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The Use of Biodiesel Fuels in the Land Force

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GREENER CAF BY USING GREEN FUELS: A STUDY OF THE USE OF BIODIESEL IN THE LAND FORCE

Canada is committed to reducing Canadian Armed Forces (CAF) greenhouse gas emissions by 40% by 2030, from 2005 levels.[1] In order to achieve this, many initiatives are ongoing using new technology. However, these initiatives have to be implemented with what is widely perceived as the worst procurement system in the Western world.[2] Most carbon emission reduction discussions consider the use of electricity, the use of hydrogen - and the implementation of new technologies. Although, none of these approaches really look at the carbon footprint cost of the construction and maintenance of the new infrastructure required in order to implement these technologies, nor what is possible to do with our current construct and infrastructure. The total cost of implementation of many new projects probably increases the carbon footprint in the short-term.

In order to implement new technologies, the CAF faces tough challenges. The procurement system the CAF is currently forced to use means the Forces gets equipment procured 14 to 16 years ago.[3] So, it is fair to assume that the procurement that is done today does not take into consideration the technology of tomorrow. This element is key to consider when looking at what the CAF needs to do in order to be able to meet the Canadian 2030 emission goals. Furthermore, it also means that Canada is purchasing

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[1] Department of National Defense, *Defence energy and environment strategy* (Ottawa: National Defence: 2020), 1.
[2] Tasha Kheiriddin, "Canada Needs the Ability to Defend itself in an Increasingly Uncertain World," *National Post* (March 02, 2022). https://nationalpost.com/opinion/tasha-kheiriddin-canada-needs-the-ability-to-defend-itself-in-an-increasingly-uncertain-world. 1.
[3] LCdr J. I. Findlater, "Department of Ational Defence Equipment Procurement and Capital Axquisition in the 21st Century. A Study of the Defence Procurement Process and New Defence Procurement Strategy: A True Reformation Or Merely Tentative Steps Forward?" CFC JCSP39, 5.

vehicles today that use diesel – which means that in 2036, the CAF will most likely be receiving these orders from today, while the Government of Canada is implementing a ban on the purchase of fuel vehicles by 2035.[4] This dire situation brings us to a fundamental question: Is there a way to reduce harmful emissions with the equipment the CAF possesses today? It would be hard to try to completely eliminate emissions from the current CAF land fleet, as it runs on low sulfur diesel. Although, there might be a way to reduce harmful emissions with the diesel engines currently in use.

This paper will look at the potential use of biodiesel blends by the Canadian Land Forces, and the potential reduction in greenhouse gas (GHG) emissions from its use. Even if biodiesel is not the 100% solution to GHG elimination, it should have enough positive effects to warrant its use by the Canadian Land Forces.

BACKGROUND OF THE DIESEL ENGINE

The diesel engine was invented at the end of the 19th century by Rudolf Diesel. Knowing he wanted to be an engineer since he was 14 years old, Rudolf always had a passion for engines and for efficiency. With a goal of increasing the efficiency of the engines of the time (steam at 6% and gasoline at 12%) he thought he could get up to 75% efficiency with a compression ignition engine. After 8 years working on his project, he was finally able to produce a diesel engine that yielded an efficiency of 26.2%. This incredible breakthrough was even more impressive as he was using 100% peanut oil in order to power his engine. Rudolf died in 1912, where some theories stipulate that he

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[4] Helena Hanson, "New gas-powered cars are set to be banned in Canada & here's everything we know so far," *Narcity*, 3 April 2022.

committed suicide, whereas others speculated that he was assassinated by the petroleum industry, scared that Rudolf had invented an engine that did not run on petroleum.[5]

The engine that was created worked on the principle of pressurising air in order to create heat. At a certain temperature, certain oils burn. Therefore, the whole principle of Rudolf was to create an area that would pressurise air containing a volatile fuel until that fuel explodes. From this simple principle comes the common term used today: Compression Ignition (CI) engine. This is the same principle that is used in every diesel engine today.

According to the Government of Canada, diesel fuel is: "middle distillate fuel composed of hydrocarbons and naturally occurring, petroleum-derived non-hydrocarbons that boils in the range of 130°–400°C and that is intended for use as a fuel in compression-ignition engines."[6] From this definition, any type of oil (the common factor of all oils, is that they are made out of *carbon*) that has a boiling temperature in the right range should be decent for a CI engine.

As the first diesel engine ever produced was powered by a renewable green fuel (peanut oil), there has to be a way to use diesel engines of today in a fashion that does not pollute the human living environment.

This paper will focus on how the Land Force in the CAF could use its current CI engines in a way that emissions are less than they are in their current use, by modifying the source of energy from diesel to biodiesel.

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[5] Diesel Brothers, *Diesel 101: History of the Diesel Engine and Who Invented It,* Diesel Power Gear, 1.
[6] Canadian General Standards Board *Diesel Fuel Containing Low Levels of Biodiesel (B1-B5),* 3.

WHAT IS BIODIESEL

According to the Government of Canada, biodiesel is “a diesel fuel substitute used in diesel engines made from renewable materials such as: plant oil, waste cooking oil, other oils, animal fats or cellulosic feedstock.”[7] The key element here is the wide array of potential sources of biodiesel. Many references about biodiesels only discuss plant oil, where crops are farmed for singular purpose of creating biofuels. For example, biodiesels made from oils extracted out of starch like corn, wheat, soy or grains. From the definition above, many raw materials that can be used to produce biodiesel is a by-product of current industries in Canada. There needs to be a shift in the biodiesel consumer mindset that looks for clean raw material to produce an end product towards using waste from certain industries in order to create a new product.

Staying within diverse types of biodiesel, there has been much research conducted on how to create better and more sustainable methanol. Methanol (methanol and ethanol are common alcohols used in biodiesel production) can be produced from natural gas, waste water, biomass or recycled carbon dioxide. For example, Environmental Science and Pollution Research International has positive results of creating methanol from municipal waste water, using microalgae to capture CO_2 from the air and creating biomass.[8] This biomass is then transformed into methanol. The research also stipulates

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[7] Canada. Natual Resources Canada, *Alternative fuels, Biofuels,* Ottawa, Greener Homes, 15 May 2020, Biodiesel (nrcan.gc.ca), 1.
[8] Maheshwari Neha et al., "Biological Fixation of Carbon Dioxide and Biodiesel Production using Microalgae Isolated from Sewage Waste Water," *Environmental Science and Pollution Research International* 27, no. 22 (2020), 27319-27329. doi: https://www.proquest.com/scholarly-journals/biological-fixation-carbon-dioxide-biodiesel/docview/2259114731/se-2?accountid=9867, 27320.

that the algae produces fatty acids that are less saturated than those from feedstock, where lower amount of saturated fatty acids makes for better fuel.[9]

The United Arab Emirates announced in Sept 2021 the opening of a biodiesel refinery in Dubai. This refinery will be using only waste, as per their announcement, the raw material for their refinery will come from “UCO (Used Cooking Oil), Animal Tallow (slaughterhouse waste products), POME (Palm Oil Mill Effluent Waste) and Acid Oils, such as Grease Tap collection.”[10] It is assessed that the refinery can produce up to 30 000 metric tons annually of biodiesel. The specifications of the fuel produced is not available readily, although, this shows that the technology is available to produce it at an industrial level.

In Canada, many businesses have transitioned to produce renewable biodiesel. In Edmonton, AB, Enerkem produces ethanol and methanol from municipal waste from the city of Edmonton.[11]

Biodiesel is not only the first fuel ever used in CI engines, it is also currently the subject of research in order to make it part of existing systems, like waste recycling systems, instead of requiring a new raw material. As per the Dubai and Edmonton examples, there are already industries that are in the business of recycling waste in order to create fuel. This will be critical when looking at the cost of production in a further section.

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[9] Ibid.
[10] Canadian General Standards Boards, *Diesel fuel*, ICS 75.160.20, 2015, 3.
[11] "Waste to Biofuels and Chemicals Facility," accessed 15 Apr, 2022, 1.

Biodiesel is often used as a blend with fossil fuel diesel. In the written form, the letter B is used followed by the concentration. Thus, B10 corn is a blend of 10% corn biodiesel mixed with 90% fossil fuel diesel.

Characteristics of biodiesel

Biodiesel seams to be *the solution* to the fuel problem of the 21st century, although, many considerations need to be made before it can completely replace fossil fuel diesel. Since the invention of the CI engine, there was a fast transition from biofuel to fossil fuel diesel. CI engines have been engineered to take into consideration the characteristics of low sulfur diesel, which comes from fossil fuels. Fossil fuels are composed of biomass that has decomposed for millions of years under immense pressure within the crust of the Earth. On the other hand, biodiesels are made from fresh biomass that undergoes one of the different oil extraction processes. As both biodiesel and fossil fuels are made of the same main ingredient, biomass, which is composed of carbon, why wouldn't they be interchangeable as a CI engine fuel?

One of the key considerations for Canadian fuel is the lowest temperature at which the fuel can be used. Usually, this is the temperature at which fuel will start to create particles. These particles can clog lines, reduce the efficiency of the engine or fill the fuel filter at an extremely fast rate. At a temperature of -48^{o}C, diesel meets the most stringent regulations in Canada.[12] One of the common tests for the low functioning temperature of a fuel is the *cloud point*, which is the term that will be used in this paper to refer to the low functioning temperature of a fuel.

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[12] Canadian General Standards Boards, *Diesel fuel*, ICS 75.160.20, 2015, 3.

Another critical characteristic of fuel is its water solubility. Low-sulfur (fossil fuel) diesel does not mix with water, as some biodiesel fuels will absorb a certain quantity of water. Water absorption can change characteristics of a fuel, and requires different handling methods. For example, ethanol, methanol and most biodiesels are not suitable for transport through pipelines due to their water absorption characteristics.[13]

Studies have shown that in general, the calorific value of biodiesel is lesser than that of fossil fuel diesel.[14] This simply means that there is a slight reduction in fuel efficiency of engines when using a high concentration of biodiesel in a fuel mix, which has been seen when quantities of more than 20% of biofuel is used.[15] Other studies report that the addition of aluminum oxide nano particles can increase the brake power (increase fuel economy) of biodiesel fuels, to offset the lower calorific values found in biodiesels.[16]

Biodiesels are most of the time solvents, which means that they clean tanks and lines. This cleaning effect creates particles in the fuel and can disrupt the proper functioning of the engine. Furthermore, some physical components of engines might not be designed to resist a solvent, thus, its use can deteriorate some engines faster than if the engine ran on fossil fuel diesel.

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[13] Jennifer Littlejohns et al., "Current State and Future Prospects for Liquid Biofuels in Canada," *Biofuel Research Journal* 5, no. 1 (2018), 759-779. doi:http://dx.doi.org/10.18331/BRJ2018.5.1.4. https://www.proquest.com/scholarly-journals/current-state-future-prospects-liquid-biofuels/docview/2442974142/se-2, 771.

[14] "A Comprehensive Review of the Application Characteristics of Biodiesel Blends in Diesel Engines." *Applied Sciences* 10, no. 22 (2020), 8015. doi:http://dx.doi.org/10.3390/app10228015. https://www.proquest.com/scholarly-journals/comprehensive-review-application-characteristics/docview/2461179633/se-2, 3.

[15] Harish Kumar Patel and Saurabh Kumar, "A Critical Study on Performance of Diesel Engine using Mixture of Diesel and Bio-Diesel as a Working Fuel and Influence of Aluminum Oxide Nanoparticle Additive - A Review," *Research Journal of Engineering and Technology* 8, no. 3 (2017), 295-298. doi:http://dx.doi.org/10.5958/2321-581X.2017.00050.2. https://www.proquest.com/scholarly-journals/critical-study-on-performance-diesel-engine-using/docview/1981611320/se-2?accountid=9867, 296.

[16] Ibid, 297.

An important difference between fossil fuel diesel and biodiesel is that biodiesel is renewable. All production methods for biodiesel are repeatable and are not dependant on finite quantities of resources. There will be an analysis on the required resources for biodiesel and the consequences of their use later in this paper.

Biodiesel also has lower toxic emissions than normal diesel. The only emission that gets higher with biodiesel is the NO_x, where there are mitigation methods to limit those emissions that are toxic to humans. It is important to note that the NO_x emissions are extremely low in all cases.[17]

Because biodiesel is made from oils, it often has a better lubricity than diesel produced from fossil fuels.[18] This characteristic can help to prolong the life of the engines.

Biodiesel also has a reduced impact on the environment for spills.[19] For example, regulations oblige ethanol producers to mix their fuel with 2% of unleaded gasoline to prevent it from being safe to consume by humans. I used a gas example as ethanol is pure alcohol, which is safe for human consumption and would create issues if people would try to consume this type of fuel. With biodiesel, it is less likely that a person would try to take oil from a fuel station as the price of cooking oil is similar per quantity if not cheaper than pure biodiesel (B100).

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[17] YongYuan Ku, JauHuai Lu and Ko Wei Lin, "Impacts of Biodiesel on the Durability of an Advanced After-Treatment Diesel Engine," *SAE International Journal of Fuels and Lubricants* 10, no. 1 (2017), 1-9. https://www.proquest.com/scholarly-journals/impacts-biodiesel-on-durability-advanced-after/docview/2540574176/se-2?accountid=9867.
[18] "A Comprehensive Review of the Application Characteristics of Biodiesel Blends in Diesel Engines," 21.
[19] Littlejohns,"Current State and Future Prospects for Liquid Biofuels in Canada," 772.

The renewability and reduction in toxic emissions are good enough reasons to offset all other comparisons that favour fossil diesel. Industry is therefore working on methods to compensate or eliminate the potential negative characteristics of biodiesel. In the next section, we will see in more details what is required to produce each type of biodiesel and the consequences of the life cycle of the products.

Life Cycle Analysis

The cost of production for biodiesel does not only lie in the amount of dollars invested in order to harvest the resources and produce the fuel. The real cost of production needs to take into consideration the second and third order effects on society. When looking at biodiesel, the Life Cycle Assessment (LCA) of the production needs to be considered. For all methods of productions, there are advantages and drawbacks. The business approach of *opportunity costs* is the best approach to be able to find viable sources of raw material for renewable and sustainable biodiesel production.

Forestry:

In Canada, the forestry sector has the potential to provide a large amount of biodiesel. In 2015, the forestry industry was at around 90 million cubic meters of lumber under the Canadian annual allowable cut regulation.[20] The best way to produce biodiesel would be to harvest this delta in potential exploitation, as the infrastructure for exploitation is already in place. As the lumber biodiesel industry would grow, it would create competition for lumber and create inflation on this good. In this case, a focus on sawmill residues would allow a bi-product of wood production. The current residues in

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[20] Ibid, 762.

Canada are used to provide energy, where about 70% of the residue is transformed already, which leaves a 30% of the residue available for biodiesel.[21] The competition for feedstock in this case is more equitable as both options go towards producing renewable energy. There is potential with this amount, with the 2015 level of wood production to get around 6 000 million L of biodiesel per year with the leftover 30% of residues from sawmills only.[22]

The economic viability, for both client and producer, must be established first. The goal is to stay away from long-term governmental subsidy requirements, as these are indirect costs to the population and prevent the money from being invested elsewhere.

Agriculture:

As discussed earlier, one of the current industrial methods used to produce biodiesel is through the transformation of crops. "Three major types of biomass which could be used as feedstock for biofuel production are field/special crops, agricultural residues, and livestock wastes."[23] Canada already uses 4.2% of its farmland to grow crops to produce biodiesel.[24] This means that this land cannot be used to produce food for humans or animals. Thus, biodiesel production from crops in Canada is in competition with food production. Even if agricultural land is not currently used for agriculture, removing vegetation in order to farm has a negative carbon footprint from the time of the cut and throughout the life-cycle of the land use as crop land compared to the land

[21] Ibid.
[22] Ibid.
[23] Ibid, 763.
[24] Ibid.

staying in its current state. Furthermore, as the Canadian population grows, more farmland will need to be used to produce food for the Canadian population.

When looking at the issue of biodiesel produced from cultivating single use crops, we quickly face an opportunity cost dilemma that could impact our society more than it seems at first glance. Land is either being used by human infrastructure, is cultivated, cannot be cultivated or is bearing of a current ecosystem. Therefore, any change of land-use from its current state to agricultural comes at a cost. Potential agricultural land that is currently not used for agriculture is because it sustains some sort of ecosystem. The destruction of this ecosystem (mostly forests in Canada or Amazonian forests in South America) would have great consequences, as these ecosystems are key for the preservation of the environment that favors human life. That leaves an option to transition the land use from food or animal feedstock production to biodiesel production.[25] Some studies demonstrated that it was not popular amongst farmers to transition from their current crops towards biomass production.[26] A push towards single use crops biodiesel production might create a push for the industry to get subsidies from governments to be able to compete against current agriculture to get access to more agricultural land. This would be detrimental to societies, as it would reduce land use for agriculture and push

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[25] Alexander Popp et al., "The Economic Potential of Bioenergy for Climate Change Mitigation with Special Attention Given to Implications for the Land System," *Environmental Research Letters* 6, no. 3 (2011). doi: https://www.proquest.com/scholarly-journals/economic-potential-bioenergy-climate-change/docview/2551241660/se-2?accountid=9867, 2.
[26] Jeremy R. Porter, Philip B. Mason and Frank M. Howell, "Metropolitan Influence and Land use Competition in Potential Biomass Crop Production: A Spatial Demographic Analysis," *Population Research and Policy Review* 32, no. 2 (2013), 285-310. doi: https://www.proquest.com/scholarly-journals/metropolitan-influence-land-use-competition/docview/1317151606/se-2?accountid=9867, 289.

prices up to stay competitive in land-use and end up creating inflation. Biodiesel made from single use crops is also taxing on water requirements.[27]

This analysis shows the importance of the selection of the right type of industry when looking at doing big purchases in biofuels. There could potentially be many negative impacts to the economy and ecosystems by choosing the wrong source of biofuel. These impacts would negate or be counter-productive when compared with the potential reduction in carbon footprint through the use of biofuel.

Microalgae

A similar production method to agriculture is the use of microalgae – which is the cultivation of microscopic algae strains in cloudy water. The similarity does stop at the point that the raw material used is a plant that is cultivated. There is a myriad of types of microalgae that can be cultivated, then transformed into biodiesel or green crude oil (in this case the “green” crude comes from both the color of the oil and the fact that it is environmentally friendly produced). The basic principle of microalgae is to cultivate a specific trend of algae in a controlled environment. The environment is water-based and needs a substantial quantity of nutrients. The algae then breathes CO_2, uses photosynthesis to convert solar energy and consumes nutrients that are found in the water where they reside.[28] In order to grow efficiently, the concentration of CO_2 needs to be higher than what is present in the air, therefore, this industry is a direct consumer of carbon that has been captured from industries. The best location for microalgae

[27] Popp, "The Economic Potential of Bioenergy for Climate Change Mitigation with Special Attention Given to Implications for the Land System," 8.
[28] Maheshwari Neha, "Biological Fixation of Carbon Dioxide and Biodiesel Production using Microalgae Isolated from Sewage Waste Water", 27320.

cultivation is within a waste water facility (food for the algae), close to industries that use carbon capture, or that produces XCO_2 products (for CO_2) and with access to energy, to allow for 24hr/day photosynthesis (photosynthesis can be helped with LED lights). The result of the growth of the algae is the capture of the carbon from the CO_2, and production of oxygen (O_2).

Amity University Haryana, in India, has conducted a study on height different microalgae and brought back very interesting findings about the potential of microalgae for the future of biofuels. To begin, the fatty acids produced by algae are less saturated than the ones produced by plants cultivated on land. This results in fuel with lower cloud point, which performs better in cold environments.[29] Compared to other biofuels, some microalgae biodiesel has emissions inverted from other biofuels, where CO_2 and CO emissions are higher (mostly at lower engine load) and produces less NO_x and HC emissions than fossil fuel diesel at all engine loads tested.[30] Many other studies show a reduction in all emissions while using fuel from microalgae.[31] While looking at the LCA, it is important to note that all the carbon emitted from microalgae biodiesel is carbon that has been taken from the atmosphere by the microalgae.

Although the process is in its infancy, when looking at the land required for the cultivation of the algae, the current yield is about 250 times those of crops like soybean feedstock.[32] Microalgae is therefore a strong competitor for the future of biodiesel. The

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[29] Marcin Dębowski et al., "A Comparative Analysis of Emissions from a Compression–Ignition Engine Powered by Diesel, Rapeseed Biodiesel, and Biodiesel from *Chlorella Protothecoides* Biomass Cultured Under Different Conditions," *Atmosphere* 12, no. 9 (2021), 1099. doi:http://dx.doi.org/10.3390/atmos12091099. https://www.proquest.com/scholarly-journals/comparative-analysis-emissions-compression/docview/2576378427/se-2, 2.
[30] Ibid, 11.
[31] Ibid, 16.
[32] Littlejohns, "Current State and Future Prospects for Liquid Biofuels in Canada", 770.

major drawback at the moment is that the processes are not energy sustainable, reaching a very low energy return-on-investment (EROI), compared to other biodiesels, which makes it almost an energy negative process.[33] Industrial level production facilities need to be designed and tested to produce fuel with an EROI that would make the process worthwhile.

EMISSIONS

Many studies have been conducted on emissions of biodiesels and renewable fuels that gave very different results. The key points to consider is how research has been done and how the fuel has been developed. For example, some research uses the tank to wheel emission comparisons, where the emissions of the combustion alone are taken into consideration. Some other methods will estimate the production means, and include the carbon footprint of the transformation means of the raw materials to the final product into the calculation of the footprint. Going further, some studies take into consideration the carbon capture of the raw material as well. And some studies will include the land use change in the calculation. When comparing emissions with those of fossil fuels, all emissions from research, drilling and extraction of the fossil fuels need to be included in the data, which is not always the case, in order to compare life cycle emissions.

One of the reasons that explains the reduction in emissions from use of biodiesel is the higher cetane number and higher presence of oxygen in biodiesel, which allows for

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[33] Spyros Foteinis, Antonis Antoniadis-Gavriil and Theocharis Tsoutsos, "Life Cycle Assessment of Algae-to-biodiesel Shallow Pond Production Systems in the Mediterranean: Influence of Species, Pond Type, by(Co)-product Valorisation and Electricity Mix," *Biofuels, Bioproducts & Biorefining* 12, no. 4 (2018), doi: https://www.proquest.com/scholarly-journals/life-cycle-assessment-algae-biodiesel-shallow/docview/2068243282/se-2?accountid=9867, 542.

a more complete combustion in the cylinders.[34] This is even if most biodiesel fuels have a lower calorific value than fossil diesel. Using the Brake Thermal Efficiency (BTE), a study demonstrated, that, while using fish oil diesel blend, B20 is the most efficient fuel.[35,36] This means that using this specific biodiesel, the oxygen and cetane numbers allowed for the most work achieved by the engine when compared to the potential energy contained in the fuel. This will be important, as the addition of a catalyst can actually increase burning efficiency of different types of biodiesels to reach the energy production of fossil fuel diesels.[37] This could also mean that B20 would be a good goal to maximise greenhouse gas reduction in the short term, as this blend seems to have the most complete combustion from this study.

The following table demonstrates the emission trends for different types of biofuels compared to fossil diesels. No numbers are included, due to the diversity of the results from different studies. Following Table 1, we will look at one specific study in figure 1, showing trends that are common to most studies that have been looked at for this research.

Table 1 demonstrates, that, other than from microalgae and some blends of Argemone biodiesel, no other combination gives a reduction of all emissions. When contribution to GHG is measured in tons of CO_2, we can see that most biodiesels do actually have a positive impact by reducing the emissions. Although, in order to be

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[34] "A Comprehensive Review of the Application Characteristics of Biodiesel Blends in Diesel Engines.", 7.
[35] Ibid.
[36] Noor A. Ahmed, "Overview of Biodiesel Combustion in Mitigating the Adverse Impacts of Engine Emissions on the Sustainable Human–Environment Scenario," *Sustainability* 13, no. 10 (2021), 5465. doi:http://dx.doi.org/10.3390/su13105465. https://www.proquest.com/scholarly-journals/overview-biodiesel-combustion-mitigating-adverse/docview/2533036377/se-2, 16.
[37] "A Comprehensive Review of the Application Characteristics of Biodiesel Blends in Diesel Engines.", 17.

conscious of the wellbeing of the population, the military needs to be an example to society and make sure that the solution it pursues fits the most stringent ethical decision making process – ensuring it works towards reducing all emissions.

Raw Materials	Blends	Trends Compared to Conventional Diesel			
		HC	CO	NO_x	PM
Waste cooking-oil biodiesel	D100, B10, B20, B30	↓	↓	↑	↓
Soybean biodiesel	D2, B10, B20, B50, B100	↓	↓	↑	↑
Palm oil	D100, B20, B100, PO20	↓	↓	↑	
Waste fish oil	D, B25, B50, B75, B100	↓	↓	↑	
Mixed inedible feedstocks	B0, KB5MB5, KB10, MB10, KB10MB10, KB20, MB20	↓	↓	↑	
Pongamia biodiesel	D, B20, B40, B60, B80, B100	↓	↓	↑	
Castor biodiesel	D, B20, B40, B60, B80, B100	↓	↓	↑	↑↓
Mustard oil biodiesel	D100, M10, M20, M30	↓		↑	↓
Spirulina microalgae biodiesel	B0, B20, B40, B60, B80, B100	↓	↓	↓	↓
Citrus sinensis biodiesel	D, B5, B10, B20		↓	↑	
Camelina biodiesel	D, B7, B100		↓	↑	
Canola biodiesel	D, B5, B10, B15, B20	↓	↓	↑	↑
Cymbopogon flexuosus biofuel	DF, C10, C20, C30, C40, C100	↓	↓	↑	↓
Microalgae Chlorella protothecoides biodiesel	PD, B20, B50, B100		↓	↓	↓
Licella biofuel	R0, R5, R10, R20		↑	↑	↓
Aphanamixis polystachya oil	Diesel, APME5, APME10	↓	↓		
Jatropha biodiesel	D100, JME5, JME10, JME20, JME30, JME100	↓	↓	↑	↓
Argemone biodiesel	D, AB10, AB20, AB30, AB50	↓	↓	↓↑	↓
New series of non-edible biodiesel	D, MD, WD, MWD	↓	↓	↑	↓

Table 1. Emission characteristics of different fuels with biodiesel. (arrows up mean increase in emissions, down means decrease and both means it depends with concentrations)[38]

For example, a study from the University of Johannesburg in 2006 published a study that compares biodiesels made from *Parinari polyandra* (which is a plant commonly used in Africa to produce oils). The results of this study, on figure 1, shows emission results similar to most studies used in this analysis. This study only takes into consideration tank to wheel emissions, thus do not factor in any of the benefits or trade-

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[38]"A Comprehensive Review of the Application Characteristics of Biodiesel Blends in Diesel Engines.", 16.

offs of the production of the biofuels. From both table 1 and figure 1, the NO_x emission is higher for most biofuels, but can be offset by the addition of nano-aluminum oxide (n-Al_2O_3) while increasing the Brake Power Thermal Efficiency (BPTE) (BPTE is a type of fuel efficiency, the higher the BPTE, the lower the fuel consumption).[39] This additive has been shown to reduce the emissions of NO_x by increasing the burning efficiency of the fuel – and increasing fuel efficiency.

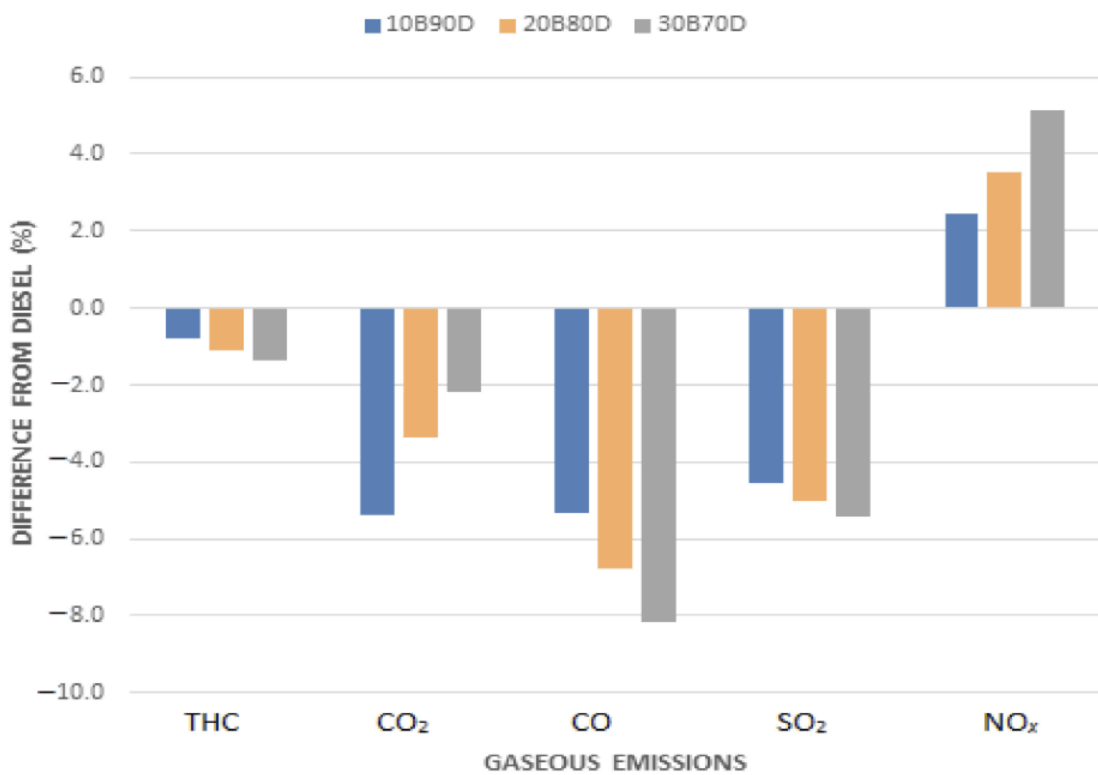

Figure 1: Average exhaust emissions of biodiesel blends compared with diesel.[40](in this graph, 10B90D means 10% biodiesel and 90% diesel)

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[39] Patel "A Critical Study on Performance of Diesel Engine using Mixture of Diesel and Bio-Diesel as a Working Fuel and Influence of Aluminum Oxide Nanoparticle Additive - A Review", 297.
[40] Ahmed, "Overview of Biodiesel Combustion in Mitigating the Adverse Impacts of Engine Emissions on the Sustainable Human–Environment Scenario", 13.

CURRENT USE AND REGULATIONS

As the Canadian military is asked to be able to deploy around the world at short notice, it is important that the equipment used is able to function on resources that are available in the area where the Forces are deployed. For example, the European Union, "where the Renewable Energy Directive (RED) specified a 10% renewable content by 2020 but has been scaled back to the 5-7.5% range."[41] To compare, Canada has a regulation for a 2% renewable content in diesel fuel[42] – excluding the three territories, Newfoundland and land North of the 60th parallel in Québec.[43] There is also an opt-in possibility in Canada for a 5% biofuel under the Canadian Renewable Fuels Regulation, which stipulates the characteristics of the end product to be considered as fuel with a 5% content of renewable diesel.[44]

Looking at the Canadian regulations, the cloud point seems to be the hardest target to meet, as it is the biodiesel characteristic that prevents its use in extreme cold temperatures. The regulations differ for use below and above the 60th parallel because the use of fuel above this line requires it to withstand cold temperatures and to be stored for extended periods of time, as some northern locations are replenished only once a year. As seen earlier, some sources of biofuels with less saturated fatty acids possess characteristics closer to those of fossil fuel diesel, thus, able to perform in cold conditions. Furthermore, there are some additives that allow to change the fuel characteristics, as per the cloud point.

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[41] Lane, Jim. "Biofuels Mandates Around the World :2016" *The Digest*, 3 January, 2016.
[42] *SOR-2010-189-Renewable Fuels Regulations*, 12.
[43] Littlejohns, "Current State and Future Prospects for Liquid Biofuels in Canada", 761.
[44] *SOR-2 010-189-Renewable Fuels Regulations*, 2.

Within the Canadian regulations, when blended at the crude level, 20% of renewable crude per volume is accepted during a distillate compliance period.[45]

It is clear that Canadian regulations accept blended diesel fuels in order to reduce GHG emissions in Canada. Looking at what the European Union is doing is an insight on the type of regulations that the Canadian Forces should be looking at in order to ensure interoperability with European Forces. In this case, if the European Union functions on B10 in the future, Canadian Land Forces need to ensure that the material used when working with European Forces meets the requirements and have been tested with this type of fuel. The current major hurdle to compatibility is that there is no international standards for biofuels.[46]

CANADA LAND FORCES REQUIREMENTS

The requirements of the Canadian Land Forces is for a diesel type of fuel that can be used across all platforms without any modification. The current use of diesel is used to power camp generators, heaters, soft skin vehicles, transport vehicles, light-armored vehicles and tanks. The current contract for fuel provision is done to fit in all those engines, therefore, the future fuels need to be able to power any of these engines as well.

The environment in which the Land Forces conduct operations includes all locations within Canada. Because many operations are on call, reserve of fuels must be maintained at different locations. Even if some of these reserves are a partnership with local populations (to ensure a rotation of fuel, preventing it to be stagnant for too long or passing its shelf-life), the fuels need to be able to sustain cold temperatures and be stored

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[45] Ibid, 15.
[46] *Biofuels: Policies, Standards and Technologies World Energy Council 2010*, 54.

for long periods of time. This can only be done by ensuring that the fuels meet the most stringent requirements in Canada, as per CAN/CGSB-3.520-2020 for B1 to B5[47], and CAN/CGSB-3.522-2011 for biodiesels B6 to B20.[48]

Because the CAF land forces fuel requirements touch all types of diesel engines, with different uses, this study will only consider generic diesel engine data. The agricultural, construction and transport industries have a similar variety of engines and uses as the CAF - and therefore warrant comparable recommendations, as explained in the next section. According to the World Energy Council of 2010, "B20 and lower-level blends generally do not require engine modifications."[49] Because of the various fuel properties of biodiesel blends higher than B20, there is no need at the moment to figure out which engine can and cannot meet higher biodiesel blends.

Biodiesel Usage Tests

In 2002-2003, the Société des Transports de Montréal participated in a study led by the Canadian Renewable Fuels Association to test biodiesel over a period of 12 months. The results showed that considerations must be taken when transitioning from B5 to B20, during the study period. The study showed no issue with functioning in constant temperatures around -30°C – taking into consideration that the buses were held in a garage heated at 15°C at night. This project does not take into consideration any additives that could change the cloud point of the blend used, as the blends were made on site from diesel and B100.[50]

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[47] *Canadian General Standards Board Diesel Fuel Containing Low Levels of Biodiesel (B1-B5).*
[48] *Canadian General Standards Board Diesel Fuel Containing Biodiesel (B6-B20).*
[49] *Biofuels: Policies, Standards and Technologies World Energy Council 2010*, 36.
[50] Littlejohns, "Current State and Future Prospects for Liquid Biofuels in Canada", 772.

The Government of Canada launched a project through the National Renewable Diesel Demonstration Initiative, to study the impacts of biodiesel in Canadian conditions in 2008. One part of this project studied off-road impacts on "construction and forest equipment, generator set and agricultural equipment operations."[51] The result of this study showed that there was no issues with the use of B5. As the goal was to prove that 2% was safe to use in Canada, a 5% confirmation was a very safe result.[52]

A study by the Canadian Royal Military College evaluated biofuel blends from animal tallow, yellow grease and canola oil to see the change in properties over 10 months of temperature change. The results showed that all blends between B2 and B20 were way more stable than B100, and within acceptable parameters of standard in ASTM D6751 (US Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels).[53]

From these three studies, we can conclude that a B5 fuel is safe to use in all engines in Canada. As it has been assessed earlier that B20 is the most effective, it would be safer to test with the engines of the CAF and the conditions at which the CAF operates before using this level, as the buses study mentions consideration when transitioning from B5 to B20.

DISCUSSION

There are many ways to produce biodiesel, which creates fuels with different properties. It has been shown that a concentration of biofuels B5 or below is safe to use

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[51] Ibid, 773.
[52] Ibid.
[53] Ibid.

according to Canadian regulations - and up to B20 for trial periods. It would be an option for the Canadian forces to work with industries towards finding a B20 fuel that would meet regulations and allow the Land Forces to reduce its carbon footprint at the same time. According to tests that have been conducted in Canada, two types of industries that are similar to the Canadian land force have been able to implement a B20 over a long period of use. The cloud point would be the most important factor to look for due to the fact that the CAF leaves most of their vehicles outside at night.

While deciding which type of fuel to use, it is critical that the source is considered, choosing an industry that does not compete with agriculture nor the wood industry, in order to avoid inflation for the Canadian population. This leaves sources of biodiesel that use residues as raw materials or green crude industries as the most viable options. The last factor in the choice of source to consider is a process that is energy positive, thus a fuel that is less energy intensive to produce than the energy produced.

CONCLUSION

The Canadian Army has a very vast diversity of engines that function with diesel. A transition towards a higher proportion of biodiesel than what is mandated by the Government of Canada could be beneficial towards reducing the carbon footprint of the Canadian Forces for the Government of Canada emission goals of 2030. Due to the lengthy and difficult procurement process, the Canadian Forces do not have the potential to change their fleet towards one that would use a different source of energy by 2030. Even if it would be possible to transition a portion of the fleet to an alternate source of energy that has a smaller carbon footprint, the logistical challenges of the implementation will be very hard.

The way ahead offers multiple options, according to different fuel types:

- B5: should be adopted immediately, as there are no potential negative impacts;
- B10: should be strongly considered, considering the cloud point of the fuel from the provider; and;
- B20: should be considered after proof of concept from the provider or from testing within the CAF department of research.

All these fuels should meet the requirements of the Government of Canada for biodiesel under regulations for 1-5% and 6-20%.

All other carbon reduction initiatives for the CAF should still be continued, although, biodiesel or green diesel are options that are achievable in the short-term and can have an impact in the short-term while not requiring capital project investment.

Some interesting projects are being conducted by many businesses in the world, like Rolls Royce, which is developing a Small Nuclear Reactor (a nuclear reactor that works out of nuclear waste) that fits on the back of a transport truck. The potential with these types of innovations for the military are endless.[54]

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[54] Rolls-Royce, "Small Modular Reactors", 2022, doi : https://www.rolls-royce.com/innovation/small-modular-reactors.aspx

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