ALTERNATIVE MARINE FUELS WITH ONBOARD CARBON CAPTURE CAN REDUCE GREENHOUSE GAS EMISSIONS IN THE MARITIME SECTOR

A Life-Cycle Analysis by Arvid Hjortsberg and Malin Wahlström

One of the most important issues of our time is the need to quickly reduce global greenhouse gas (GHG) emissions. The Earth is approaching the 1.5 degree threshold and not reaching the Paris Agreement requires the industry to change quickly. An industry responsible for large GHG emissions is the transport sector, with the maritime transport sector contributing to about 3% of the global GHG emissions and 80% of the world's transported goods.

The International Maritime Organization (IMO) has introduced several emission regulations in an effort to reduce the climate impact from the maritime industry. Limitations on the amount of NO_x emissions implemented in 2011 were followed by SO_x emission regulations in 2020 to reduce harm to the environment. These are already adopted in large by the global maritime sector but two goals are yet to be achieved; the goals posed in the 2018 GHG strategy. The 2018 GHG strategy introduced goals to reduce the total GHG emissions from the maritime industry with ambitious goals to reduce GHG emissions by 50% by 2050 (will be reviewed to net zero GHG emissions by 2050).

To comply with IMO's 2050 goals, several alternative methods have been, and are currently explored by the maritime sector. The first is the optimization of the engine efficiency to reduce energy consumption and achieve *better* combustion. This is deemed to be insufficient alone so alternative fuels are researched and have been implemented at a commercial level. Examples of this are: LNG, Biofuels, Methanol, Ammonia, etc.

Several alternative fuels have the potential to significantly reduce emissions but supply issues, cost, etc exist and the majority of the fuels only lower emissions, they do not sequester certain pollutants like CO_2. This has led to a third way to be investigated; removing pollutants from the exhaust gasses. A proposed method is to have a post-combustion carbon capture unit aboard the shipping vessel.

This master thesis aimed to investigate the climate impact of including an onboard carbon capture to reduce the CO_2 emissions from the engine and compare the global warming when the ship is powered by different alternative marine fuels. The captured CO_2 was then assumed to be permanently stored below the sea bed.

Three alternative fuels were reviewed (the type was chosen as the same MAN energy solution engine can use all three types). Heavy fuel oil with a lower sulfur content called very low sulfur fuel oil (VLSFO) was used as a baseline for comparison as this fossil fuel is the most common marine fuel today. The second fuel type tested was a biodiesel (fatty acid methyl ester, FAME) made from four different feedstocks: Soybean oil (most common in the US), Rapeseed oil (most common in the EU), Palm oil (possible worst case), Used cooking oil (possible best case). Lastly, methanol (MeOH) was investigated; produced by two different methods. Green methanol; made from captured CO_2 and renewable electricity to synthesize the methanol and methanol from natural gas synthesized by gasification. The two cases were picked as green methanol was deemed as being a possible best case and methanol from natural gas is the most common method to produce methanol.

The fuels were combusted in a theoretical ship model and the total emissions from producing 1 MJ of mechanical energy on the shaft/propeller is the reference that all the fuels are expected to produce.

Ship systems are relatively complex and not every component contributes significantly to the emissions produced. Thus a simplified model has been used to determine the emissions from the ship. The schematic of this model can be seen in Figure 1.

The ship's propulsion systems revolve around the ship engine that converts 50% of the energy in the fuel to mechanical energy. The mechanical energy is mainly used to power the propeller, but some is also used to produce electricity onboard. The engine combustion produces pollutants like NO_x, SO_x, CO_2 etc and these pollutants make up the flue gas. The flue gas is cleaned in three steps. First, they pass through the selective catalytic reducer (SCR) that removes NO_x from a reaction with urea. Secondly, the flue gas passes through the scrubber that removes SO_x using a reaction with NaOH. Lastly, the flue gas passes through to onboard carbon capture (OCC) that removes 70% of the CO_2 using a reaction with amine.

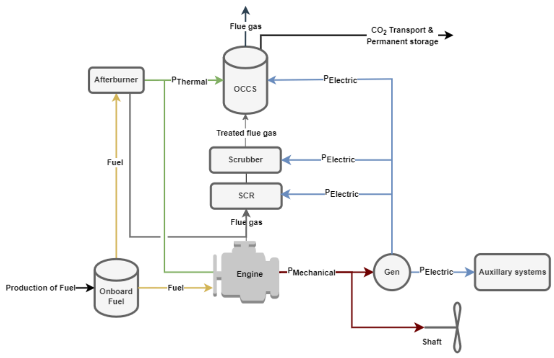
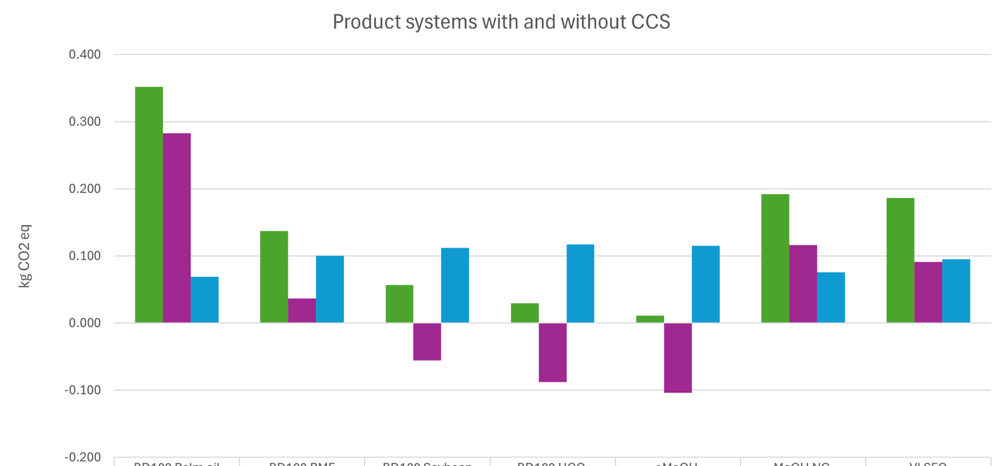


Figure 1: Simplified propulsion system of a theoretical ship.

The OCC requires large amounts of thermal energy to boil the amine to release the CO_2 for storage. This thermal energy is mainly supplied by the waste energy from the engine but the waste heat alone is not enough to capture 70% of the CO_2. This is why the so-called afterburner was added. The afterburner burns fuel to add thermal energy to the OCC.

Captured CO_2 can either be used in industrial processes or permanently stored to remove CO_2 from the atmosphere. This



	BD100 Palm oil	BD100 RME	BD100 Soybean	BD100 UCO	eMeOH	MeOH NG	VLSFO
Without CCS	0.352	0.137	0.057	0.029	0.011	0.192	0.186
With CCS	0.283	0.037	-0.056	-0.088	-0.104	0.116	0.091
Difference	0.069	0.101	0.112	0.117	0.115	0.076	0.095

Figure 2: The global warming impact from the different fuels with and without the inclusion of an onboard carbon capture unit and permanent storage.

thesis chose to permanently store the CO_2 to give the greatest CO_2 reduction.

All of the fuels considered in the master thesis were mainly reviewed by how they impacted global warming (GWP).

It was found that the production method of methanol greatly affected the GWP with methanol from natural gas performing worse than VLSFO. Green methanol performed best and had the lowest GWP from a well-to-wake perspective, both with and without CO_2 capture. There are, however, severe supply limitations as of 2024 for green methanol, and FAME from used cooking oil can work as a substitute. The biofuels displayed a great spread in GWP with FAME from palm oil performing worst of all the fuels and FAME from used cooking oil displaying the second lowest GWP of all the fuels. FAME from soybean and rapeseed both performed better than VLSFO in the case of this study but this is highly influenced by the level of influence that the growing of the crop has on the environment.

The inclusion of an OCC greatly reduced the GWP of all the cases but the increase in fuel consumption required to heat the OCC led to fuels with a low impact from production performing better than fuels with a high impact from production.

The master thesis has thus shown that alternative fuels have the potential to reduce the GWP from the maritime sector, this reduction is amplified if an OCC is included. The combination of systems could therefore serve as an important inclusion to quickly achieve the IMO 2050 goal set.

Little consideration of other environmental-, or health impacts was taken into account and no conclusion regarding other impacts can be made.