NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Biofuel as Sustainable Marine Fuel for Low Carbon Shipping

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Biofuel as Alternative Fuels

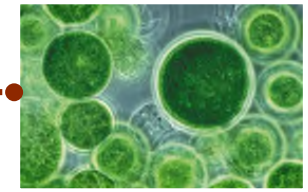
Liquid or gaseous fuels produced from biomass

Through thermal, chemical and biochemical conversion, biomass can be converted into a variety of biofuel products

Waste and genetically modified algae

4th

3rd



Algae (macro and micro algae)

Lignocellulosic biomass and inedible oils

2nd

1st

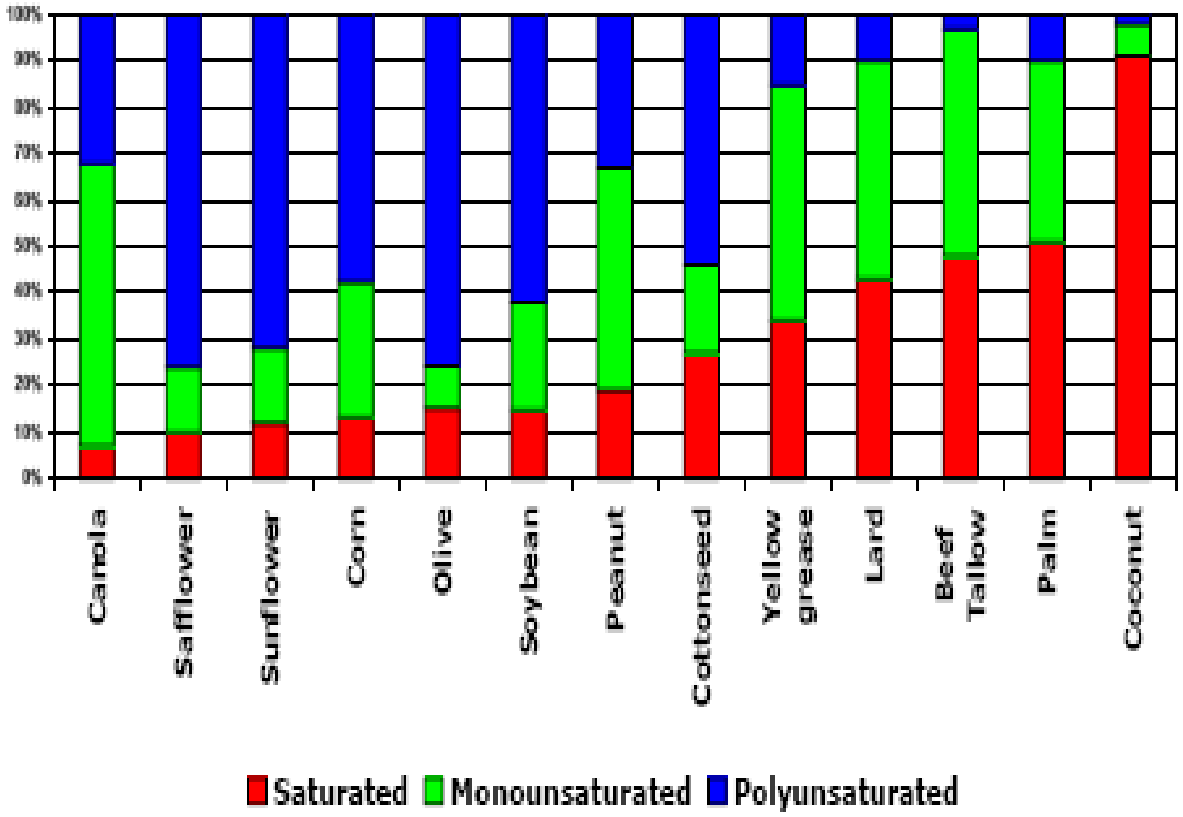
Vegetable (edible) oils –palm, soybean, sunflower, rice bran, sesame, peanut, olive, coconut, rapeseed & animal fats and plants containing sugar & starch

Biodiesel Stability: Important Factors

- Biodiesel tends to degrade over time
- Degradation of biodiesel impacts the fuel quality and the storage duration

Name of Ester	Carbon Atom Number	Unsaturated Double Bonds	Oxidative Stability (Relative)
Linolenate	18	3	Low
Linoleate	18	2	Low
Oleate	18	1	Medium
Palmitoleate	16	1	Medium
Palmitate	16	Zero	High
Stearate	18	Zero	High

FAME composition



Feedstock Type

Source: Bureman et al., Biodiesel Exposicion Tecnica, 2007.

Biodiesel Stability: Important Parameters

Key properties related to stability

- Kinematic viscosity – increases as oxidation progresses
- Water content – higher content leads to degradation
- Acid value – quantity of FFAs in the biodiesel
- Iodine value – measure of unsaturation
- Oxidation stability – susceptible to oxidation

Undesired Product	Equipment Problem	Customer Problem
Sludges, Sediments	- Filter clogging - Fuel injector deposits	- Engine stalling - Smoke formation
Acids	- Corrosion to engine components	- Extra costs - Engine stalling
Peroxides	- Elastomer embrittlement	- Fuel seepage - Unexpected downtime

Source: Bureman et al., Biodiesel Exposicion Tecnica, 2007.

Biodiesel Stability: Remedial Approach

Role of antioxidants

Antioxidant Type	Name of Antioxidant	Nature
Natural	αT– α tocopherol	**CI -** Chain inhibitor
	βC– β carotene	**CI**
Synthetic	BHA– Butylated hydroxyanisol	**CI**
	BHT– Butylated hydroxytoluene	**CI**
	TBHQ– Tert-butylhydroquinone	**CI**
	PG– Propyl gallate	**CI**
	PY– Pyrogallol	**OQ -** Oxygen quencher
	HC– Hydrogenated cardanol	**OQ**
	AHC– Alkyl hydrogenated cardanol	**OQ**
	GA– Gallic acid	**RA -** Reducing agent

Oxidative instability chain reaction:

Step 1: Initiation

$RH \rightarrow R\bullet$

Step 2: Propagation

$R\bullet + O_2 \rightarrow RO_2\bullet$

$ROO\bullet + RH \rightarrow R\text{-}OOH + R\bullet$

Step 3: Termination

$R\bullet + R\bullet \rightarrow R\text{-}R$

$ROO\bullet + R\bullet \rightarrow R\text{-}OO\text{-}R$

Further polymerization results in the formation of sludge and sediment.

Source: Lau et al., Sustainable Energy Technologies and Assessments 2022, 52: 102296.

Key Challenges to Adopting Biodiesel

- **Limited Production Capacity:** Not meet the high demands of the maritime industry
- **Production Costs:** More expensive to produce than traditional marine fuels
- **Compatibility and Engine Modifications:** Some ships may require engine modifications to use high-blend biofuels (>B50)
- **Energy Density:** Lower energy density than fossil fuels, affecting vessel performance

Summary and Future Directions

Gaps for implementation of high-blend biofuels
• There is a lack of standards for the fuel quality of high-blend biofuels • Need for improvement of fuel quality for long-term biofuel storage • Limited adoption of B100 in existing harbour craft, especially those with higher engine power (e.g., > 600 – 1000 kW) and specific operational requirements that make them harder to electrify (e.g., tankers and tugboats)

Work Scope	Methodology
• Biofuel quality improvement for long-term storage	o Addition of additives/antioxidants to biofuels o Conduct laboratory tests for fuel quality and material compatibility
• Assessment of biofuel combustion characteristics and engine performance with related additives	o Interviews/survey with engine makers o Analysis of combustion process o Testbed study of engine performance o Sea Trial

Thank you

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