Assessing the synthesis, performance, and emissions of biogasoline derived from algae

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Claim

Explore the chemical synthesis of a biofuel produced from algae and its comparisons with existing fuel sources

Background

What are algal fuels, and why do they warrant investigation?

Algal fuels are considered 'Third Generation' biofuels, developed to improve the viability of biomass derived fuels at large scale. Third generation fuels are derived from aquatic biomass, and therefore do not compete with traditional land based agriculture. Another advantage is reduced waste products due to lack of cellulose and fibrous materials. These fuels require more water than their predecessors, but can grow in high salinity environments, like the ocean. (Journal of Biotechnology and Bioengineering Research, 2024)

What fuels are created by algae

While third generation fuel sources can processed into ethanol, similarly to maize or sugar cane, their high oil and lipid content allows them to be refined into previously impractical fuel options. Biogasoline is one of these, and is touted as a 'drop in replacement' for unleaded gasoline.

Research question

How does the synthesis of gasoline and biogasoline differ, and does biogasoline possess combustion and emission properties on par, or better than traditional gasoline so that it could one day be a dominant fuel source for passenger vehicles.

Production and refinery

Production of gasoline from crude oil

Our current crude oil reserves are the result of organic matter pyrolysing underground over "millions of years" (Energy Education, n.d.-a).
Pyrolysis is the process of breaking down longer "heavy" hydrocarbon chains into smaller, "lighter" products in the absence of free oxygen molecules. In this case, the long molecules that make up the organic matter are broken down into more simple chains. Molecules not present in the shorter chains, such as oxygen, nitrogen, and hydrogen, form by-products such as H_2O (water), NH_3 (ammonia), CO (carbon monoxide) and CO_2 (carbon dioxide) (Australian Institute of Petroleum, n.d.).
Oil is pumped from "wells", stored in, and sold by the barrel. While the product collected is heterogeneous, and contains a huge variety of unusable hydrocarbons, further pyrolysis under controlled conditions and in the presence of a catalyst permits controlled reformation of the crude product into useful and refined fuels. These products can then be separated through fractional distillation (Energy Education, n.d.-a).

Production biogasoline of bio oil

How is algae produced

While natural cultivation of algal fuels has been investigated most due to its low capital cost, artificial cultivation is more viable for fuel production on industrial scale. Environmental conditions are controlled using closed loop systems and key consumables, notably CO_2, water, and nutrients, are dispersed throughout the system as required. The system itself can take the form of either 'raceways' or tubes; however, both fundamentally do the same thing—circulate algae from storage into a light-rich environment so that photosynthesis occurs, then back into storage. Photosynthesis allows the algae to 'capture' the carbon from the CO_2 bubbled into the system, or from the open air, while simultaneously releasing the oxygen attached to the carbon (Adeniyi et al., 2018).

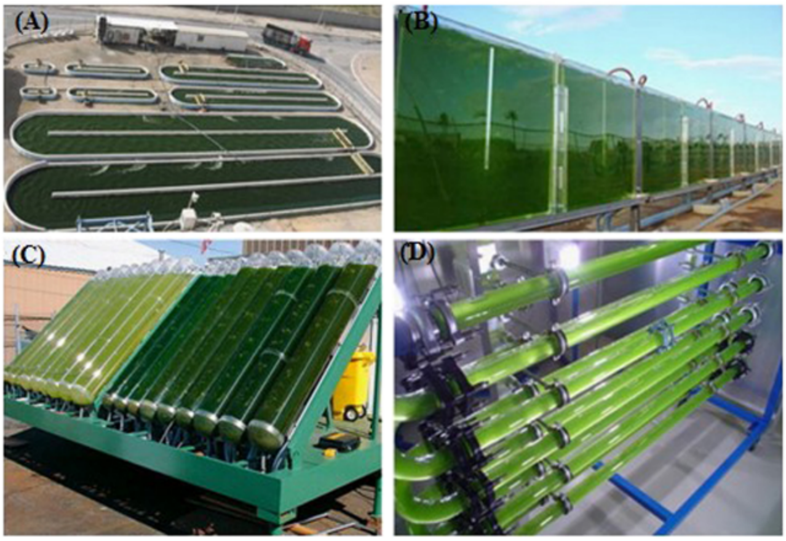

Figure 1: Raceways and closed loop systems (Adeniyi et al., 2018)

As the algae grows and reproduces, carbon will accumulate in the system in the form of glucose, and within the oils that algae produce to store energy long term. The oils produced by certain species of algae contain high content of lipids; a portion of which are fatty acids. Fatty acids are long hydrocarbon chains with a carboxyl group at one end. Harvested biomass is processed, and oils are extracted. The dried biomass then undergoes pyrolysis, which converts any remaining compounds into bio-oil, and similar by-products to crude oil (U.S. Department of Agriculture, n.d.).

Algae to biofuel synthesis
Processing of algal/bio-oils is less efficient than crude oils. Since the main source of hydrocarbon chains is fatty acids, the carboxyl group adds a significant amount of oxygen to the reaction mixture. While pyrolysis of crude oil is often aided by a catalyst, effective pyrolysis of bio oils requires one.

Biogasoline production by co-cracking of model compound mixture of bio-oil and ethanol over HSZM-5 (2014) by Wang et al. investigated the effect of temperature, pressure, additives, and presence of a catalyst on the yield of high-grade hydrocarbon fuels. It was found that the addition of ethanol to the cracking mixture improved yields significantly. Ethanol improves the H/C_{eff} (Hydrogen to carbon effective ratio) of reactants, which was previously found to improve cracking performance. Furthermore, the oxygen present in the hydroxyl group (OH) is likely to join with excess carbon to form CO_x compounds and H_2O, as opposed to forming CH_3COOH (acetic acid) or other by-products/coking agents. Ethanol

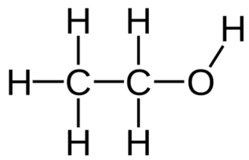

Figure 2: Ethanol Structure

At 400°C, $2MPa$, 99% and 91.5% of the product was hydrocarbons and aromatic hydrocarbons by weight respectively. While coking did occur, use of the catalyst HSZM-5 improved yields, and was stable enough for coke removal to be achieved through combustion, allowing for reuse of catalyst. The high hydrocarbon content of the final product is commendable; however, this does not equate to a high yield. While the overall selectivity, or ratio of oil weight to final usable product weight, was 31.5%, this is lower than crude oil's 43.3% when it is cracked to form components of similar high-quality fuel at lab scale (Akah et al., 2025).

Performance

Exhaust gas temperature and power

When complete combustion occurs, all hydrocarbon bonds are broken, and reformed into CO_2 and H_2O. This results in the maximum amount of energy being released. The conversion of liquid fuels into gasses, and the rapid release of energy as heat result in increased cylinder pressure, and therefore more 'power' being generated by the engine.

While the output of an engine can be measured using a dynamo, this gives in incomplete picture of how much combustion is actually occurring. Therefore exhaust gas temperature (EGT) is also measured. A higher exhaust gas temperature generally means that a larger portion of combustion is occurring with optimal stoichiometric ratios. When fuels have similar energy content, exhaust gas temperature can be directly compared to determine which fuel has more desirable combustion characteristics.
(Ge et al., 2022)

Metrics
Ge et al. (2022) compared the performance of a cooking oil derived bio gasoline synthesised using similar cracking techniques. Studies on the combustion characteristics on algal derived fuels are sparse, but the bio oil the fuels are derived from both contain similar fatty acids, and once pyrolysed, their products are nearly identical in terms of hydrocarbon make up.

It was found that as biogasoline proportion of the fuel increased, both power, and EGT increased in a loosely quadratic manner. At lower concentrations, such as 10%, biogasoline exceeds the performance of regular gasoline alone, and demonstrates higher power, and EGT. This indicates that this blend combusts more completely, and offers superior performance to gasoline alone.

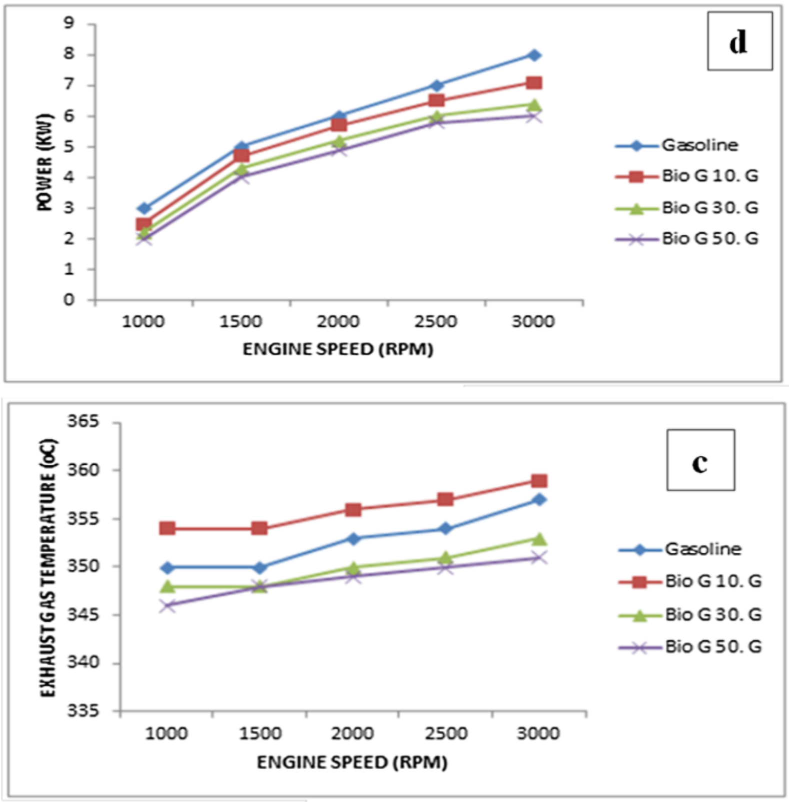

Figure 3: Performance metrics over engine speed

Table 2
Properties of BioG vs fossil gasoline and UCO.

Property	Unit	Method	Fossil Gasoline	UCO	BioG
Calorific value	Cal/g	ASTM D 240	10,604 to 11,297	8561	10,000
Fire point	°C	ASTM D 92	−53	345	<30
Flash point	°C	ASTM D 92	−43	305	<30
Pour point	°C	IS: 1448 Part 10	−40 to −60	9	<-10
Cloud point	°C	IS: 1448 Part 10	NA	24	< −10
Specific gravity@25 °C	–	ASTM D 1298	0.72 to 0.78	0.96	0.75
Viscosity @40 °C	Cst	ASTM D 445	0.5 to 0.6	45.35	1.2

Figure 4: Properties of Biogasoline and Fossil Gasoline

However, once the biogasoline concentration was increased to 30%, and beyond, decreases in power and EGT are apparent. The difference between the power generated by Bio G10. G and Bio G50. G was 2 kW, roughly 19% of the engines total rated capacity. Considering such a loss in performance, it must be questioned whether biogasoline is truly a 1:1 replacement as many sources suggest.

The caloric value of biogasoline was found to be only $94 - 89\%$ of unleaded gasoline (Ge et al., 2022), which somewhat accounts for the lower performance, however this is clearly not the only factor at play; As mentioned before, the 10% blend performed better than gasoline alone.

Tailpipe Emissions

A closely related topic is the fuel's burning emissions. As mentioned previously, combustion characteristics differ between fuels. The amount of fuel being burnt daily is tremendous; Transitioning to a fuel with higher emissions will multiply even the smallest difference many times. Further considering the lower energy content of biogasoline, more fuel will be required to release the same amount of energy, therefore higher greenhouse gas (GHG) or nitric oxide (NO_x) emissions per gram will further contribute to the issue.

It should be mentioned that while the carbon released from combustion of biogasoline is derived from the atmosphere and therefore "net zero". Tailpipe emissions of CO_2 aren't necessarily a concern, however, CO and NO_x emissions require investigation, as both have much higher potential to harm people. NO_x emissions in particular are exceedingly concerning, as they can form nitric acid rain, and are not reabsorbed during algae production.

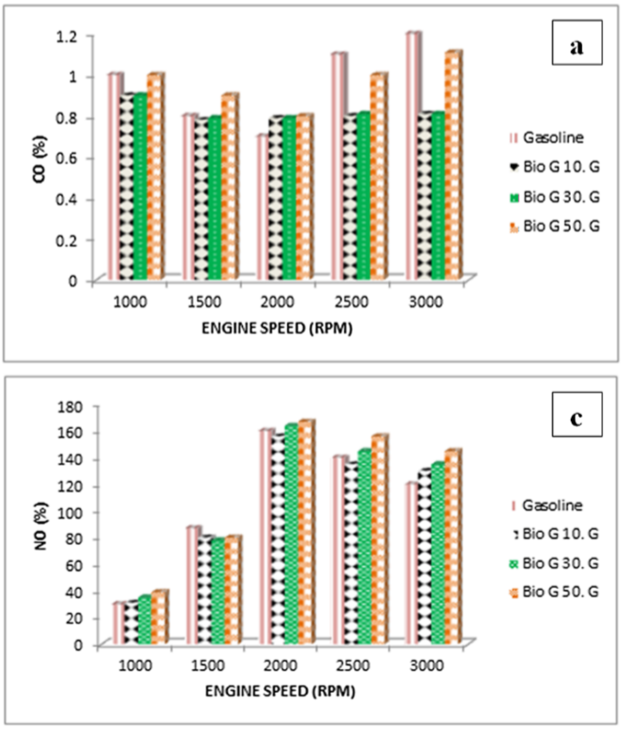

Figure 5: Emissions over engine speed (Ge et al., 2022)

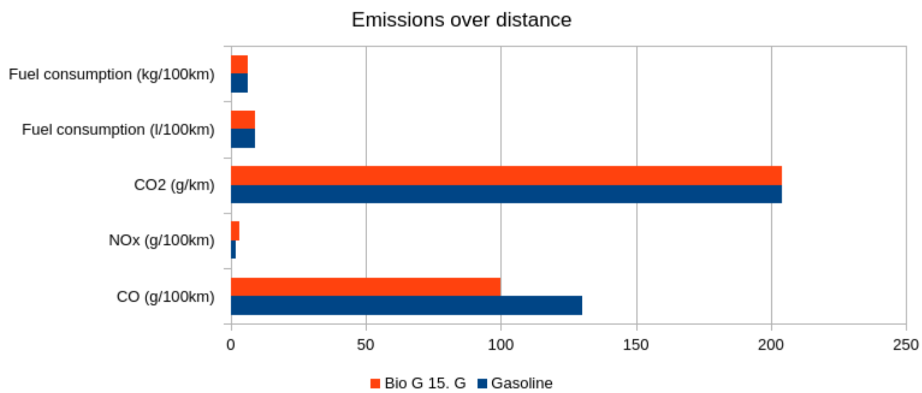

Figure 6: Emissions over distance (Aakko-Saksa et al., 2011)

Considering the previously cited study by Ge et al. (2022), and Aakko-Saksa et al. (2011), a clear trend can be observed. At low biogasoline concentrations by weight, NO_x emissions are decreased, however once concentrations increase past $\approx 10\%$, NO_x emissions increase to match, or exceed under high load as shown in Figure 6, the emissions of gasoline. It appears that large quantities of biogasoline as a fuel additive marginally increases NO_x emissions, much like other 'green' fuels such as ' E10 '(NSW Government, nd).

Discussion

The synthesis of biogasoline is incredibly similar to that of gasoline. It can easily be inferred that with enough feedstock, biogasoline could be produced on scale with similar yields. While algal feedstock production is currently low, it's unique ability to be grown in aquatic environments allows opens up opportunities for large scale production; Not to mention the fact that it is a renewable resource, unlike conventional fossil fuels. It appears that low concentrations of biogasoline produce more power than gasoline alone, attempting to run an engine on exclusive biogasoline may yield significant penalties and losses. While biogasoline does possess a lower caloric energy content, the difference is relatively small ($\approx$ 10%). In the future, it is possible that vehicles could be designed to be adapt to the combustion properties of biogasoline, much like they were for ethanol blends.
Increased NO_x emissions are somewhat concerning, with a 15% blend demonstrating a 28.1% increase (Figure 6), however these were still below the Euro 5 limit. While significant GHG's are produced during synthesis, these and tailpipe emissions of CO_2, and CO to some extent, are considered to be nullified by the fact that the carbon released was absorbed from the atmosphere, and therefore there is no real net increase in carbon abundance in the atmosphere.

Overall viability

Limitations

Lab Scale
The synthesis methods investigated were preformed on lab scale, and therefore do not fully represent the yields of industrial production.
Fuels derived from alternative feed stock investigated
As previously mentioned, the emissions figures provided by Ge et al. were based on fuel derived from used cooking oil. While the gasoline is very similar, the hydrocarbon's present are in different concentrations. The figures present likely do not accurate represent algal bio fuels, but the fuel general characteristics were considered similar enough, and multiple studies were considered when emissions were compared.

Extensions

100% biogasoline
Studies that studies the characteristics of engines running on biogasoline alone were sparse, and often not accessible. This is concerning, as many consider biogasoline to be a 1:1 replacement for gasoline solely based on the presence of similar hydrocarbons. Investigation of the performance of pure biogasoline could reveal potential issues with it as a fuel source in the future.
Comparison to other 'green' fuels
Ethanol fuels and fuel blends have been a topic of discussion for a significant period of time. Alternative processes allow algal biomass to be fermented due to its high glucose content. Further investigation of such synthesis processes could consider whether the advantages of algae as a feedstock could make it viable as a replacement for traditional stocks, like cane or sugar beet.
Flexibility
While not explicitly mentioned, algae speces can be grown in a variety of climates.

Conclusion

Overall, biogasoline shows promise to be a competitive renewable fuel in future. It's production process is unique and offers many advantages to both biofuels

While its combustion properties differ from conventional gasoline, they are not necessarily worse. Biogasoline does have a lower energy content per gram ($\approx$ 10%), but passenger vesicles will likely not be hindered in their ability to operate based on this factor alone.

Emissions data presents a mixed picture, but it seems that high concentration fuels may increase NO_x emissions. Further investigation is required to determine the impact and potential mitigation techniques.

With investment and adoption, biogasoline possesses desirable properties and is a viable long term replacement for gasoline.

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