuels + Detection at key nodes along supply chain	+ Sample neat biofuels and biofuel blends + GCMS to reveal chemical fingerprint + Only for FAME and FA contained fuels	+ Seal tank holds and valves after biofuel loading + Seals are serialised for recording	+ Monitor movement of neat biofuels during transport	+ Sample biofuel blends + Standard methods to determine bio-component content in fuel blends
Current techniques			☑	☑	☑
Emerging techniques	☑	☑			

Digital tracing

* Partially
GCMS - Gas Chromatography - Mass Spectrometry
FAME - Fatty Acid Methyl Ester
FA – Fatty acids

GHG abatement | Traceability

Deployed three tracers and investigated their efficacy across marine fuel supply chains

Mapped marine fuel supply chain

to understand physical flows and key custody points

Identified potential integration points of tracers

within supply chains to ensure minimal disruption to-operations

Leveraged existing marine fuel supply chains

to dose tracer at the furthest upstream location permitted under BAU operations

Implemented comprehensive sampling protocol

to collect aliquots at strategic nodes

Analysed samples to confirm tracers' presence and concentration

to assess tracer detectability and robustness along supply chain

GHG abatement | Traceability

Competitive benchmarking of tracer candidates

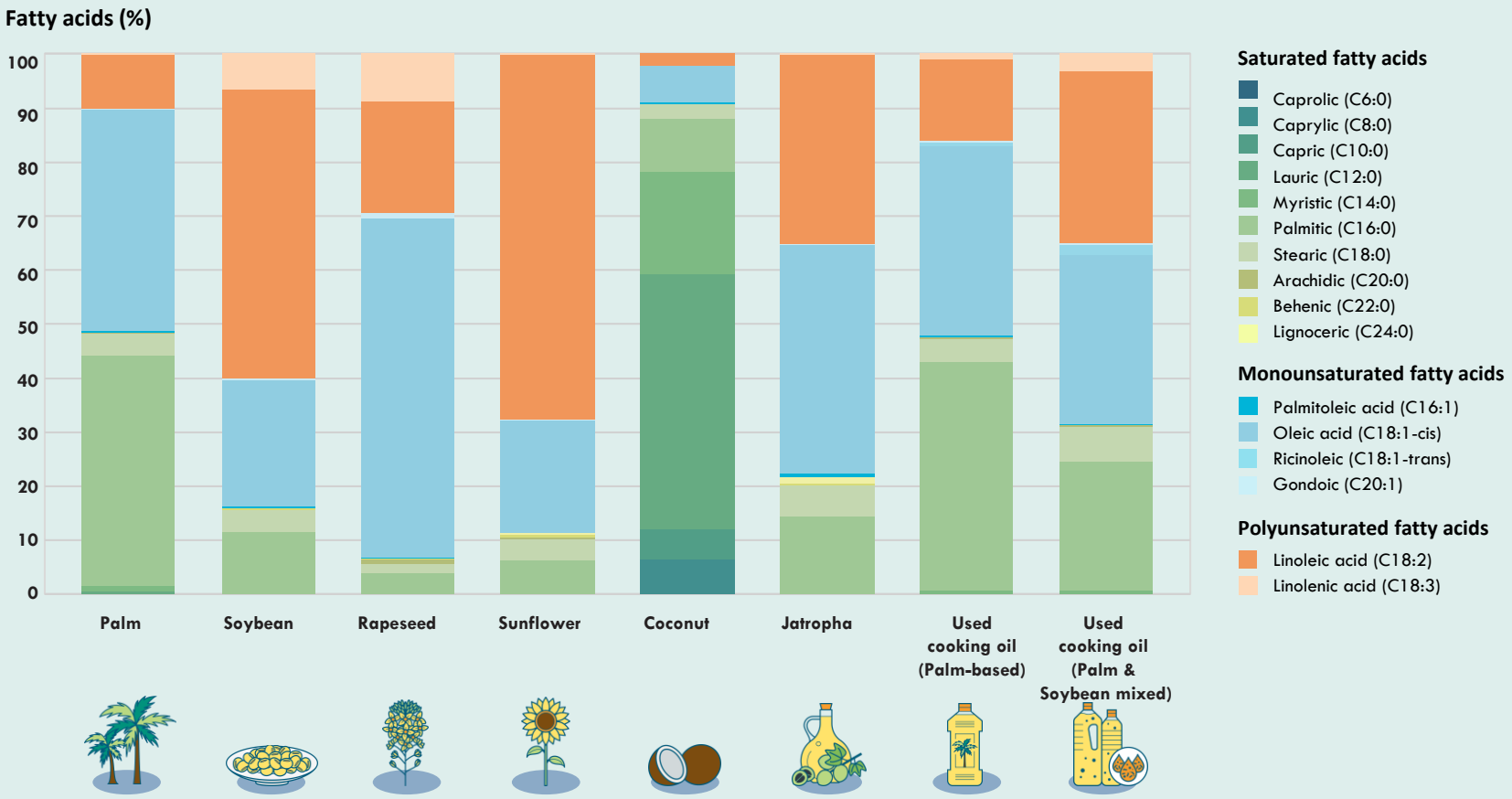
	Tracer A		Tracer B		Tracer C	
	Identifier	Quantifier	Identifier	Quantifier	Identifier	Quantifier
Technology	Synthetic DNA	Require to use with other tracers	Stable isotope, mixture of elements		Non-fluorescent chemical, organic compounds	
Function	✓	✗ [a]	✓	✓ Up to 30% deviation relative to the expected conc	✓	✓ <5% deviation relative to the expected conc
Permutations	Indefinite (ideal)	NA	Based on 14 elements		Numerous	
Customisation of tracer based on	Neat biofuel		Biofuel blend		Neat biofuel	
Stability in neat FAME	✓	✗ [a]	✓	✓	✓	✓
Analytical instrument	Lab-based	NA	Lab-based, commonly found in fuel test lab		Lab-based, commonly found in fuel test lab	
Current usage/ past trials	Diesel, residual marine fuels *	NA	Residual marine biofuel		Neat bioethanol, bioethanol blended gasoline, FAME blended diesel, LPG, residual marine biofuel	
Potential application for future fuel	○ ✗ [a]		✓	✓	✓	✓
	Liquid fuels		Single-molecule liquid fuels		Liquid and gaseous fuels	

[a] Require further R&D

GHG abatement | Traceability

FAME has unique chemical fingerprints depending on feedstock origin

Existing databases of fatty acid profiles of different feedstocks



Acquiring FAME fingerprints

- Fingerprints are derived from the unique chemical make up of fatty acids in feedstocks.
- Analysed with a gas chromatograph, an instrument commonly found in fuel test labs
- Requires about an hour, similar to current fuel testing turnaround time

GHG abatement | Traceability

Blind-tested 16 market samples; approximately 1/3 warranted a closer look

Labelled as virgin oil-derived FAME

1 2 3

Labelled as used cooking oil-derived FAME

4 5 6 7 8

9 10 11 12 13

Labelled as waste-derived FAME

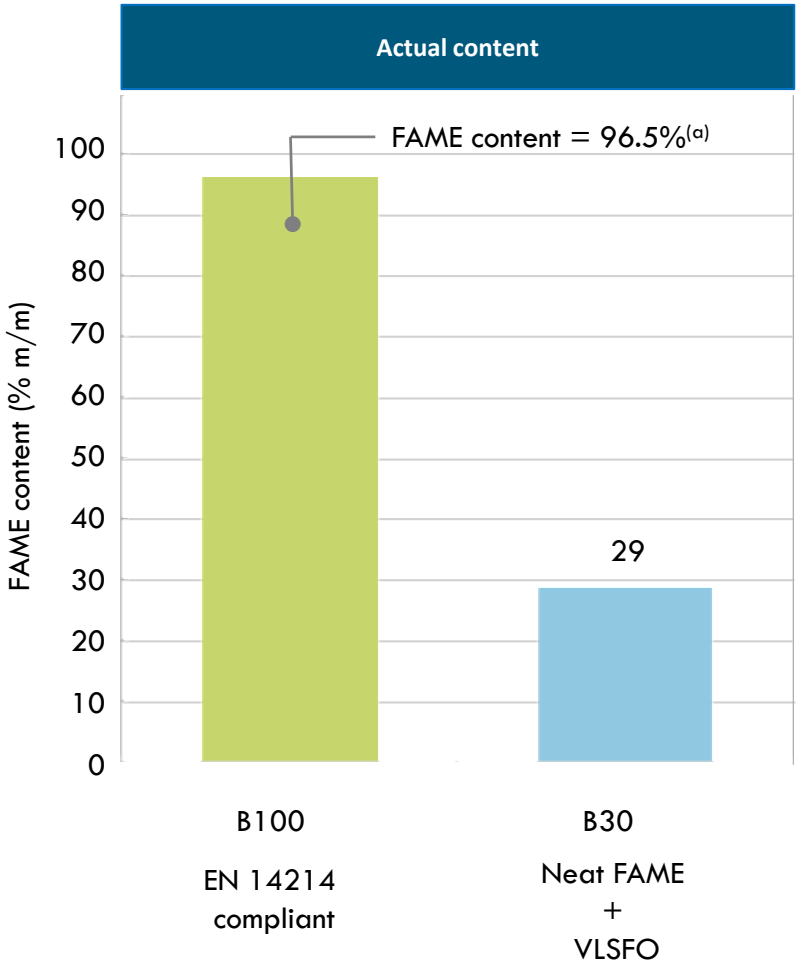
14 15 16

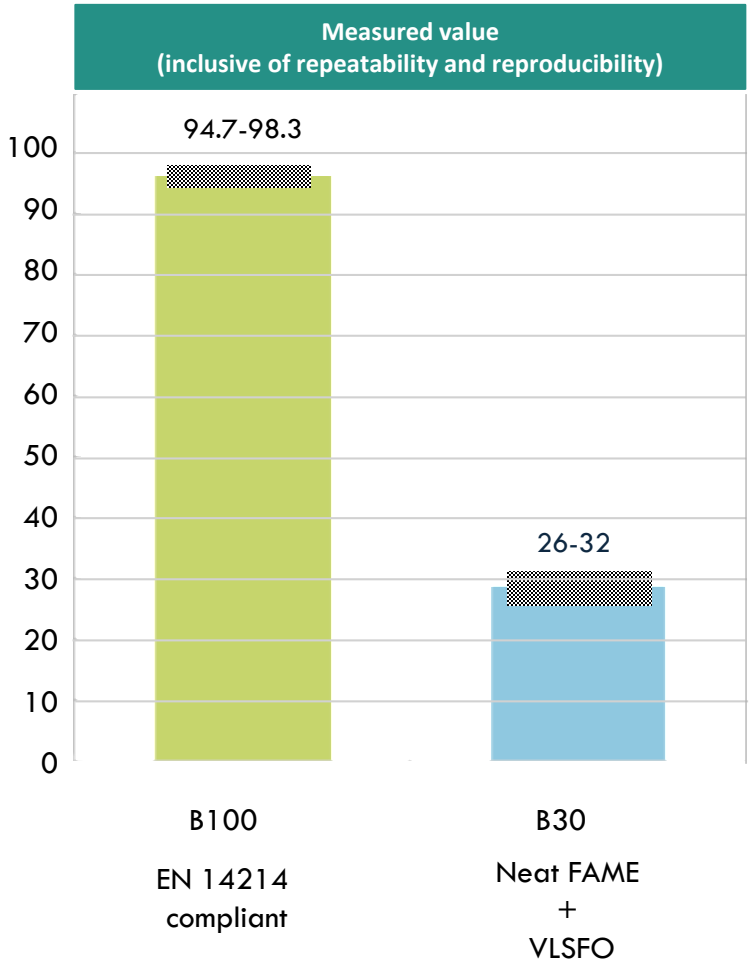
Observation

- **FAME 1 to 3:** fingerprints profiles were consistent with their labels.
- **FAME 1 and FAME 16 consistent with POME:** fingerprints were identical although FAME 16 was labelled as from "food waste".
- **FAME 9:** fingerprint indicates a palm-soybean oil blend.
- **FAME 7-8** and **FAME 11-13:** showed fatty-acid markers consistent with repeated heating (typical of used cooking oil).
- **FAME 4-6** and **FAME 10:** fingerprints were almost identical with others labelled UCO, but they lack markers from repeated heating.
- **FAME 15:** showed a profile identical to palm-oil derived FAME, despite being labelled as palm oil mill effluent-derived FAME.

Quantity | Verifying FAME content in blended marine fuels

Declared vs. measured FAME content may differ; standardised thresholds can avoid dispute and unsupported claims, particularly when lower-purity FAME grades are permitted.





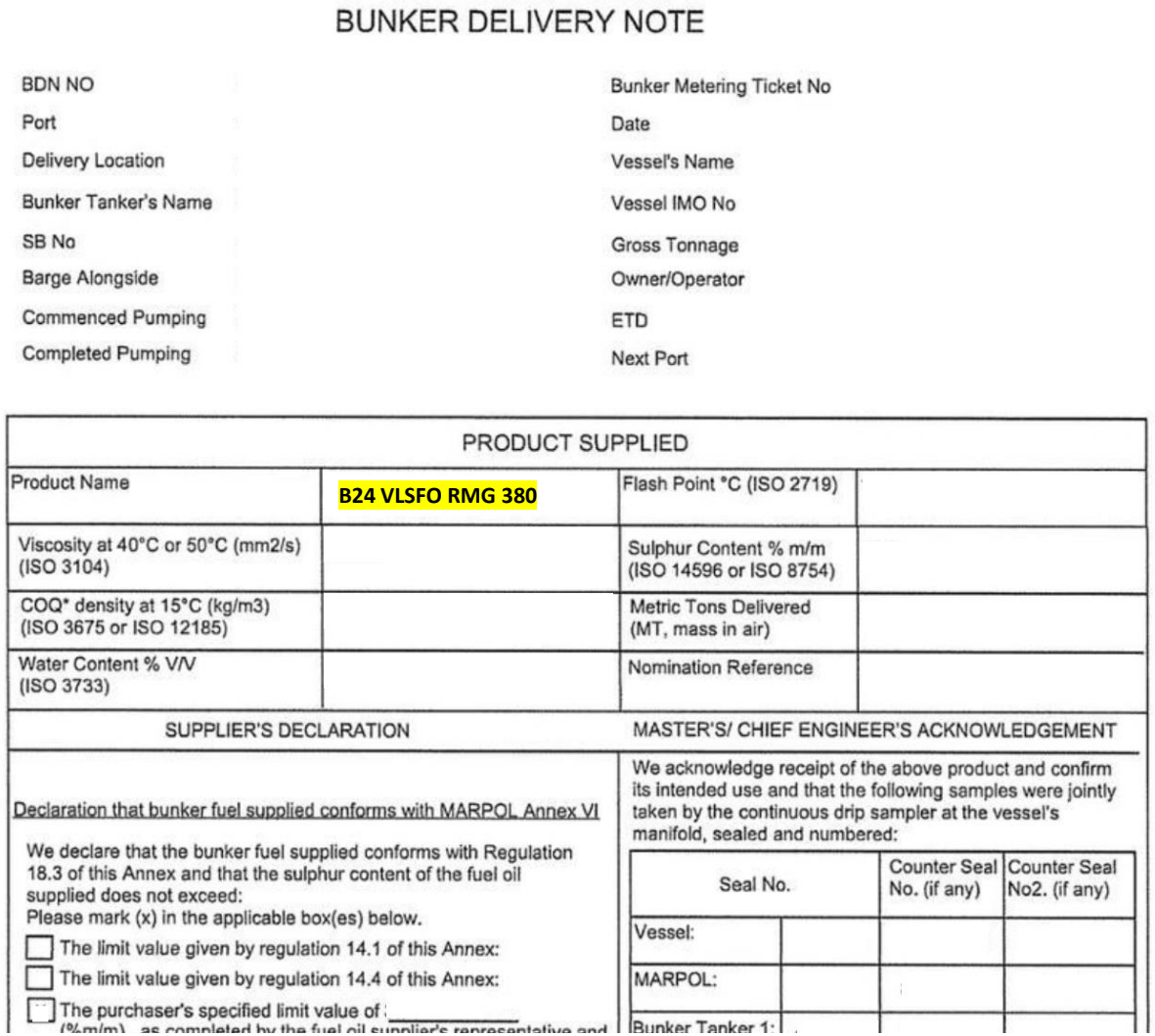
Pilot data:

- Neat FAME purity varied (96.5%–100%) but remained EN 14214-compliant.
- Measured FAME content was below the nominal Bxx value (B30: 26.6%; B24: 21.5%).
- Differences between Bxx and measured FAME content were attributed to FAME purity and test repeatability and reproducibility (R&R).

(a) With the remainder made up of glycerides (mono, di, tri) and glycerol

Quantity | Documentation

BDN bio-fraction should be measurement-backed, not self-declared



BUNKER DELIVERY NOTE

BDN NO	Bunker Metering Ticket No
Port	Date
Delivery Location	Vessel's Name
Bunker Tanker's Name	Vessel IMO No
SB No	Gross Tonnage
Barge Alongside	Owner/Operator
Commenced Pumping	ETD
Completed Pumping	Next Port

PRODUCT SUPPLIED

Product Name	B24 VLSFO RMG 380	Flash Point °C (ISO 2719)	
Viscosity at 40°C or 50°C (mm2/s) (ISO 3104)		Sulphur Content % m/m (ISO 14596 or ISO 8754)	
COQ* density at 15°C (kg/m3) (ISO 3675 or ISO 12185)		Metric Tons Delivered (MT, mass in air)	
Water Content % V/V (ISO 3733)		Nomination Reference	

SUPPLIER'S DECLARATION

Declaration that bunker fuel supplied conforms with MARPOL Annex VI

We declare that the bunker fuel supplied conforms with Regulation 18.3 of this Annex and that the sulphur content of the fuel oil supplied does not exceed:
Please mark (x) in the applicable box(es) below.

- ☐ The limit value given by regulation 14.1 of this Annex:
- ☐ The limit value given by regulation 14.4 of this Annex:
- ☐ The purchaser's specified limit value of _____ (%m/m) as completed by the fuel oil supplier's representative and

MASTER'S/ CHIEF ENGINEER'S ACKNOWLEDGEMENT

We acknowledge receipt of the above product and confirm its intended use and that the following samples were jointly taken by the continuous drip sampler at the vessel's manifold, sealed and numbered:

Seal No.		Counter Seal No. (if any)	Counter Seal No2. (if any)
Vessel:			
MARPOL:			
Bunker Tanker 1:			

Pilot insights:

- Bio-fraction on the BDN is currently self-declared by suppliers (often supported by a Certificate of Quality (CoQ).
- However, self-declared information can be subjected to discrepancies.
- In contrast, other compliance/operational parameters (e.g., sulphur, viscosity, water content, flash point) are measured and recorded as mandatory field.
- Bio-fraction could be treated similarly — measured and recorded on the BDN.

Operationalising the framework

Quality

Leverage trial evidence

FAME is environmentally and operationally stable across the supply chain.

Apply compatibility guidance

Avoid HVO-in-HFO unless lab testing confirms compatibility

Follow good practice

Keep tanks dry and clean, practice "fresh-in, fresh-out"

GHG abatement

Harmonise definitions and thresholds

Align Sustainable Marine Fuels (SMF)'s definition

Establish clear rules for GHG allocation across end products

Strengthen traceability and proof of origin

Deploy verification technologies (e.g., fingerprinting, physical tracers)

Quantity

Implement standardised bio-content testing

Define purity range and accepted threshold of neat FAME

Report neat FAME purity before blending

Require reporting of measured bio-fraction on BDN/e-BDN

Consolidate lab results and delivery data

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