Hydrogen as a fuel source in the armed forces

A potential future use of hydrogen as a fuel source in military application

by Filip Tagesson

Resumé

Försvarsmakter världen över står inför ett vägskäl. De fossila bränslen som används idag, både civilt och militärt, kommer inom en inte alltför avlägsen framtid bli svårare att hitta och deras tillgänglighet förändras. I och med denna förändring kommer möjligheterna att nyttja etablerade drivmedelskedjor för militära operationer att försvinna. Militärmakter kan således välja om de själva vill upprätthålla drivmedelsproduktion och distribution för sina egna syften, eller, följa med på resan mot hållbara och i flera avseenden operationellt fördelaktiga alternativ. Ett av dessa möjliga framtida bränslen är vätgas som, i och med dess i sammanhanget enkla tillverkningsmetod, och mycket långa hållbarhet, är ett alternativ att beakta när fossila alternativ inte längre är livskraftiga.

SUSTAINABILITY, GREEN FOOTPRINT, carbon offsetting, circular economy, cradle to grave, and well to wheel. The sustainability movement is traveling across the world fast, punching a hole through any entity that won't accept responsibility and adapt to hundreds of new legislative requirements and policy changes in a world heading towards unprecedented environmental change. That is the case for individuals, companies, cities, countries, and whole continents. From legislative actions banning the use of plastic bags[1] to legally binding international treaties on climate change like the Paris agreement[2], action is being taken across the world to improve the living conditions for all and mitigate the effect of global warming and high levels of pollution.

In addition, the world is moving towards an increased scarcity of gas, oil, and coalThis scarcity will also drive the change, as those who don't adapt fast will be forced to pay premiums for the remaining fossil fuels and ultimately perish in the wake of the future.

This moves our focus to the situation in most armed forces in the world today. Armies, navies, and air forces are dependent on a multitude of enriched fossil fuels, ranging from Marine Diesel Oil to different Aviation Turbine Fuels. All of these fuels are essential to the success of operations on all parts of the playing field, and a major disturbance in supply or logistics would be detrimental to any campaign. Disrupting fuel availability and securing it for oneself has always been a strategy in warfare, as the Anglo-Soviet invasion of Iran in 1941 to secure access to oil, and the Wehrmacht's drive towards Baku and the oilfields of the Caucasus in 1942. Moving forward, oil scarcity will increase[3] and fuel oil will be a High-Value Target in any conflict in the future, especially when civilian use of oil becomes limited as the main energy source for private vehicles will move away from today's fuel types. Also, nations that do not produce their own fuel oil will be especially vulnerable in regards to fuel logistics when the fuel networks of today are removed and exchanged for other systems. Judging by the pace and direction of today, the civilian petroleum-based fuel stations will largely be a thing of the past, making refueling there impossible for armies.[4]

Many militaries also face political resistance and their public opinion has decreased over the last several years, with a small recent break in the trend[5], and are seen as uncaring and uninterested in their environmental impact. To some, the armed forces use of large vehicles is seen as an unnecessary environmental burden. Ships, planes, tanks, and other vehicles are spewing massive amounts of harmful emissions for "no just cause". To those adept within the armed force sphere of influence, these emissions are a necessary evil justified by their greater cause of upholding stability and security in a dangerous world. Yet others look past the emissions in favor of the job opportunities the armed forces and their entailed subcontractors provide.

Arms companies, who often get clumped with the military in the eye of the public as they exist within the same sphere, have increased profits over the last years[6] They are often seen as exploiters of war and suffering, with the perception that their funding often comes from countries that don't put human rights first. Unfortunately, in the eyes of the public, arms companies and armed forces are often clumped together where the negative view on arms companies spill over onto the armed forces.

All these factors obstruct the modern militaries in a world where citizens demand sustainability from all big actors. It won't be long until people start demanding sustainability from the militaries around the world, as other parts of society step up one after the other. Countries are beginning to take action and some are demanding 100 per cent fossil free propulsion as early as 2045.[7]

Taking steps towards fossil free fuel use early on could be beneficial in the eye of the public and pioneering the field would show that the armed forces are moving with time and not fighting against it. The changes in fuel consumption will be unavoidable in the future as fuels will need to be changed from fossil-based sources as these become more scarce and increasingly more expensive. Taking steps early also allows more time to implement deliberate future-proof solutions, as well as avoiding high implementation costs once time has already run out. One of these steps is to look at alternative sustainable fuel sources, such as hydrogen.

Hydrogen combustion

The combustion of hydrogen gas is quite simple in principle, as seen in the reaction below:

$$2H_2 + O_2 \rightarrow 2H2O$$

Hydrogen gas, H_2, is burned in the presence of oxygen, O_2, and the only product of this reaction is water, meaning that no harmful emissions are created. While this is true in principle, an effect of combustion is creation of heat, and heat causes nitrogen in the air to react with oxygen forming nitrogen oxides[8], NOx, according to:

$$\{H_2 + O_2 + N_2 \text{ -> } H_2O + NO_X\}$$

NOx has harmful effects on human health and can be harmful to crops and ecosystems- The largest difference between carbon-based fuels, such as diesel, and hydrogen in terms of emissions is carbon dioxide, CO_2, carbon monoxide, CO, and in some cases sulphur, SThe reaction can be simplified[9] as[10]:

$$C_XH_y + O_2 + N_2 \rightarrow CO_2 + H_2O + NO_X$$

Hydrocarbons, C_XH_y are combusted in air, O_2, N_2, creating CO_2, H_2O and NO_X, as well as soot[11] and unburned hydrocarbons.[12]

The NO_x formed during the hydrogen combustion can be limited by for example utilizing Homogeneous Charge Compression Ignition.[13] In Homogeneous Charge Compression Ignition combustion the injected hydrogen is very well mixed and the combustion is initiated by compression like in a common diesel engine[14] and results in far less NO_x produced than other combustion strategies.

Hydrogen production

The challenges of trying to implement hydrogen as the main fuel in any armed force are several, where the initial issue is production. Hydrogen gas is produced by electrolysis, a process where a current is passed through water, and hydrogen gas and oxygen is formed. The overall reaction is as follows:

$$2H_2O \rightarrow 2H_2 + O_2$$

The reaction is simple and the only thing required is electricity. The energy required can come from several different sources, the most beneficial would be non-fossil and sustainable. This is easily acquired at locations where the power can be produced and where demand for electricity is low, for example at night at hydropower plants. The production of hydrogen is not problem free and the gas produced must be pressurized to high pressures for efficient storage and transportation.

However the main issue wouldn't be the production of the fuel. A larger problem is the system changes that need to happen. All engines and refueling vehicles are made to be used with liquid fuels at atmospheric pressure. The new system must instead be designed for a highly flammable gas under tremendous pressure and must be built into the system from the start. Most engines cannot be retrofitted to accept hydrogen as hydrogen combustion engines must be purpose-built.

Operational implications

Today the availability of carbon-based fuels such as diesel is near abundant. Militaries around the world have large storage facilities filled with fuels ready to use when demand increases and availability decreases. However these locations are very vulnerable and the transportation of the fuel is just as delicate. A successful operation to neutralize an enemy refueling station or fuel transport would hinder the strategic availability of certain vehicle and weapon types, on the ground, in the air, and at sea. These storages will be the central in fuel transport which will sometimes be long logistics chains of transports and deliveries, putting them at risk. It is also important that a replacement fuel for petroleum fuels keeps for long periods of time in storage. Alternative green fuels such as bio-diesel can go bad within six months as algae will grow in it, and certain types of diesels go bad as the fuel composition changes over time.

Hydrogen on the other hand has the advantage that it keeps for several years with minimal changes and leakages.[15]

Large-scale implementation of hydrogen-based fuel would have other positive effects. In large-scale operations, the knowledge of vehicle types and numbers in specific areas is intelligence that can shift outcomes greatly. This knowledge can come from many different sources, but one source is satellite and ground-based emissions analysis. This technology can, from a large distance, measure the emissions of an area using sensors and thus determine locations and composition of emissionsThis can further be analyzed and compiled into estimates of the number and location of vehicles. This ties into the hydrogen case as hydrogen combustion produces emissions on a far lower level than fossil fuel combustion. If the combustion is clean enough the presence of the emissions in the atmosphere can be lower than detectable levels and thus conceal large operations.

The effect of changing to hydrogen will also affect the way fuel is acquired. Electrolysis of hydrogen needs large amounts of electricity, which can come from several sources, such as hydropower, wind turbines, power plants, and more. The need for electricity is an issue as the fuel production is tied to locations that are noticeable and easy to sabotage which would affect civilian life as well. The spread-out nature of these sources of power is however an advantage as no direct route to a large supply of fuel is ever established as happens with today's fuel transports.

Hurdles

With a universal change from today's petroleum-based fuels to hydrogen-based fuel systems, several hurdles must first be overcome or accepted. The initial hurdle is the need for energy for hydrogen electrolysis. To produce 1 kg of hydrogen 39 kWh is requiredAn optimum solution to this would be a mobile energy source that could be used anywhere, such as small modular nuclear reactorsWith such a solution refueling could happen anywhere and no long haul of fuel would be necessary. This would however create new high-value units necessary for the success of any operation.

Another issue that must be overcome is the fact that all engines must be modified or changed to engines that can run on hydrogen as today's engines aren't equipped for hydrogen combustion. Due to the large number of fossil drivelines that would need to be changed that cost will be large as well. But this might not be the largest issue. Due to new regulations vehicles must abide by emissions standards and new production will very soon require specific exhaust emission control units such as three way catalysts, selective catalytic reactors and even particle filters. When this step needs to be taken the possibility of taking a step in a different direction might be appropriate. Driving this change and approaching a sustainable mindset could also attract new groups of people that have opposed the military establishment historically. New individuals could be attracted to the military and bring with them different outlooks than those established within the armed forces and this increased polarity of beliefs might drive change in a positive way.

Hydrogen is also extremely flammable and in certain conditions quite explosive, so safety concerns must be addressed. This is one of the reasons why hydrogen as a fuel source hasn't been adapted by society as people are uncertain about sitting on explosive gases. Although much research is being conducted within the area, as of now it seems as if electric vehicles will be a dominant player in the future.

A comparison between pure electric drivelines and hydrogen fuel based drivelines has to be made. A clear advantage for the military to go with hydrogen instead of electric is the recharge times and the ability to store the fuel. Recharge time for batteries is quite slow and electricity in its pure form cannot be stored. Hydrogen however can be stored and refueled quite quickly. This issue is however negated if the possibility to quickly exchange batteries on vehicle systems exists, but the issue of storing charged batteries remains as batteries tend to go bad or lose charge over time. Batteries are superior in the sense that their conversion efficiency is far superior compared to that of the hydrogen process described earlier.

Another issue is the energy density of hydrogen compared to diesel. Energy content can be measured either in MJ/kg (energy per weight) or MJ/L (energy per volume). Hydrogen at 119.93 MJ/kg and 4.5 MJ/L (at 69 MPa) has higher specific energy than diesel (45.6 MJ/kg) but a much lower energy density (38.6 MJ/L) which means that the storage volume of hydrogen of the same energy amount will be substantially higher than a diesel tank but it will be lighter.[16]

Conclusions

All combined the use of hydrogen as fuel source would be a step forward for armed forces in regards to sustainability transition, public opinion, future-proofing, and self-sufficiency. All of which are important aspects for a military that needs to be able to sustain operability in the future.

As hydrogen storage and production can be de-centralized, it opens for the possibility of disconnecting fuel transports from the public and other installations. This would be very beneficial as fewer high-value units are in circulation.

Also, hydrogen's smaller emission signature would benefit large operations as emissions tracking would become more difficult. Hydrogen could also be used in fuel cells to generate electricity at remote locations where large and loud generators are used today.

The main drawbacks are substantial and cannot be ignored.

First, the production of hydrogen requires large amounts of energy, and that energy must come from somewhere.

Second, all drivelines must be changed from the ones used today. This imposes a very large cost as all engines and fuel systems must be changed to allow for the new fuel. However, holding on to the old systems will become increasingly more expensive as more and more emission reduction needs to be applied to fossil fuel burning engines to cope with new legislation.

Third, as the energy content of hydrogen is different from fossil fuels, the implications of possible decrease in range must be addressed or accepted.

All of the above-mentioned points are possible to solve or mitigate, and the potential winnings from transitioning to hydrogen will likely outweigh the drawbacks. Each step in the transition would need special consideration and new tactics must be created around the new technology. As today's militaries move into a future where fossil fuels become more scarce and the green movement keeps gaining momentum, early steps towards sustainability could benefit their long term strategic and tactical development.

The time for action is now. Militaries can choose to pioneer sustainability in the military field, drive the transition as a frontrunner and shape the green development to fit their needs.

The alternative would mean letting change be forced upon them. Waiting until there are no more choices, being forced to adapt systems and technology unable to meet their needs. The cost of catching up later will be indisputable, both monetarily, technologically, publicly and legislatively.

Taking early steps towards new future-proof fuel systems will not only save money in the long run, it will allow for specific customization and adaptation of technology, tailored to the military's unique conditions and demands. Let us start exploring what sustainability could mean in a military context. Let us stop pretending we can stand idly by, doing nothing, as the world outruns us. Let us instead take the first steps towards sustainability by exploring the possibilities of alternative fuel sources.

The author is second lieutenant and naval engineer.

Noter

1. Grönberg, Anna: ”Förbud mot plastkassar i flera länder”, *SVT*, 2016-07-11, *https://www.svt.se/nyheter/utrikes/plastforbud*, (2021-09-14).
2. *The paris agreement*, United Nations Framework Convention on Climate Change, 2020, *https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement*, (2021-09-21).
3. Ibid.
4. Petroleum fuel for long haul application will still be available as these vehicle types are difficult to replace at the moment but refueling stations will be fewer and further apart compared to now.
5. Mecklin, John (ed.): “At doom’s doorstep: It is 100 seconds to midnight. 2022 Doomsday Clock Statement”, *Bulletin of the Atomic Scientists*, Science and Security Board, 2021, *https://thebulletin.org/doomsday-clock/current-time/*, (2021-09-29); Berndtsson, Joakim; Bjereld, Ulf and Ydén, Karl: ”Svensk försvarspolitik i ny terräng” in Andersson, Ulrika; Carlander, Anders and Öhberg, Patrik (eds.): *Regntunga skyar*, Göteborgs universitet, SOM-institutet, 2020, pp. 337-351.
6. *Annual report 2020 BAE Systems plc*, BAE Systems, *https://investors.baesystems.com/~/media/Files/B/Bae-Systems-Investor-Relations-V3/PDFs/results-and-reports/results/2021/bae-ar-complete-2020.pd*; *Annual and sustainability report 2020*, SAAB AB, *https://www.saab.com/globalassets/cision/documents/2021/20210304-saab-publishes-its-annual-and-sustainability-report-2020-en-0-3908922.pdf*.
7. *Färdplan för fossilfri konkurrenskraft – fordonsindustrin – tunga fordon*, Fossilfritt Sverige, 2020, pp. 8.
8. *Vehicle NOx emissions: The basics*, The International Council on Clean Transportation, 2021-07-19, *https://theicct.org/stack/vehicle-nox-emissions-the-basics*, (2021-10-05).
9. The carbon fuel combustion reaction is greatly simplified as it goes through a very large number of reactions before the final products form.
10. Op. cit., Heywood, John, see note 11.
11. Soot is a product of fuel burned in a rich environment (more fuel than required) and not mixing with lean (more air than required) areas before combustion temperature decreases.
12. Unburned hydrocarbons are parts of the fuel that has not been fully converted into the reaction product and are thus still rich in energy. It must be noted that small amounts of these emissions are produced during hydrogen combustion but then as the lubricating oil from the cylinder walls and crankcase ventilation, but their level is negligible when comparing carbon fuel to hydrogen-based fuel; Op. cit., Heywood, John, see note 11.
13. Gomes Antunes, J. M.; Mikalsen, Rikard and Roskilly, Tony: “An investigation of hydrogen-fuelled hcci engine performance and operation”, *International Journal of Hydrogen Energy*, vol. 33, no. 20, 2008, pp. 5823-5828.
14. Op. cit., Heywood, John, see note 11.
15. Panfilov, Mikhail: “Underground and pipeline hydrogen storage”, *Compendium of Hydrogen Energy*, 2015, pp. 92-116.
16. Not including pressure vessels to contain the high pressure gas which will increase the weight substantially. Op. cit., Heywood, John, see note 11.