



Global Centre for

MARITIME DECARBONISATION

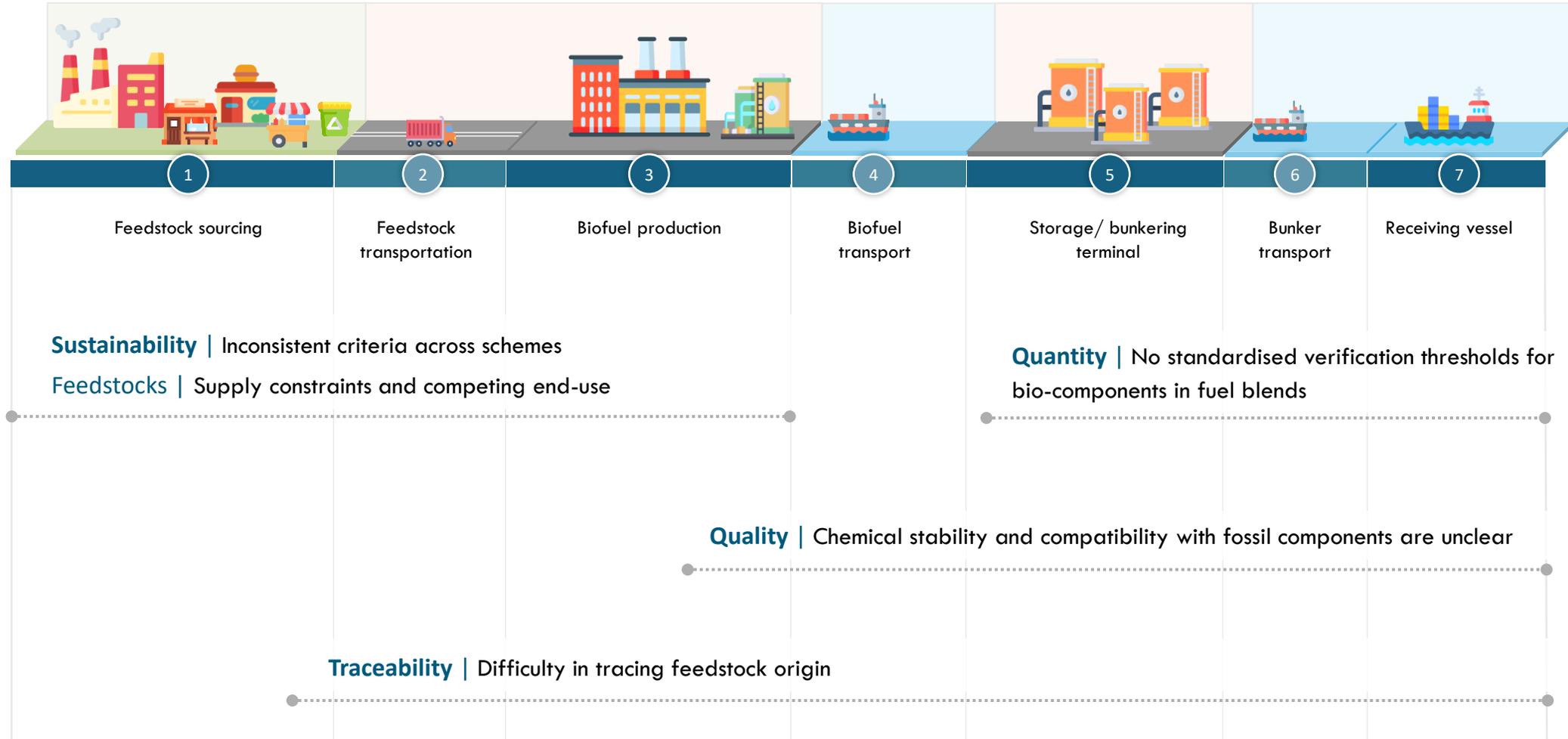
**Drop-in biofuels:
Developing a framework for quality, quantity and GHG
abatement assurance**

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Date: 12 February 2026

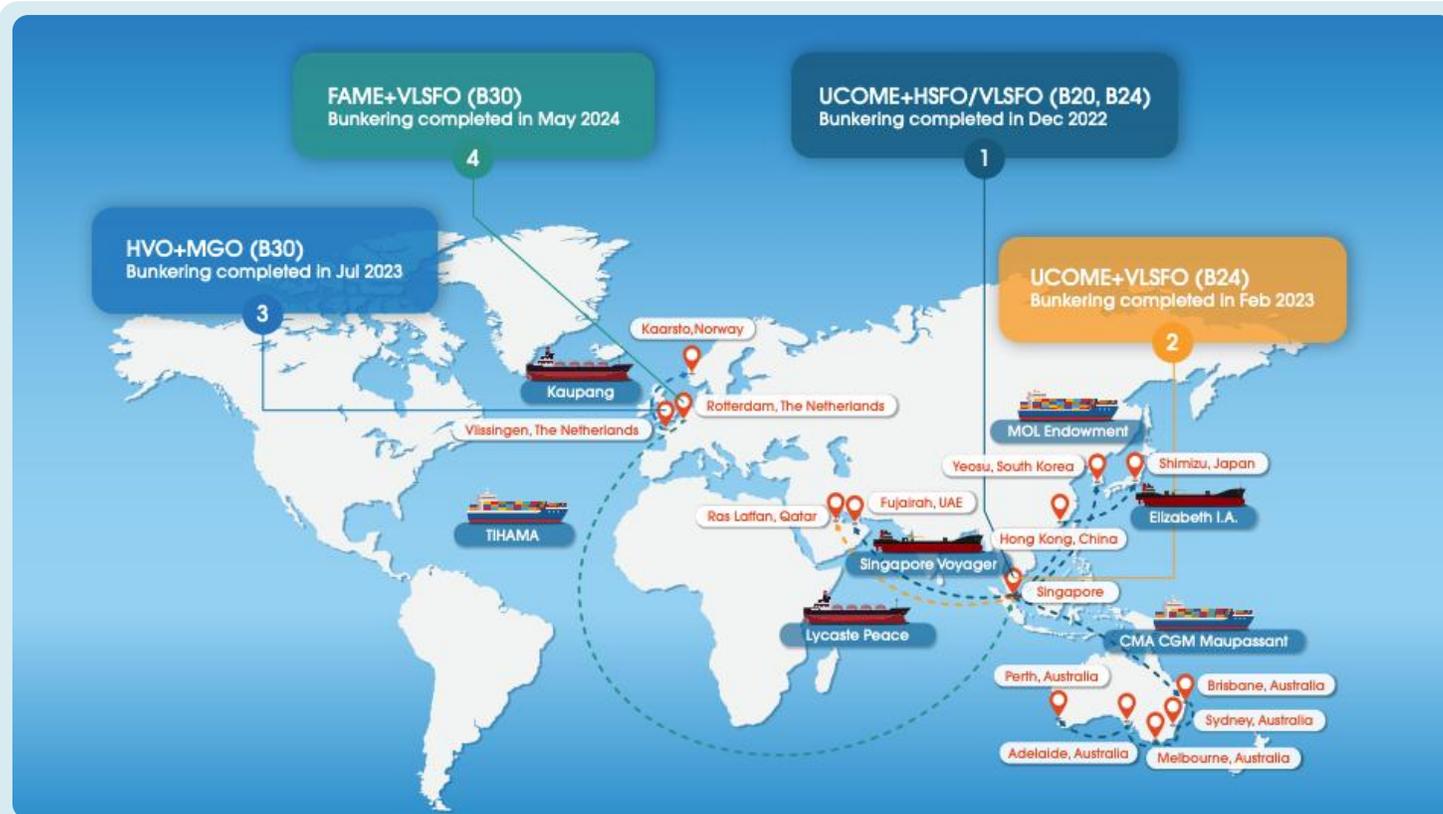
Adopting drop-in biofuels is not without challenges

Interlinked + multifaceted barriers span the entire value chain



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

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

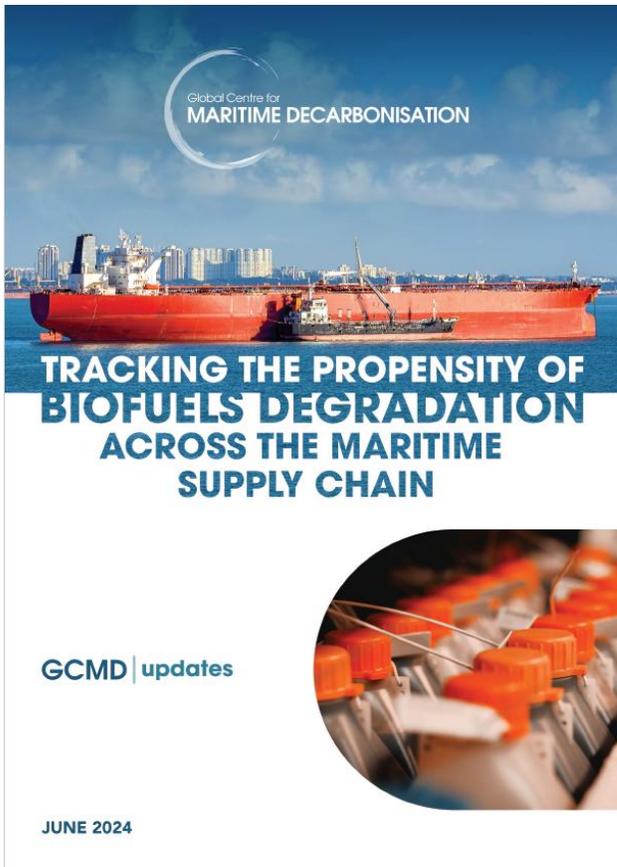
- + Bio-component fraction in fuel blends
- + Documented in BDN

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:

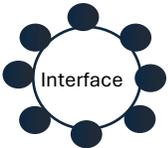
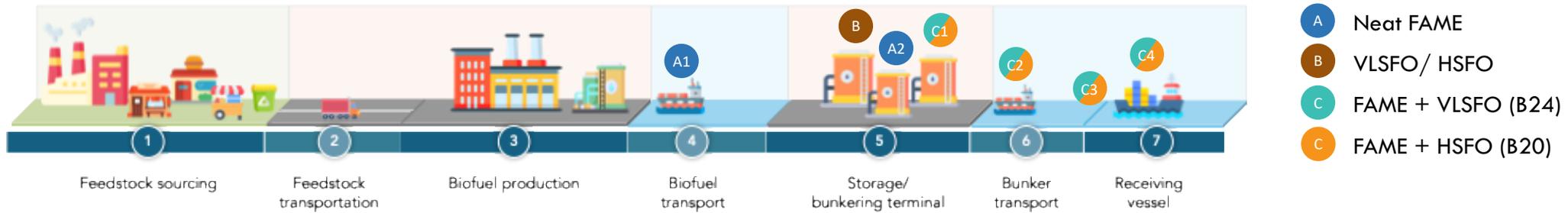
Mechanism	Undesirable by-products	Impact on fuel systems	Relevant fuel properties
Autoxidation <i>Free radical reactions</i> 	<ul style="list-style-type: none"> ○ Free radicals ○ Formic and acetic acids ○ High-molecular weight products/sediments 	<ul style="list-style-type: none"> ○ Hardness and swelling of o-rings and gaskets ○ Corrosion of parts ○ Clogging of filters, pipes, etc. 	<ul style="list-style-type: none"> ○ Peroxide value ○ Acid value ○ Viscosity
Hydrolytic oxidation <i>Reaction with water</i> 	<ul style="list-style-type: none"> ○ Free fatty acids ○ Alcohols 	<ul style="list-style-type: none"> ○ Corrosion of parts ○ Safety 	<ul style="list-style-type: none"> ○ Free fatty acid content and acid value ○ Methanol content
Microbial growth 	<ul style="list-style-type: none"> ○ Slime ○ Acids 	<ul style="list-style-type: none"> ○ Clogging of filters, pipes, etc. ○ Pit corrosion in fuel tanks 	<ul style="list-style-type: none"> ○ Viscosity ○ Microbial contamination

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

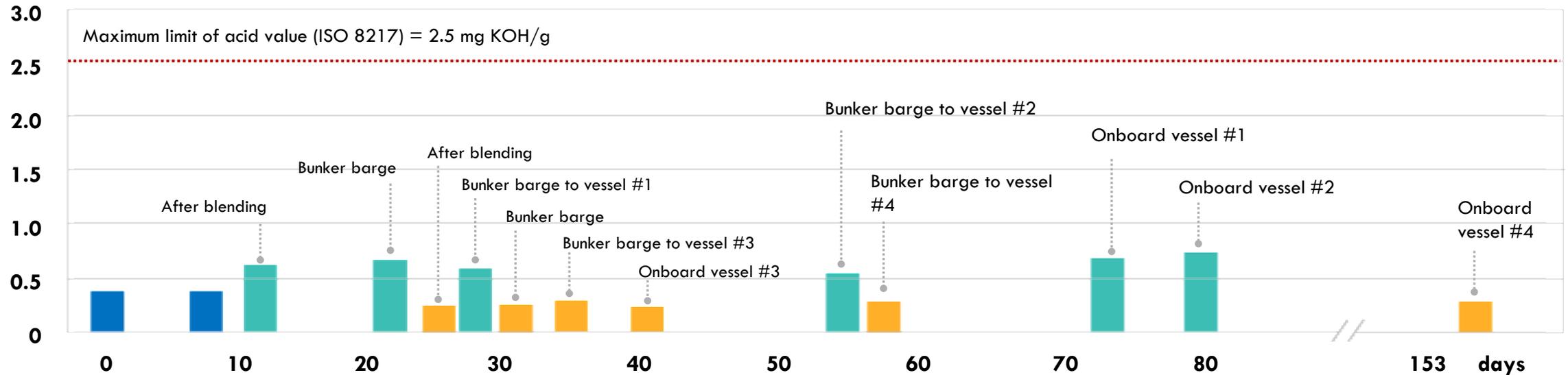
Quality | Stability of FAME-based biofuels

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



Acid value (mg KOH/g)

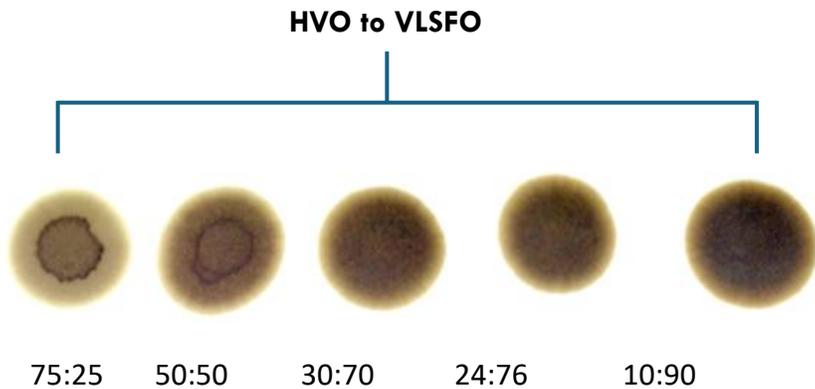
Acid value: VLSFO = 0.6 mg KOH/g, HSFO = 0.27 mg KOH/g



Quality | Compatibility of HVO blends

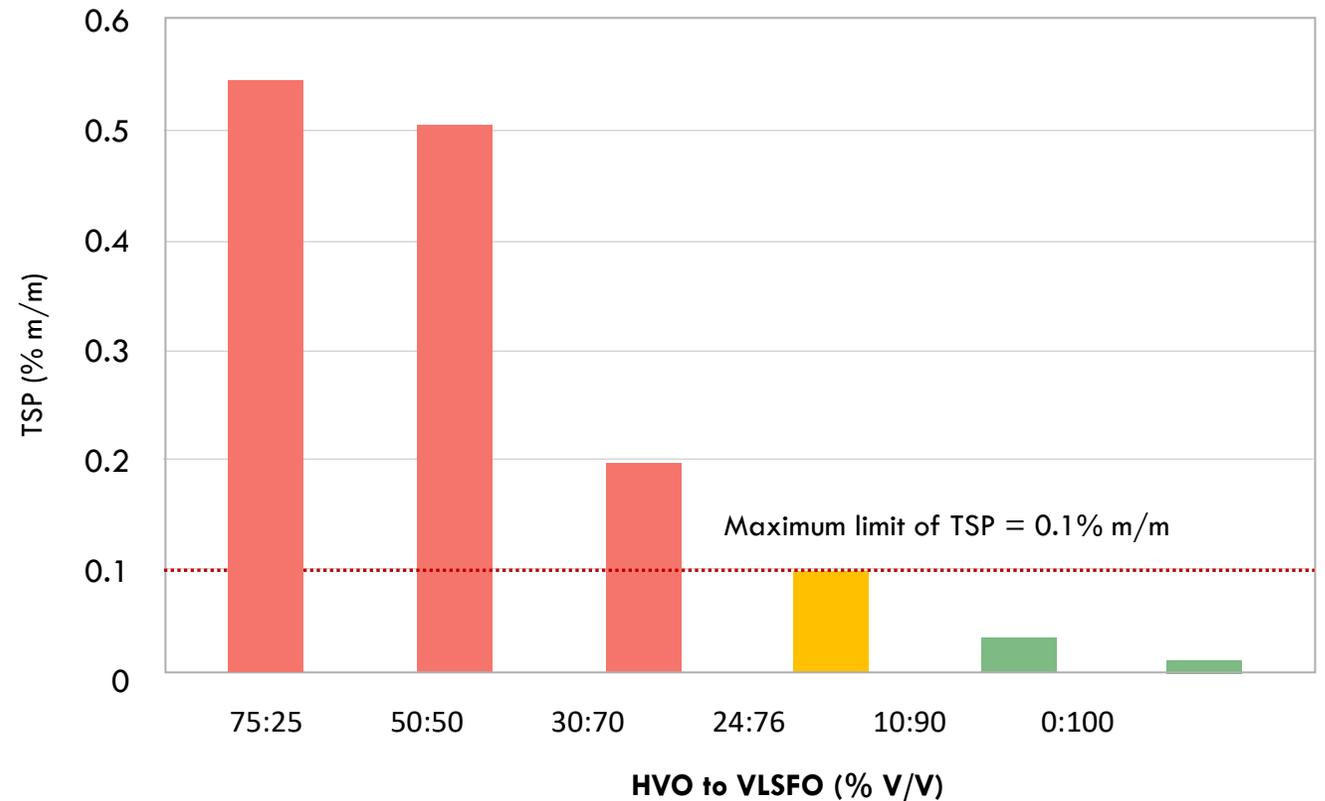
Compatibility depends on fuel type and blend ratio

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

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	<ul style="list-style-type: none"> + Main engine: 2,947 hours + Generator engine: 1,813 hours + Fuel oil purifier: > 3,000 hours

Project partners



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

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

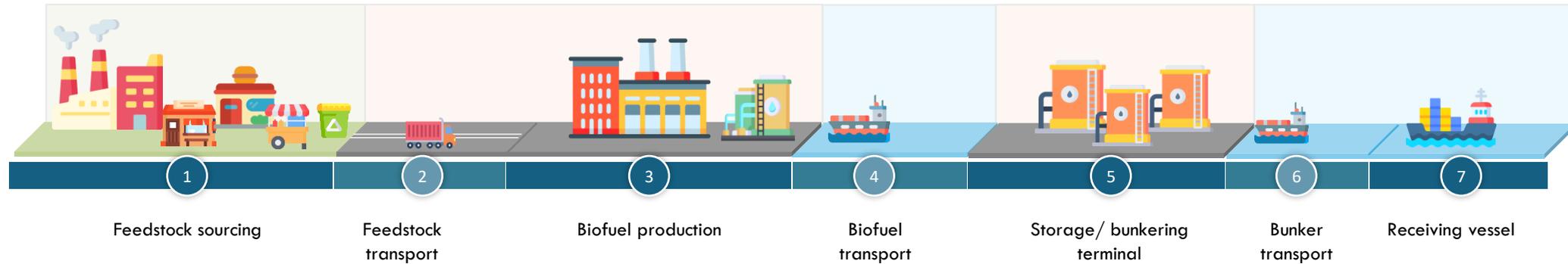
Techniques	 Physical Tracers	 Fingerprinting	 Lock and seal system	 Automatic identification systems	 Standard methods
Function	1 + 2 + 3	2	1 + 2*	1 + 2*	3
Description	<ul style="list-style-type: none"> + Dose in neat biofuels + Detection at key nodes along supply chain 	<ul style="list-style-type: none"> + Sample neat biofuels and biofuel blends + GCMS to reveal chemical fingerprint + Only for FAME and FA contained fuels 	<ul style="list-style-type: none"> + Seal tank holds and valves after biofuel loading + Seals are serialised for recording 	<ul style="list-style-type: none"> + Monitor movement of neat biofuels during transport 	<ul style="list-style-type: none"> + 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	

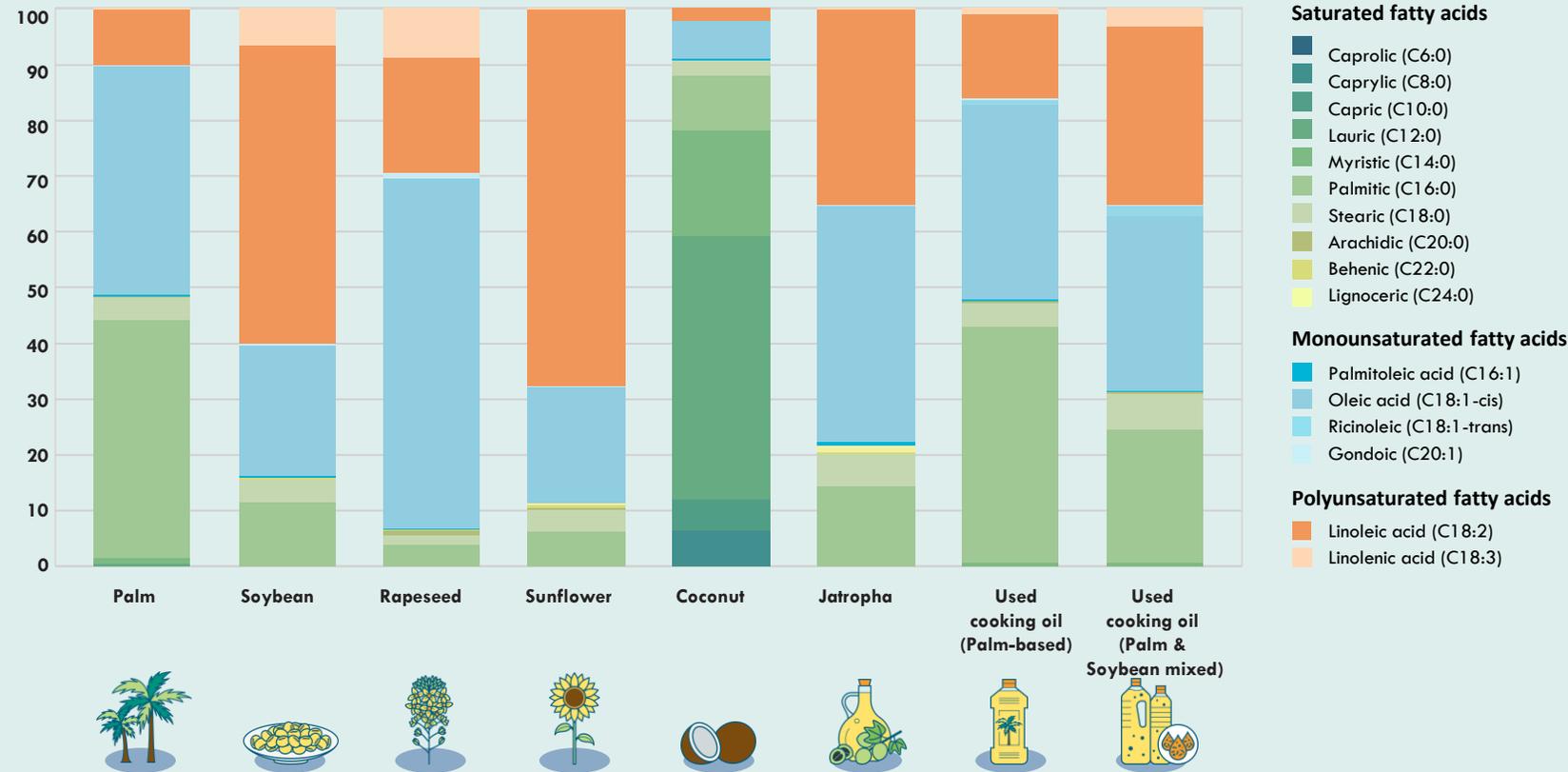
^(a) Require further R&D

GHG abatement | Traceability

FAME has unique chemical fingerprints depending on feedstock origin

Existing databases of fatty acid profiles of different feedstocks

Fatty acids (%)



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



Labelled as used
cooking oil-derived
FAME



Labelled as waste-
derived FAME

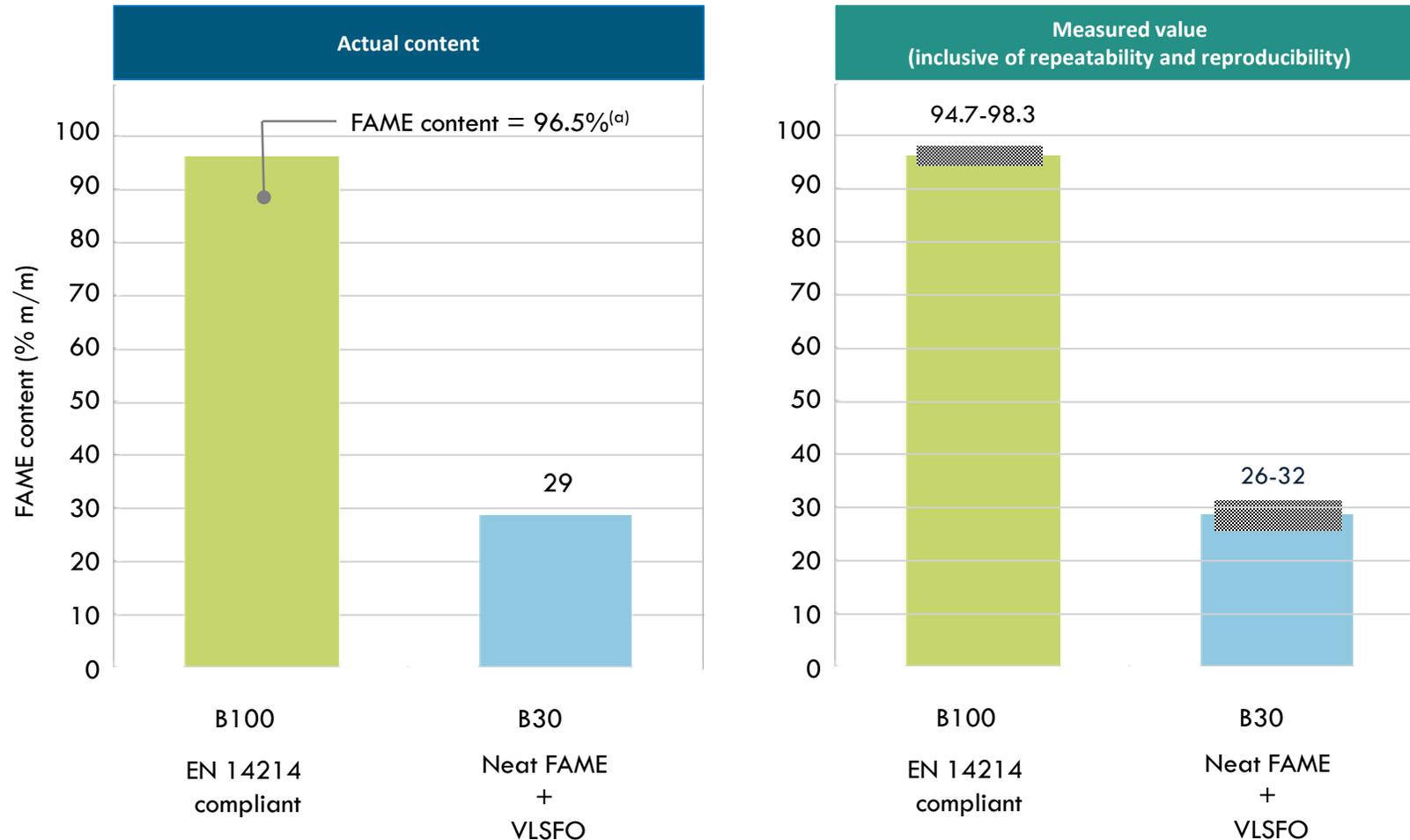


Observation

- + **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 (mm ² /s) (ISO 3104)		Sulphur Content % m/m (ISO 14596 or ISO 8754)													
COQ* density at 15°C (kg/m ³) (ISO 3675 or ISO 12185)		Metric Tons Delivered (MT, mass in air)													
Water Content % V/V (ISO 3733)		Nomination Reference													
SUPPLIER'S DECLARATION		MASTER'S/ CHIEF ENGINEER'S ACKNOWLEDGEMENT													
<p><u>Declaration that bunker fuel supplied conforms with MARPOL Annex VI</u></p> <p>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.</p> <p><input type="checkbox"/> The limit value given by regulation 14.1 of this Annex: <input type="checkbox"/> The limit value given by regulation 14.4 of this Annex: <input type="checkbox"/> The purchaser's specified limit value of: _____ (%m/m), as completed by the fuel oil supplier's representative and</p>		<p>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:</p> <table border="1"> <thead> <tr> <th>Seal No.</th> <th>Counter Seal No. (if any)</th> <th>Counter Seal No2. (if any)</th> </tr> </thead> <tbody> <tr> <td>Vessel:</td> <td></td> <td></td> </tr> <tr> <td>MARPOL:</td> <td></td> <td></td> </tr> <tr> <td>Bunker Tanker 1:</td> <td></td> <td></td> </tr> </tbody> </table>		Seal No.	Counter Seal No. (if any)	Counter Seal No2. (if any)	Vessel:			MARPOL:			Bunker Tanker 1:		
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Vessel:															
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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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