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European Military Fuel Readiness

The Role of Alternative Fuels in Military Logistics

Irina Patrahau, Ron Stoop and Thomas Jansen

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Authors:

Irina Patrahau, Ron Stoop and Thomas Jansen

Contributors:

Michel Rademaker and Bjorn de Heer

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Executive Summary

Fuels are the lifeblood of military operations. The resilience of fuel supply chains often determines who can move faster and more efficiently, fight longer and, ultimately, win the battle. Due to the renewed security risks on NATO's Eastern Flank, there is a push to revitalise European fuel supply chains as essential ingredients for operational readiness.

At the same time, European militaries must adapt to new energy realities. Military fuel readiness is heavily reliant on civilian fuel supply chains. Fossil fuels are set to be slowly phased out, while alternative sustainable fuels – advanced and sustainable biofuels as well as synthetic fuels – are introduced. Military fuels are sourced through civilian channels. The storage and distribution of military fuels are managed through the NATO Pipeline System (NPS), but this is also interdependent the civilian sector. In peacetime, the NPS primarily serves non-military users, which allows it to maintain operations and generate income.

It is essential to understand early on how the energy transition can be leveraged to enhance military effectiveness, considering the need for European Allies to revitalise fuel readiness while civilian decarbonization is reshaping the conditions of military operations. This report analyses challenges and opportunities of adopting alternative sustainable fuels across the air, land and maritime domains as of 2025. Based on the analysis, five key conclusions emerge:

- 1. The most important feature of a military fuel is its alignment with military performance requirements.** Military fuels are judged based on availability, flexibility, logistical simplicity and battlefield performance, with upfront fuel cost taking a secondary role. Most European militaries use the NATO Single Fuel Policy, a framework that aims to harmonise fuel usage policies for all NATO Allies, focused on F-35 jet fuel, also known as JP-8 in the United States.
- 2. Changes in civilian fossil fuel availability and logistics infrastructure call for a reassessment of military fuel readiness.** As the civilian market moves away from fossil fuels, the available supply as well as adequate infrastructure to handle and move these fuels through Europe will likely deteriorate. This brings risks for military fuel readiness. At the same time, the growing domestic alternative sustainable fuels market can strengthen the resilience of military supply chains and therefore mitigate some of these risks.
- 3. The gradual adoption of domestically produced drop-in fuels can reduce dependence on oil imports, thereby enhancing supply chain resilience.** The most likely candidates for swift adoption are drop-in fuels that can be blended with fossil fuels, notable synthetic fuels and advanced biofuels. They meet performance needs, diversify supply, and fit existing military systems and fuel infrastructures without any changes.
- 4. While it is in both the civilian and military sectors' interest to increase adoption of drop-in fuels, the scale of this industry has not yet kicked-in.** The growing maturity of synthetic and bio-based alternative fuels markets could offer medium-and long-term term opportunities for the military, provided that sufficient investments are made for scaling.
- 5. Other alternative fuels such as synthetic and bio-based methanol and ammonia are not fit for military use.** Their low density, the associated requirements for new military hardware and heavy investment in new fuel infrastructure and logistics, and high toxicity and flammability make it unattractive for military consumption.

1. Introduction

For the first time in decades a full-scale war erupted on the European continent, which prompted European governments and NATO to invest in necessary capabilities to boost deterrence and operational readiness. A long period of European military demobilisation following the Cold War fostered a reluctance to consider the practical prerequisites of military readiness. The European Union (EU) released its first Defence Industrial Strategy in 2024 to support its military industrial capacity development. In parallel, European members of NATO are raising defence investments to meet the minimum spending of 5% of their GDP, including 1.5% on defence- and security-related investments like infrastructure and industry.¹

As a key pillar of all military operations, fuel supply is central to these discussions. Europe's military fuel infrastructure has suffered from a structural deficit in investment over the last decades. Five bottlenecks undermine military fuel supply security in 2025: crude oil import dependence; a shrinking refining capacity that is unequally distributed across Europe; inadequate distribution lines, especially on the Eastern Flank; insufficient storage; and challenges to maintaining both fossil and sustainable fuel supply chains in the energy transition.²

This paper zooms in on the fifth bottleneck, namely managing the energy transition in a way that does not hurt readiness but maximizes strategic advantages. Throughout Europe, the civilian sector is moving towards fossil fuel phase-outs. This impacts European armed forces given their reliance on civilian energy infrastructure for fuel supply. The fuel demands of military systems³ like tanks or fighter jets make it extremely challenging to significantly reduce fossil fuel consumption in the short- and medium-term. It is therefore essential to manage the transition in a way that not only maintains but even boosts military readiness.

The energy transition can be turned into a strategic military advantage. A gradual adoption of domestically produced drop-in fuels – i.e., fuels that can be blended into or in some instances fully replace conventional fossil fuels without major changes to existing engines or infrastructure – allows European militaries to mitigate fossil fuel import dependence.⁴ In a tense security environment, this reduces European Allies⁵ exposure to fuel supply risks. The production pathway – whether it is a fossil or a synthetic fuel – is not relevant as long as the supply chain is resilient and the fuel is certified under military standards.

This report analyses challenges and opportunities of the energy transition for military fuel readiness across the air, land and maritime domains as of 2025. It focuses on liquid fuel consumption on the European continent, including fossil and alternative fuels, defined throughout this paper as synthetic fuels, and advanced and sustainable biofuels.

¹ NATO, 'The Hague Summit Declaration Issued by NATO Heads of State and Government (2025)', 2025, https://www.nato.int/cps/en/natohq/official_texts_236705.htm.

² Ron Stoop and Irina Patrahau, *Securing European Military Fuels in a Tense Security Environment: Supply, Distribution and Storage* (2025), <https://hcss.nl/wp-content/uploads/2025/04/Securing-European-Military-Fuels-in-a-Tense-Security-Environment-HCSS-2025-v2.pdf>.

³ Throughout this paper, 'military systems' refer to the combat and non-combat equipment the military uses, such as tanks, armoured vehicles, aircraft, ships etc.

⁴ *Alternative Fuels: Types and Climate Benefits* | HyFIVE, n.d., accessed 3 November 2025, <https://www.hy5.energy/glossary/alternative-fuel/>.

⁵ Allies refers to NATO members.

The analysis supports forward-looking decision making by the EU, NATO, national Ministries of Defence, ministries responsible for energy policy, and the commercial fuel industry, for securing liquid military fuel supplies in Europe.

The rest of the paper is organized as follows. After discussing the European military fuel supply chain in 2025 in section 2, section 3 looks at the impacts of the energy transition on military readiness. Section 4 analyses how different fuels fit into air, land and maritime military operations, followed by the conclusion.

2. Military fuel readiness in Europe

The civilian and military fuel systems are effectively interconnected and mutually dependent. Terminals, refineries, and parts of the distribution network used for the civilian market also serve military needs. The supply chains differ in that the military requires large volumes of specific fuels that can withstand harsher conditions than the civilian sector, so diesel and jet fuel normally used for civilian purposes need to be made to specification to fulfil military standards. The military supply chain, military fuel standards and principles of military fuel use are discussed below.

2.1. The military supply chain

Supply

The supply chain begins with crude or refined oil supply. Most European countries rely on imported crude that arrives through maritime routes or pipelines. While the global oil market is highly diversified and liquid, most of these imports move through physical chokepoints such as international ports and straits, presenting geopolitical risks.⁶ Fuel supplies are also at risk of being cut off by adversaries through physical or cyber attacks, increasing supply uncertainty.⁷

The next step after the import of crude is the refining (this step is skipped if refined oil products are imported). Crude is converted into final products such as diesel and jet fuel, and often blended with additives to make it combat-ready. Refining capacity is unevenly spread across Europe and has declined in recent years.⁸ There is a concentration of capacity in north-western Europe, while half of Europe's biorefineries are located in northern Europe.⁹ Between 2009 and 2024, the number of active refineries decreased from 117 to 96.¹⁰ More refinery closures have been announced or are expected.¹¹ The EU's refining capacity could drop from

⁶ 'Securing European Military Fuels in a Tense Security Environment: Supply, Distribution and Storage', HCSS, n.d., accessed 17 October 2025, <https://hcss.nl/report/securing-european-military-fuels-in-a-tense-security-environment-supply-distribution-and-storage/>.

⁷ Al Jazeera Staff, 'Russian Gas Flow to Europe via Ukraine Stopped: Who Does It Hurt?', Al Jazeera, accessed 17 October 2025, <https://www.aljazeera.com/news/2025/1/1/russian-gas-flow-to-europe-via-ukraine-stopped-who-does-it-hurt>.

⁸ 'Securing European Military Fuels in a Tense Security Environment'; Amaar Khan, 'European Refineries Must Adapt to Survive: Panel | Latest Market News', 1 October 2025, <https://www.argusmedia.com/en/news-and-insights/latest-market-news/2737762-european-refineries-must-adapt-to-survive-panel>.

⁹ 'Refinery and Biorefinery Sites in Europe', Concawe, <https://www.concawe.eu/refineries-map/>.

¹⁰ 'Refineries Map', Concawe, accessed 27 October 2025, <https://www.concawe.eu/refineries-map/>.

¹¹ Kelly Norways, 'Europe's Refining Sector Braces for Major Downsizing as Margins Stall', S&P Global Commodity Insights, 18 July 2024, <https://www.spglobal.com/commodity-insights/en/news-research/latest-news/crude-oil/071824-europes-refining-sector-braces-for-major-downsizing-as-margins-stall>.

13 million barrels a day in 2024 to 1.7-2.1 million barrels a day in 2050.¹² Since most current and future military systems will continue to rely on fossil fuels, the decline of refining capacity in Europe is becoming a military security issue.

Storage and distribution

After import and/or refining, fuel is stored in tank storage units. These can be primarily destined for civilian use, or specialised military fuel storage, both being fit for purpose. Up until this point, civilian and military supply chains are mostly similar. However, after these steps the distribution networks start to differ.

The military distribution supply chain is split up in the distribution towards the theatre logistical base, i.e., the local base from which operations are taking place, and distribution towards units. These are explained below.

The distribution towards the theatre logistical base starts with jet fuel and diesel arriving at a seaport or airfield. This applies for all three domains, air, land and sea. For the maritime domain, fuel is either delivered directly at port to ships, or when ships are seaborne via vessels through Replenishment At Sea.¹³ For the land and air domains, military fuel logistics in Europe are organised via the NATO Pipeline System (NPS). This system is a collective of national infrastructure that connects European refineries via nine separate pipelines to storage facilities across 13 NATO Allies.¹⁴ It makes use of underground pipelines that, in peacetime, serve the commercial system. This also means that the operational costs can be kept lower through the revenue generated in peacetime, while ensuring a strong logistics network in conflict scenarios.

In addition to the NPS, fuel for land or air operations can move inland by road and rail tankers.¹⁵ Pump stations and regulating storage tanks maintain pressure and flow. In the land domain, after arriving at intermediate depots, fuel is stored in collapsible or fixed tanks.¹⁶ The US Army uses modular systems that can carry from 60.000 to 1.2 million gallons of fuel, called Fuel System Supply Points (FSSP).¹⁷ From these points, tactical distribution takes place.

During the distribution towards units, the bulk fuels split according to user. Kerosene flows either to airfields or Forward Arming and Refuelling Points (FARPs), which are temporary take-off sites for helicopters or aircraft.¹⁸ Diesel is dispatched towards the forward land operations. The US uses Heavy Expanded Mobility Tactical Trucks (HEMTTs), modular trailers with fuel storage units on top, or assault hoses to bring the fuel directly to the theatre of war.¹⁹

¹² John Leavens et al., *Study on the Potential Evolution of Refining and Liquid Fuels Production in Europe* (Concawe & S&P Global, 2025), <https://www.concawe.eu/wp-content/uploads/Study-on-the-potential-evolution-of-Refining-and-Liquid-Fuels-production-in-Europe-.pdf>.

¹³ Department Of The Navy, *Naval Warfare Publication - Underway Replenishment (NWP 4-01.4)* (2001).

¹⁴ Dominik P. Jankowski, *The NATO Pipeline System: A Forgotten Defence Asset* (NATO Defense College, 2020), 1, <https://www.jstor.org/stable/resrep25101>.

¹⁵ Headquarters Department of the Army, *Petroleum Supply Operations* (2015).

¹⁶ Headquarters Department of the Army, *Petroleum Supply Operations*.

¹⁷ '61st Quartermaster Battalion Conducts Fuel System Supply Point Training to Boost Operational Readiness', *Www.Army.Mil*, 3 October 2025, https://www.army.mil/article/288881/61st_quartermaster_battalion_conducts_fuel_system_supply_point_training_to_boost_operational_readiness.

¹⁸ 'FM 1-113 Appendix E', accessed 17 October 2025, <https://www.globalsecurity.org/military/library/policy/army/fm/1-113/AE.HTM>.

¹⁹ 'Pipelines, Hoselines & Fuel Bags: Great Contributors to Winning Large-Scale Combat Operations', *Www.Army.Mil*, 4 November 2019, https://www.army.mil/article/227941/pipelines_hoselines_fuel_bags_great_contributors_to_winning_large_scale_combat_operations.

Forward mobile support in the land domain is managed through the Refuel-on-the-Move (ROM) concept.²⁰ These temporary ROM sites consist of HEMTTs or trailers with fuel that can be offloaded to operational units such as tanks or other (armoured) vehicles. In the air domain kerosene is pumped through small-scale, localised aviation refuel systems like Advanced Aviation Forward Area Refuelling System (AAFARS) or HEMTT Tanker Aviation Refuelling System (HTARS) for helicopters and airplanes.²¹ Alternatively, aircraft and helicopter can be supplied via Air to Air Refuelling (AAR), with specialised refuelling aircraft delivering the fuels mid-air.²²

Consumption

Fuel use in the military depends on a variety of factors, notably on whether the operation is taking place in peacetime or wartime, although the border between the two can be blurry. In peacetime, military fuel consumption is relatively low and stable compared to wartime. A considerable part of fuel usage goes towards base camp heating, electricity and cooling.²³ Military systems see limited usage outside of training during peacetime.²⁴ In wartime, fuel use expands dramatically. In large part, this increase is dominated by air operations, but fuel usage in land operations (vehicles, base generators) also increases considerably.²⁵ Since the Russian annexation of Crimea in 2014 and its full-scale invasion in 2022, NATO has been on high alert along especially its eastern border.²⁶ European Allies are operating in the 'grey zone' between peace and war, meaning that military fuel use is not as high as in wartime but it is higher due to increased military training, patrolling and forward stationing.²⁷

The exact difference between war and peacetime fuel use has been notoriously hard to pin down, partly due to the many variables that influence the final fuel use and the sensitivity of this type of information. Generally, it is accepted that fuel use in wartime is orders of magnitude higher than in peacetime. However, the exact difference depends in great part on the type of military operation (e.g., land-heavy, sea-heavy or air-heavy) and the stage the war is in (early stages, attrition etc.). To give a partial indication: a 2008 report by the Defense Science Board Task Force noted that army generators consume about 98 million litres of fuel annually in peacetime, but 1.3 billion litres annually during wartime.²⁸

²⁰ 'Maintaining Momentum through Refuel on the Move', *Www.Army.Mil*, 4 January 2016, https://www.army.mil/article/159656/maintaining_momentum_through_refuel_on_the_move.

²¹ 'QM5094 LESSON 7', accessed 17 October 2025, <https://rdl.train.army.mil/catalog-ws/view/100.ATSC/05A-91DA9-C411-4A6C-8F29-5BB5DB0E75A5-1274389462978/qm5094/lsn7.htm>; 'Advanced Aviation Forward Area Refueling System', *GTA Containers*, n.d., accessed 17 October 2025, <https://www.gtacontainers.com/capability/advanced-aviation-forward-arearefueling-system/>.

²² *Air-to-Air Refuelling Consolidation - Joint Air Power Competence Centre*, 19 March 2014, <https://www.japcc.org/white-papers/air-to-air-refuelling-consolidation/>.

²³ 'Energy & Water', *Focus Area*, accessed 17 October 2025, <https://serdp-estcp.mil/focusareas/ad3a1430-0bce-4183-bdcc-cba9399f557d/energy-water>.

²⁴ 'Energy & Water'.

²⁵ 'Gulf War 30: Logistics', *Army Benevolent Fund*, accessed 21 October 2025, <https://armybenevolentfund.org/commemorations/gulf-war-30-logistics/>.

²⁶ NATO, 'Strengthening NATO's Eastern Flank', NATO, 23 October 2025, https://www.nato.int/cps/en/natohq/topics_136388.htm.

²⁷ 'Deterring Kremlin Grey Zone Aggression Against NATO', 30 October 2025, <https://www.rusi.orghttps://www.rusi.org>. NATO, 'Strengthening NATO's Eastern Flank', NATO, accessed 3 November 2025, https://www.nato.int/cps/en/natohq/topics_136388.htm.

²⁸ U. S. Government Accountability Office, 'Defense Management: Increased Attention on Fuel Demand Management at DOD's Forward-Deployed Locations Could Reduce Operational Risks and Costs | U.S. GAO', accessed 17 October 2025, <https://www.gao.gov/products/gao-09-388t>.

Moreover, fuel use is dominated by the air domain. Around 70% of total fuel use is for powering military aircraft.²⁹ During the 1990-1991 Gulf War, the US Air force used roughly five times (3,785,000 m³) as much fuel as was used by the US Army (783,000 m³).³⁰ This is equivalent to 32% of Germany's annual kerosene consumption. In comparison, the land domain only used the equivalent of 1% of Germany's annual diesel consumption during the Gulf War.³¹

2.2. NATO military fuels

European militaries use certified fuels with guaranteed battle performance. This is done at two different levels. First, NATO STANAG standards are formal NATO documents that establish common standards for different military applications, including fuel. The main purpose of the NATO STANAG codes is to make sure that the different NATO Allies use interoperable military equipment, methods and procedures. NATO STANAG codes are implemented based on consensus and are "aimed at the achievement of the optimum degree of order in a given context".³² This includes documents setting common fuel standards for Allies to be able to use fuel supplies from every other Ally.³³ NATO STANAG codes serve as a bridge between the operational F-Codes and technical specifications. An example of this is STANAG 3747 that has been agreed upon by the different NATO Allies, which is the equivalent of F-34.

Second, the operational level includes the designations known as the F-code and the JP-code. These codes are used at the operational level of the different military domains to reference a specific fuel. The F-code is used by NATO while the JP-code is used specifically by the US military – JP stands for US Jet Propulsion fuels. The JP-codes roughly align with NATO F-code standards. An overview of the different NATO F-code fuels is seen in Table 1.

²⁹ Neta Crawford, 'Pentagon Fuel Use, Climate Change, and the Costs of War', Brown University, 19 November 2019, <https://costsofwar.watson.brown.edu/paper/pentagon-fuel-use-climate-change-and-costs-war>.

³⁰ James P. Stucker et al., *Assessment of DoD Fuel Standardization Policies* (RAND, 1994), https://www.rand.org/pubs/monograph_reports/MR396.html.

³¹ Stucker et al., *Assessment of DoD Fuel Standardization Policies*.

³² NATO, 'Standardization', NATO, 14 October 2024, https://www.nato.int/cps/en/natohq/topics_69269.htm.

³³ NATO, 'Standardization'.

Table 1. NATO military variants of jet fuel and diesel. Gasolines are excluded from the table due to reduced use across domains.



NATO F-code	Common Name / Equivalent	Primary Application(s)
F-34	JP-8 (Civilian Jet A-1 with additives)	Aviation, land vehicles, some generators under the Single Fuel Policy. ³⁴ It contains both icing inhibitor (S-1745) and lubricity improving (S-1747) additives. F-34 = F-35 + additives.
F-35	Civilian Jet A-1	Aviation. ³⁵
F-37	JP-8 with increased thermal stability	Aviation, where extra thermal stability is required. Contains the additive S-1749 for thermal stability. ³⁶
F-40	JP-4	Wide cut type aviation turbine fuel for use in land based military aircraft gas turbine engines. Contains the Fuel System Icing Inhibitor (S-1745) and the Lubricity Improving Additive (S-1747). It serves as an emergency substitute for F-34/F-35 but is rarely used. Mostly for training purposes. ³⁷
F-44	JP-5	Naval aviation / carrier-based aircraft with a higher flash point than F-34/F-44, making it suitable for shipborne operations with high fire risk. Contains additives S-1745 and S-1747. ³⁸
F-54	Diesel (middle distillate, similar to civilian EN 590 / ASTM D975)	Land vehicles (compression ignition engines), some marine use. Interchangeable with commercial diesel. ³⁹
F-63	Arctic diesel (cold-climate diesel)	Land vehicles in very cold climates. Contains the additive S-1750, which enhances lubricity and ignition performance. ⁴⁰
F-65	M1 Fuel Mix	F-54 diesel blended with kerosene aviation fuel meant for low temperatures. ⁴¹
F-75	Naval distillate fuel with low pour point	Compression ignition engines, naval gas turbines and ships' boilers for steam raising. ⁴² Has a low pour point. ⁴³
F-76	Naval distillate fuel (marine diesel)	Primary naval fuel. Ships, naval vessels, shipboard generators ⁴⁴ Contains lubricity improver additive (R655) and antioxidant additive (AO-37). ⁴⁵
F-77	Also known as fuel residual	A naval residual fuel used for boiler steam raising for certain ships. May also be used in slow speed diesel engines. ⁴⁶

³⁴ Standards Council of Canada, 'Aviation Turbine Fuel (Military Grades F-34, F-37 and F-44) | Standards Council of Canada', 9 July 2024, <https://scc-ccn.ca/standards/notices-of-intent/canadian-general-standards-board-cgsb/aviation-turbine-fuel-military-2>.

³⁵ 'Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment', in *NATO Logistics Handbook* (1997), <https://www.nato.int/docu/logi-en/1997/lo-15a.htm>.

³⁶ Standards Council of Canada, 'Aviation Turbine Fuel (Military Grades F-34, F-37 and F-44) | Standards Council of Canada'.

³⁷ *NATO Logistics Handbook* (NATO, 2012), 101, https://www.nato.int/docu/logi-en/logistics_hndbk_2012-en.pdf.

³⁸ Standards Council of Canada, 'Aviation Turbine Fuel (Military Grades F-34, F-37 and F-44) | Standards Council of Canada'.

³⁹ *NATO Logistics Handbook*, 101–2.

⁴⁰ *NATO Logistics Handbook*, 102.

⁴¹ Jill M Bramer, *U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – GROUND VEHICLE SYSTEMS CENTER*, n.d.; 'NATO Logistics Handbook: Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment', October 1997, <https://www.nato.int/docu/logi-en/1997/lo-1511.htm>.

⁴² 'NATO Logistics Handbook: Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment', October 1997.

⁴³ *NATO Logistics Handbook*.

⁴⁴ *NATO Logistics Handbook*, 102.

⁴⁵ Environmental Protection Agency, *Chemicals of Potential Concern (COPCs) Recommendations Fuel Additives Red Hill Bulk Fuel Storage Fuel Facility* (2016), https://www.epa.gov/sites/default/files/2016-07/documents/red_hill_navy_fuel_additives_list.pdf.

⁴⁶ 'NATO Logistics Handbook: Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment', October 1997.

Military standards typically build on civilian ones. ASTM (American Society of Testing and Materials) standards, for instance, are recognized across the global civilian fuel industry. ASTM standards measure viscosity, sulphur content, and octane number.⁴⁷ In doing so, they provide universal definitions and classifications. Military standards often build on ASTM standards and adapt them for special mission usage. ASTM standards remain at the core of most of their military counterparts.⁴⁸

Most European militaries use the NATO Single Fuel Policy, a framework that aims to harmonise fuel usage policies for all NATO Allies. The centre piece of the NATO Single Fuel Policy is the usage of F-34 (JP-8) jet fuel. This fuel is also compatible with most land-based military systems in Europe. The supply chains of both land and air operations can be interoperable, if a wartime scenario were to require that. This places the supply chain of jet fuel at the heart of military preparedness plans in Europe. Other aspects of the Single Fuel Policy are the usage of grade F-54 diesel, and F-76 diesel for maritime operations, as well as additional requirements on labelling and standardisation of auxiliary products (e.g., type of lubricants).⁴⁹ These fuel standards are tested by NATO Allies using prescribed methods, and after validation these fuels are ready to be used by any NATO Ally. Even though NATO can only suggest or recommend policies, most allies adhere to the single fuel concept.⁵⁰

The Single Fuel Policy is the backbone of military fuel operations in NATO territory. Therefore, any alternative fuel intended for near-term military use must conform to the technical requirements of the Single Fuel Policy to be a viable option.

2.3. Five principles for military fuel use

Fuel policies in military operations follow a distinct logic compared to fuel considerations in the civilian domain, outlined in the paragraphs below. These have been presented to military experts for validation. The considerations are ranked in general order of importance, though their priority can shift depending on the operational context.

Availability

Fuel availability often outweighs performance quality or cost considerations because military operations are entirely reliant on continuous fuel supply. Forces need fuel where and when they fight, and the fuel characteristics are sometimes of secondary importance. European fighter platforms such as the RAF's Typhoon can operate on commercial Jet A-1, given the fuel adheres to its national 'Defence Standard 91-091' that specifies the suitable additives that should be used.⁵¹ The possibility of using commercial fuel supplies shortens supply lines and strengthens operational capability and is thus allowed in emergency situations.⁵²

⁴⁷ Sydney Casey, 'What Is It – ASTM Petroleum Standards', *Mansfield Energy*, 27 September 2023, <https://mansfield.energy/2023/09/27/what-is-it-astm-petroleum-standards/>.

⁴⁸ Jones, 'Are MIL Specifications and ASTM Specifications Equivalent?', American Galvanizers Association, 20 April 2023, <https://galvanizeit.org/knowledgebase/article/are-mil-specs-and-astm-specs-equivalent>.

⁴⁹ 'NATO Logistics Handbook: Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment', accessed 20 October 2025, <https://www.nato.int/docu/logi-en/1997/lo-15a.htm>.

⁵⁰ NATO, 'The "fuel Soldiers"', NATO, 21 October 2013, https://www.nato.int/cps/en/natohq/news_103862.htm.

⁵¹ Joint Inspection Group, 'DefStan 91-091 Issue 18', *Joint Inspection Group*, 7 February 2025, <https://www.jig.org/documents/defstan-91-091-issue-18/>.

⁵² Department of Defense, *DEPARTMENT OF DEFENSE STANDARD PRACTICE QUALITY ASSURANCE/ SURVEILLANCE FOR FUELS, LUBRICANTS AND RELATED PRODUCTS* (2016), 88.

Fuel flexibility

In combat, the priority is ensuring that engines start, run reliably and do not catch fire or explode. Most land combat forces can temporarily accept lower fuel efficiency or corrosion but cannot afford unusable tanks or armoured vehicles. A balance must be found between theoretical performance and practical applicability. This is different in the case of the air domain, which is strongly reliant on high performance fuels. The NATO Single Fuel Policy is based on applying fuel flexibility to both land and air vehicles, in which land vehicles can easily switch to jet fuel (F-34 or JP-8) if needed.

For example, The Leopard 2(A8) tank is built with fuel flexibility in mind. It is powered by the MTU motor that primarily runs on diesel, but also boasts 'multifuel' capabilities.⁵³ Although the other fuel types suitable for this system are not specified, it is likely that JP-8 can also be used. While this makes the system very flexible and reliant, it does lead to higher fuel consumption compared to conventional diesel engines due to the lower energy density of JP-8.⁵⁴ However, this downside is acceptable for land-based military operations if it results in more flexible minimum operability requirements.

Logistics simplicity and speed

Simple and fast supply chains are key to sustaining wartime operations. Fuel doctrine in NATO operations relies on fixed standards and interoperability.⁵⁵ The ability to sustain military operations depends as much on logistics resilience and supply chains as on combat capabilities. In the early stages of the Russia-Ukraine war, inadequate supply chain planning of the Russians led to severe delays and suboptimal fighting capability.⁵⁶

Stable and reliable performance

Fuel stability and reliability are essential for military operations. Fuel types are selected based on energy density (requiring low volume per energy unit), cold-weather behaviour, thermal and oxidative stability and contamination tolerance.⁵⁷ Since battles can occur under extreme circumstances, all these properties are important for effective use of military systems.

Fully burdened cost of fuel

Although not unimportant in the long term, upfront fuel cost considerations are often secondary to the mission objective. In the end, availability, minimum operability requirements (which differ between air, land and sea), logistics and battle performance trump upfront cost. Militaries calculate costs differently from the civilian sector, taking into account the Fully

⁵³ KNDS Group, 'LEOPARD', KNDS Group, accessed 3 November 2025, <https://knds.com/en/products/leopard>.

⁵⁴ National Academies Press, *Read 'Powering the U.S. Army of the Future' at NAEdu* (2021), <https://doi.org/10.17226/26052>.

⁵⁵ 'NATO Logistics Handbook: Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment', October 1997.

⁵⁶ 'Russian Military Logistics in the Ukraine War: Recent Reforms and Wartime Operations', accessed 17 October 2025, <https://www.cna.org/analyses/2023/10/russian-military-logistics-in-the-ukraine-war>.

⁵⁷ *Read 'Powering the U.S. Army of the Future' at NAEdu* (n.d.), <https://doi.org/10.17226/26052>. *Read 'Powering the U.S. Army of the Future' at NAEdu*.

'FM 9-207 Chapter 1', accessed 17 October 2025, <https://www.globalsecurity.org/military/library/policy/army/fm/9-207/ch1.htm>.

Burdened Costs of Fuel (FBCF), a concept developed by the US Department of Defense.⁵⁸ A FBCF analysis reflects on 'the cost burdens associated with fuelling energy demanding weapons systems, where indirect costs like manpower, infrastructure, delivery assets, and security requirements, represent fiscally enormous multipliers' for the original standard price paid by the procurement office.⁵⁹ These 'associated costs' can cause a sharp increase to the total fuel costs of the military.

A cheaper fuel type that is temporarily unavailable or less stable is worthless in high-intensity military operations. For example, in NATO operations, helicopters regularly transport fuel bladders to forward operations in a theatre of war.⁶⁰ This mode of transportation is costly, but sometimes justified if it helps realise the mission objectives.

This is a key difference compared to the civilian domain. Cost considerations drive most of the non-military fuel decisions. In the military domain, cost plays a role but is generally subservient to availability, operability, logistics and battle performance.

⁵⁸ U.S. Army, 'Driving Fuel Choices', *Www.Army.Mil*, 14 December 2020, https://www.army.mil/article/241758/driving_fuel_choices.

⁵⁹ Robert M. Corley, *Evaluating the Impact of the Fully Burdened Cost of Fuel*, 1 September 2009, 15, <https://apps.dtic.mil/sti/html/tr/ADA508983/>.

⁶⁰ NATO, 'The "fuel Soldiers"'.

3. The impact of the energy transition on military readiness

Having introduced the main principles of military fuel readiness in Europe in the previous section, the paragraphs below move towards a discussion of the different types of alternative fuels that are being scaled up for the European civilian industry and that could be used for military purposes. It also analyses the challenges and opportunities that these alternative fuels bring for the military.

3.1. Alternative fuels in the energy transition

In the EU, goals for greenhouse gas (GHG) reductions have been developed for 2030 and 2040 in order to achieve carbon neutrality by 2050. By 2030, the EU should reduce net greenhouse gas (GHG) emissions by at least 55% relative to 1990 levels.⁶¹ To meet this objective, the EU has introduced sector-specific measures. ReFuelEU Aviation mandates a progressive increase in the use of sustainable aviation fuels (SAF). The framework sets specific targets that mandate that at least 2% of aviation fuel supplied to all EU airports should be SAF in 2025, this target will progressively increase to 70% by 2050.⁶² The FuelEU Maritime regulation targets reductions in the carbon intensity of shipping and the phase-out of internal combustion engines will be achieved through a proposed ban on the sale of new CO₂-emitting cars by 2035.⁶³ The Third Renewable Energy Directive (RED III) requires progressively increasing sustainable fuel blends starting in 2030 as well as penalties for those

⁶¹ European Commission, 'Fit for 55: Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality', COM/2021/550 (2021), <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550>.

⁶² 'Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on Ensuring a Level Playing Field for Sustainable Air Transport (ReFuelEU Aviation)', 2023, <https://eur-lex.europa.eu/eli/reg/2023/2405/oj/eng>.

⁶³ Regulation (EU) 2023/851 of the European Parliament and of the Council of 19 April 2023 Amending Regulation (EU) 2019/631 as Regards Strengthening the CO₂ Emission Performance Standards for New Passenger Cars and New Light Commercial Vehicles in Line with the Union's Increased Climate Ambition (2023), <http://data.europa.eu/eli/reg/2023/851/oj/eng>; Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the Use of Renewable and Low-Carbon Fuels in Maritime Transport, and Amending Directive 2009/16/EC (2023), <http://data.europa.eu/eli/reg/2023/1805/oj/eng>; 'Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on Ensuring a Level Playing Field for Sustainable Air Transport (ReFuelEU Aviation)'.

that breach these mandates.⁶⁴ The European Commission also proposed a 90% reduction of greenhouse gas emissions in 2040 relative to 1990 levels.⁶⁵

Alternative fuels considered in this paper include advanced and sustainable biofuels and synthetic fuels, in line with the RED III. Table 2 provides an overview of the main fuels and their production pathways. Advanced biofuels are made from waste biomass sources like agricultural waste or forest residue, and there are EU mandates for increasing their consumption in the coming years. Other sustainable biofuels produced from used cooking oils or animal fats are also accepted under EU standards, but their consumption is capped due to issues around feedstock availability and sustainability.⁶⁶

Table 2. Advanced and sustainable biofuels and Renewable Fuels of Non-Biological Origin (RFNBO) according to the EU RED III, with applicability in the transport sector



Fuel category	Feedstock according to EU RED III	Fuel type	End uses for the civilian sector
Advanced and sustainable biofuels	Advanced biofuels (RED III Annex IX part A): waste feedstock like forestry residue or intermediate crops; Biofuels (RED III Annex IX part B): waste feedstocks such as used cooking oils or animal fats.	Sustainable Aviation Fuel	Aviation
		Bio-methanol	Maritime
		Renewable Diesel (HVO)	Maritime
	Advanced biofuels (RED III Annex IX part A): waste feedstock like forestry residue or intermediate crops; Biofuels (RED III Annex IX part B): food and feed crops.	Renewable Diesel (HVO)	Road
Renewable Fuels of Non-Biological Origin (RFNBO)	Green hydrogen and captured CO ₂	e-SAF	Aviation
		e-diesel	Road & Maritime
		e-methanol	Maritime
	Green hydrogen and nitrogen ⁶⁷	e-ammonia	Maritime

Renewable Fuels of Non-Biological Origin (RFNBO) are also expected to grow in consumption due to EU mandates, like advanced biofuels. RFNBOs are fuels produced from renewable electricity and water, such as green ammonia and synthetic (e-) fuels.⁶⁸ Some e-fuels, including e-methanol and synthetic aviation fuel (e-SAF), require the addition of a carbon source during production. The carbon can only be sourced from biomass, Direct Air Capture (DAC) technologies, or industrial sources (e.g., steel and cement plants). Under current regulations, producers are permitted to use fossil-based carbon until 2040 to produce e-methanol and e-SAF. However, most are transitioning toward biogenic carbon sources to ensure the sustainability of their e-fuels and to comply with forthcoming EU regulations that, from 2040 onward, will prohibit the use of fossil carbon in the production of e-fuels and RFNBO.

⁶⁴ European Parliament and Council of the European Union, 'Directive 2023/2413 - Renewable Energy Directive', Official Journal of the European Union, 2023, <https://eur-lex.europa.eu/eli/dir/2023/2413/oj/eng>.
⁶⁵ European Commission, '2040 Climate Target', 2025, https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2040-climate-target_en.
⁶⁶ European Parliament and Council of the European Union, 'Directive 2023/2413 - Renewable Energy Directive'.
⁶⁷ Air Liquide, 'Green Ammonia Full Guide: Production, Uses, and Sustainability', 21 July 2025, <https://eg.air-liquide.com/green-ammonia-explained>.
⁶⁸ European Parliament and Council of the European Union, 'Directive 2023/2413 - Renewable Energy Directive'.

3.2. Alternative fuels in the military

To date, the energy transition has been pursued predominantly within the civilian domain, as the defence sector remains largely exempt from the EU's and international frameworks' climate and decarbonisation obligations. As the civilian market moves away from fossil fuels, the available supply will likely deteriorate. This brings risks for military fuel readiness in the short and medium term. At the same time, the growing domestic alternative sustainable fuels market can strengthen the resilience of military supply chains and therefore mitigate some of these risks. The following paragraphs outline the challenges and opportunities of the energy transition for military fuel readiness.

European militaries have committed to reducing GHG emissions in non-operational sectors, but remain dependent on fossil fuels in their operations. This is taking place in countries like Germany, the Netherlands, the United Kingdom and Norway.⁶⁹ Most emission reductions are achieved in military installations and bases, where the needs are relatively similar to the civilian sector: heating/cooling buildings, using electric vehicles for non-operational needs, and so on.⁷⁰ Here, fuel readiness does not determine the military's operational effectiveness, and the opportunities for sustainable fuel adoption are larger than in military systems.

The main difficulty for decarbonisation comes from operational needs, where tanks, fighter jets and frigates require fossil fuels to function and achieve military objectives. The civilian fossil fuels consumption is expected to decrease in the next 10-15 years, up to 2040, at a much faster pace than that of the military sector. Due to the interdependence of military and civilian fuel supply chains, this mismatch between fossil fuel consumption brings both challenges that should be mitigated and opportunities that can be leveraged for military readiness.

The challenges arising from the energy transition for military fuel readiness are two-fold. First, as the fossil fuel production capabilities within Europe will diminish, import dependency could increase. This applies especially to the defence sector but also to the civilian one if demand does not decrease proportionally to supply. Europe is already heavily dependent on crude oil imports (EU's import dependence on crude oil and petroleum products was 94.8% in 2023) and its refining capacity to transform crude into kerosene, diesel or other oil products is under increasing pressure.⁷¹ The declining refining capacity over the last decade increases Europe's dependence on imported oil products, bringing further vulnerability to its military fuel readiness. This contradicts the main principles of military fuel use, namely availability, logistics simplicity and speed in case of disruptions in imports.

A second challenge is the insufficient scale of the sustainable fuel market as of 2025, bringing issues for large-scale military adoption in the short-term. Biofuels like sustainable aviation fuels (SAF) or renewable diesel (hydrotreated vegetable oil, HVO) are used in relatively high

⁶⁹ Ajit Niranjana, 'Only Two European States Have Net Zero Military Emissions Target, Data Shows', *The Guardian*, 31 May 2025, <https://www.theguardian.com/world/2025/may/31/only-two-european-states-have-net-zero-military-emissions-target-data-shows>.

⁷⁰ Expert Group of the International Military Council on Climate and Security (IMCCS), *World Climate and Security Report 2024: Military Innovation and the Climate Challenge* (2024), <https://hcass.nl/report/imccs-world-climate-and-security-report-2024-military-innovation-and-the-climate-challenge/>.

⁷¹ Eurostat, 'Oil and Petroleum Products - a Statistical Overview', 4 May 2025, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Oil_and_petroleum_products_-_a_statistical_overview; Khan, 'European Refineries Must Adapt to Survive'.

proportions compared to other alternative fuels.⁷² Their commercial and technical maturity compared to other sustainable fuels make them a real alternative for consumers across the EU, but their price is still notably higher than that of fossil fuels as of 2025. Advanced and sustainable aviation biofuels cost between two to four times more than kerosene.⁷³ Moreover, a key challenge in their supply chain comes from sustainable feedstock availability and origin in the long-term.⁷⁴ Domestically available used cooking oil and animal fats are already largely employed in producing biofuels, and the use of this kind of feedstock is capped under the RED III.⁷⁵ Some of it is imported from Asia, causing dependency issues for this emerging supply chain, as well as certification challenges due to fraudulent disclosures by some suppliers.⁷⁶ Agricultural residues could have the largest contribution to advanced biofuel production, although the sustainability of their lifecycle environmental impact is sometimes debated.⁷⁷

Synthetic fuels mitigate issues related to the origin of feedstock, as they can be produced in Europe from domestic green hydrogen and carbon, but the scale of the industry is still challenging. Mandatory consumption targets and penalties under ReFuelEU Aviation and FuelEU Maritime expects the synthetic fuel sector to scale after 2030. The EU hosts around 60% of all global e-SAF projects, many of which are in advanced planning stages and awaiting final investment decisions (FID). As of 2025, no final investment decision (FID) has been reached in Europe.⁷⁸ The United Kingdom, for instance, is exploring ways to source domestically produced synthetic fuels for their military operations. They have introduced mandatory SAF blending targets for the Royal Air Force: starting at 2% in 2025, rising to 10% by 2030, and reaching 22% by 2040, thereby strengthening both fuel resilience and operational sustainability.⁷⁹

To address fossil fuel import dependency issues and allow for a gradual adoption of alternative fuels, drop-in fuels blended with fossil fuels emerge as an attractive option for the military. They give flexibility to the military to switch between fossil fuels and alternative sustainable fuels according to their needs, availability and accessibility. Drop-in fuels can be used directly, without changes to engines, pipelines or storage units. While sustainable fuel markets scale up in Europe, the military can use both fossil fuels and alternative ones. They can therefore be a practical option that can help militaries fulfil their military goals in the short- and long- term.

Moreover, increasing the use of domestically produced sustainable fuels reduces import dependence for fossil fuels and increases autonomy over fuel supplies. Decreasing import dependencies lowers vulnerability to geopolitically motivated supply disruptions but also to other types of issues that can affect maritime supply routes, including armed conflict, piracy,

⁷² SkyNRG, 'SAF Market Outlook 2025', SkyNRG, 2025, <https://skynrg.com/safmo25/>. SkyNRG, 'SAF Market Outlook 2025'.

⁷³ European Union Aviation Safety Agency, 'Sustainable Aviation Fuels'. European Union Aviation Safety Agency, 'Sustainable Aviation Fuels'.

⁷⁴ SkyNRG, 'SAF Market Outlook 2025'. SkyNRG, 'SAF Market Outlook 2025'.

⁷⁵ 'How Sustainable Are Advanced and Waste Biofuels?', T&E, 9 October 2025, <https://www.transportenvironment.org/articles/how-sustainable-are-advanced-and-waste-biofuels>.

⁷⁶ Jane O'Malley and Chelsea Baldino, *Assessment of the Potential for New Feedstocks for the Production of Advanced Biofuels: Final Report*. (International Council on Clean Transportation, 2024), <https://data.europa.eu/doi/10.2833/719121>. O'Malley and Baldino, *Assessment of the Potential for New Feedstocks for the Production of Advanced Biofuels*.

⁷⁷ O'Malley and Baldino, *Assessment of the Potential for New Feedstocks for the Production of Advanced Biofuels*. O'Malley and Baldino, *Assessment of the Potential for New Feedstocks for the Production of Advanced Biofuels*.

⁷⁸ 'Sustainable Aviation Fuels (SAF) around the World', T&E, accessed 13 October 2025, <https://www.transportenvironment.org/topics/planes/saf-observatory/saf-around-the-world>. T&E, 'Sustainable Aviation Fuels (SAF) around the World'.

⁷⁹ GOV.UK, 'Sustainable Aviation Fuel (SAF) Mandate', GOV.UK, 19 December 2024, <https://www.gov.uk/government/collections/sustainable-aviation-fuel-saf-mandate>.

or climate disasters. In turn, autonomy over fuel production significantly increases. Alternative sustainable fuels can be produced in Europe, starting with domestic sourcing of feedstock to final production into the relevant fuel. This means that in a military conflict, European armed forces can rely on European producers for supplies, cutting the length and complexity of the supply chain. For instance, Rheinmetall aims to produce e-fuels in small scale plants and distribute them throughout Europe, close-by to military units or pipelines. Due to the smaller size of the plants, the technology can be scaled up relatively quickly and create “resilience through decentralisation”.⁸⁰

Recognizing that civilian decarbonisation will reshape the conditions of military operations in the coming decades, it is essential to understand early on how this transition can be leveraged to enhance military effectiveness for two reasons. First, operational cycles that are starting up, as a result of the increased defence spending that NATO allies committed to, will last decades, so it makes sense for the military to start thinking about developing alternative sustainable fuel capabilities early on.⁸¹ Second, the sustainable fuel industry is still under development and requires significant resources to be scaled-up. This gradual approach allows the military to draw on the speed of the energy transition in the civilian sector and also shape it according to its needs.

⁸⁰ ‘E-Fuels – Giga PtX’, Rheinmetall, accessed 3 November 2025, <https://www.rheinmetall.com/en/products/e-fuels/giga-ptx>.

⁸¹ NATO, ‘The Hague Summit Declaration Issued by NATO Heads of State and Government (2025)’, NATO, 25 June 2025, https://www.nato.int/cps/en/natohq/official_texts_236705.htm.

4. Fuel alternatives across military domains

Alternative liquid fuels - advanced and sustainable biofuels, and synthetic fuels - are at the forefront of decarbonization goals. This section discusses their applicability across military domains.

Alternative sustainable fuels could play an incrementally larger role across military domains by being blended with fossil fuels. Table 3 provides an overview of fuels that can be used with no engine modifications across the air, land and maritime domains, based on the comprehensive military fuel list in section 2. Drop-in fuels like SAF blended with F-34 jet fuel have already been successfully tested by European air forces, in the United Kingdom (UK), Sweden and the Netherlands. SAF have also been added to the NATO Central Europe Pipeline System (CEPS) since 2023.⁸² Moreover, renewable diesel could play an increasing role in the land and maritime domains, blended with F-54 land fuel or F-75 and F-76 marine diesel (see Table 3).

The production pathway – whether it is a fossil fuel or not – is not relevant for the fuel's final use in the military as long as the supply chain is resilient and the fuel is certified under military standards. The key issue is ensuring that available volumes of alternative sustainable fuels are sufficient to ensure stable consumption by the military. The fuel needs and potential alternatives for each military domain are discussed below.

Table 3. Fuel alternatives across military domains with no engine modification. The most widely used conventional fuel is taken as benchmark per domain.



Military domain	Main conventional fuel	Fuel alternatives with no engine modification	
Air	Jet fuel (F-34)	Blend of F-34 jet fuel and SAF	Blend of F-34 jet fuel and e-SAF
Land	Diesel (F-54 & F-63)	Blend of F-54 or F-63 diesel and renewable diesel	Blend of F-54 or F-63 diesel and e-diesel
	Jet fuel (F-34)	Blend of F-34 jet fuel and SAF	Blend of F-34 jet fuel and e-SAF
Maritime	Marine diesel (F-75 & F-76)	Blend of F-75 or F-76 marine diesel and renewable diesel	Blend of F-75 or F-76 marine diesel and e-diesel
	High flash point jet fuel (F-44)	Blend of F-44 jet fuel and SAF	Blend of F-44 jet fuel and e-SAF

⁸² European Union Aviation Safety Agency, 'Sustainable Aviation Fuels'. European Union Aviation Safety Agency, 'Sustainable Aviation Fuels'.

Even though synthetic or bio-based ammonia and methanol are becoming promising options for the civilian maritime sector, they are not fit for military use for three reasons: (1) the need for major modifications to existing engines on naval ships, which will no longer be able to use marine diesel according to the NATO fuel standards; (2) low volumetric and/or gravimetric energy density affecting operational effectiveness; (3) their high toxicity and flammability, making them unsuitable for warships. Volumetric density is the energy stored per unit of volume, while gravimetric density is the energy stored per unit of mass. These are relevant in the military context in terms of both space and weight. The more space it takes and the heavier a fuel is, the more it will negatively affect military operations. These are briefly touched upon in the maritime domain section below.

4.1. Air domain

The air domain consists of combat aircraft such as the F-35 and Eurofighter, aerial refuelling tankers, transport aircraft for troop and equipment movement, helicopters, trainer aircraft, and unmanned aerial vehicles (UAVs).

Air operations consume by far the largest amount of fuel across military domains. For example, the Royal Dutch Airforce accounts for 59% of total Dutch military fuel consumption.⁸³ Because of this, air forces require strong supply chains with high fuel quantities available and a robust distribution chain to back it up. They also require a fuel that is lightweight and has a high energy density. This fuel needs to be able to withstand low temperatures as aircraft operate at high altitudes, while being stable and safe in operating and handling.⁸⁴

As such, fuel blends of SAF or e-SAF together with conventional jet fuel offer the most opportunities for the air force in the short term. Although both are allowed to be used in blends up to 50% according to ASTM rules, once mixed there is no loss in performance or any other characteristics that could cause extra complications in operational usage.⁸⁵

Blends with SAF or e-SAF are applicable to both peace- and wartime scenarios across the above-mentioned aircraft. Sweden tested a 50% SAF blend in its JAS 39 Gripen aircraft, the Netherlands tested 5% SAF blends into F-16 aircraft and Norway tested a 40% SAF blend in an F-35 fighter jet.⁸⁶ In 2022, the UK Royal Airforce completed a 100% SAF-powered flight with a military tanker.⁸⁷ The French military tested military NH90 helicopters on 100% SAF in 2023.⁸⁸

⁸³ Hendriks Vettehen, 'Minder Fossiele Brandstoffen Gebruiken Vraagt Technische En Militaire Innovatie', *Militaire Spectator*, 15 June 2023, <https://militairespectator.nl/artikelen/minder-fossiele-brandstoffen-gebruiken-vraagt-technische-en-militaire-innovatie>.

⁸⁴ gmcgcom, 'Why Do Planes Use Kerosene as Jet Fuel?', *GM&CG - GROUP C&SAR*®, 31 August 2024, <https://gm-cg.com/planes-kerosene-jet-fuel/>.

⁸⁵ 'Boeing Provides Guidance on SAF Usage for Defense Aircraft', Boeing, 20 June 2024, <https://boeing.mediaroom.com/news-releases-statements?item=131457>.

⁸⁶ 'Royal Netherlands Air Force Operating F-16 Fighting Falcons on 5% Biojet Blend', Bioenergy International, 16 January 2019, <https://bioenergyinternational.com/royal-netherlands-air-force-operating-f-16-fighting-falcons-on-5-biojet-blend/>; 'Norway Operates F-35s on Biofuel', Government.No, regjeringen.no, 15 January 2025, <https://www.regjeringen.no/en/aktuelt/her-flyr-norske-f-35-pa-biodrivstoff/id3083703/>; Swedish Armed Forces, 'Successful Tests with Fossil-Free Fuel', 2020, <https://www.forsvarsmakten.se/en/news/2020/12/successful-tests-with-fossil-free-fuel/>.

⁸⁷ 'Royal Air Force Completes World-First Sustainable Fuel Military Transporter Flight', GOV.UK, 2022, <https://www.gov.uk/government/news/royal-air-force-completes-world-first-sustainable-fuel-military-transporter-flight>.

⁸⁸ Mark Huber, 'French Military NH90 Helicopter Flown On Sustainable Aviation Fuel', Aviation International News, 2023, <https://www.ainonline.com/aviation-news/business-aviation/2023-02-10/french-military-nh90-helicopter-flown-100-saf>.

SAF can also be used by some military unmanned aerial vehicles (UAV). For instance, both MQ-9 Reapers and the X-300 Integrators used by the Royal Dutch Airforce use either F-34 (JP-8) or F-44 (JP-5)⁸⁹. This does not apply to others like the Black Hornets and Raven systems, which use battery driven propulsion systems.⁹⁰

The main difference that SAF and e-SAF bring to the military supply chain is at the beginning of the chain, during the production and blending process. The jet fuel must be blended with available SAF or e-SAF before entry into the military distribution and storage networks. After that, neither SAF nor e-SAF blends require significant alterations to storage facilities and distribution networks.⁹¹

Further fuel distribution for SAF and e-SAF closely mirrors the process of traditional fuel distribution. Fuel transports like pipelines, trucks, railway or barges can transport the fuel to airbases where military aircraft are either directly refuelled or from where tanker aircraft can take off to perform aerial refuelling operations.⁹² If needed, fuel can be transported to forward operating air bases closer to the front line.⁹³ However, generally, fuel distribution in the air domain is further away from the front line where airbases are already strongly integrated in both civilian and military fuel infrastructure.

4.2. Land domain

The land domain includes both combat and non-combat vehicles. Combat vehicles include tanks, armoured fighting vehicles, uncrewed land vehicles, anti-aircraft vehicles, reconnaissance vehicles and amphibious military vehicles. Non-combat vehicles comprise heavy and light trucks, fire engines, light utility vehicles, generators, heating systems and so on.

The main fuel used in land operations is diesel, although gasoline is also used in certain spark ignition engines. Moreover, under the NATO Single Fuel Policy, military land vehicles are often adapted to also be able to function on jet fuel, usually F-34. This means that ground forces mainly use diesel and jet fuel. The available alternative fuel options are therefore renewable diesel (HVO) and e-diesel in blends with traditional diesel; or SAF and e-SAF in blends with jet fuel, like in the air domain.

⁸⁹ INSITU, A Boeing Company, 'Integrator_ProductCard_DU040125', n.d., accessed 22 October 2025, https://www.insitu.com/wp-content/uploads/2025/04/Integrator_ProductCard_DU040125.pdf; Widdows, 'Military Drone Engines and UAV Propulsion Systems', *Defense Advancement*, 22 October 2025, <https://www.defenseadvancement.com/suppliers/military-drone-engines/>; Ministerie van Defensie, 'MQ-9 Reaper - Materieel - Defensie.nl', onderwerp, Ministerie van Defensie, 2 October 2023, <https://www.defensie.nl/onderwerpen/materieel/vliegtuigen-en-helikopters/mq-9-reaper>.

⁹⁰ Ministerie van Defensie, 'Black Hornet-onbemand verkenningssysteem - Materieel - Defensie.nl', onderwerp, Ministerie van Defensie, 4 May 2023, <https://www.defensie.nl/onderwerpen/materieel/vliegtuigen-en-helikopters/black-hornet-onbemand-verkenningssysteem>; Ministerie van Defensie, 'Raven-onbemand verkenningssysteem - Materieel - Defensie.nl', onderwerp, Ministerie van Defensie, 20 March 2025, <https://www.defensie.nl/onderwerpen/materieel/vliegtuigen-en-helikopters/raven-mini-uav>.

⁹¹ ICAO Environment and ACT SAF, 'SAF Logistics', n.d., 15, accessed 22 October 2025, <https://www.icao.int/sites/default/files/environmental-protection/Documents/ACT-SAF/ACT-SAF-Series-7-SAF-Logistics.pdf>.

⁹² Lukas Trakimavičius, *Mission Net-Zero: Charting the Path for E-Fuels in the Military* (NATO Energy Security Centre of Excellence, 2023), 31, <https://www.ensecocoe.org/publications/mission-net-zero-charting-the-path-for-e-fuels-in-the-military/>. Trakimavičius, *Mission Net-Zero*, 31.

⁹³ 'Life Cycle of AF Fuel: Onto Base and into Storage', Eglin Air Force Base, 2 December 2011, <https://www.eglin.af.mil/News/Article-Display/Article/391484/life-cycle-of-af-fuel-onto-base-and-into-storage/>.

Supply chains in the land domain can become very complex. Fuel distribution in this case is organised primarily through pipelines and other traditional means of transportation. Military operations utilize a variety of methods to get sufficient fuel to the frontlines, whereas the refuelling operations in the air and maritime domain can often be executed further away from the battleground. Therefore, military logistics planners value availability and uniformity as the main pillars in operations planning. Distribution in the rear can be done through well-established civilian infrastructure while distribution in the front requires a different complex operation specific logistics chain. Distribution in the front is even more costly; this is reflected in Fully Burdened Costs of Fuel calculations. As forward operating bases can be positioned in close proximity to the front line, FBCF costs can be very high. Divergent estimates by the US military calculate cost increases from an original price of \$2.82 per gallon to \$13 dollars to transport the fuel to a forward operating base. When forces operate in hostile areas the price can range from \$100 to \$600 a gallon, with the highest prices when fuel needs to be shipped in with helicopters.⁹⁴

A method to render this process more efficient would therefore be of great benefit for the land domain. The drop-in nature of SAF/e-SAF and renewable diesel/e-diesel are compatible, as they do not change the distribution arrangements as long as they have been blended at the source. Transport of fuel to forward operating bases is done via a variety of methods like trucks, railway, barge, etc.⁹⁵ Front distribution of fuel in the land domain is very mission specific but most often tanker trucks operating in convoys refuel combat units close to the front line. However, other methods like the airlift can also be used when traditional refuelling is not possible.⁹⁶

4.3. Maritime domain

The maritime domain consists primarily of naval ships, which can be split into warships and support or auxiliary ships. Warships include surface combatants like battleships, frigates or corvettes; amphibious warfare ships; aircraft carriers that act as seaborne airfields; submarines; patrol combatants. Auxiliary ships provide support during missions for transport and non-combat purposes like replenishment ships, fast combat support ships, hospital ships, spy ships and training ships, among others. Naval aviation, such as carrier-based aircraft, is also part of the maritime domain.

The main fuel used in the maritime domain is naval fuel, a type of marine diesel. For this purpose, renewable or e-diesel blends would provide opportunities in the short term. F-76, the main diesel used in navy ships, doesn't differ a lot from regular diesel. The marine variant usually has a lower sulphur content (capped at 0.1%) and has differing additive packages.⁹⁷ These additives provide stronger resistance to microbial contamination, water dispersants and better performance.⁹⁸

⁹⁴ Sandra I. Erwin, 'TRICK QUESTION: How Much Does the Pentagon Pay for a Gallon of Gas?', *National Defense* 94, no. 677 (2010): 30–32.

⁹⁵ Trakimavičius, *Mission Net-Zero*, 31. Trakimavičius, *Mission Net-Zero*, 31.

⁹⁶ *Petroleum Supply Operations*, 12–32.

⁹⁷ Mansfield Service Partners, 'What Is The Future of Marine Diesel Fuel?', *Mansfield Service Partners*, 21 June 2024, <https://msp.energy/what-is-the-future-of-marine-diesel-fuel/>.

⁹⁸ 'Marine - Diesel Fuel Additives', *Power Service*, n.d., accessed 28 October 2025, <https://powerservice.com/marine/>.

The two main distribution methods for the maritime domain are via dedicated bunkering facilities on shore or via on-sea refuelling. This means that navy vessels either must come into a friendly port or auxiliary refuelling ships have to meet combat ships at sea. Because of the drop-in nature of biodiesel and e-diesel, existing port infrastructure can service navy vessels without major alterations to the military supply chain.

Methanol and ammonia are emerging as potential alternative fuels in the maritime sector, especially in the civilian sector, but they are not feasible options for naval forces in the short term.⁹⁹ In the commercial sector methanol is in the early scale-up phase, while ammonia is approaching proof-of-concept. However, methanol and ammonia both face complexities in infrastructure that need to be overcome via “the coordinated development and deployment of new land- and sea-based technologies”.¹⁰⁰ These remaining issues are even more pressing for military usage, as discussed below.

Methanol can be produced from waste (bio-methanol) or captured carbon combined with green hydrogen (e-methanol). Methanol is not a drop-in fuel, so using it would require the retrofitting of existing engines or new installing new ones.¹⁰¹ However, methanol has a lower energy density in comparison to its traditional counterparts which translate into bigger fuel tanks on ships to maintain the same operational capacity.¹⁰² In a civilian context these problems can be overcome, but for military ships that generally need a lot more room to accommodate weapon systems as well as extra personnel, this is not preferable.

Green ammonia contains no carbon and offers the potential for zero-carbon propulsion in the civilian sector. The fuel poses challenges around toxicity, handling, and combustion efficiency. It also has a lower energy density compared to traditional maritime fuel and even methanol. The toxicity of the gas is problematic in a military context. Leaks of the gas, although easily recognizable through its distinct smell, can cause serious harm to soldiers aboard.¹⁰³

Finally, naval aviation uses high-flash point jet fuel given the high fire risk during maritime operations. This can be blended with drop-in fuels without modifications, just like all the other jet fuel variants discussed in the air and land domain above.

⁹⁹ *From Pilots to Practice: Methanol and Ammonia as Shipping Fuels* (Global Maritime Forum, 2025), 4, https://downloads.ctfassets.net/gk3lrimlph5v/42oVCMYa8EuGXsvd46hIH6/e7a183fa7ad-b94749676607ad72a2a8c/Getting_to_Zero_Coalition-From_pilots_to_practice__Methanol_and_ammonia_as_shipping_fuels.pdf. *From Pilots to Practice: Methanol and Ammonia as Shipping Fuels*, 4.

¹⁰⁰ *From Pilots to Practice: Methanol and Ammonia as Shipping Fuels*, 2. *From Pilots to Practice: Methanol and Ammonia as Shipping Fuels*, 2.

¹⁰¹ *From Pilots to Practice: Methanol and Ammonia as Shipping Fuels*, 3.

¹⁰² 'Zero-Emission Shipping Fuels: A Guide to Methanol and Ammonia', 19 August 2025, <https://globalmaritimeforum.org/news/zero-emission-shipping-fuels-methanol-and-ammonia/>. 'Zero-Emission Shipping Fuels'. 'Zero-Emission Shipping Fuels'.

¹⁰³ 'Zero-Emission Shipping Fuels'. 'Zero-Emission Shipping Fuels'. 'Zero-Emission Shipping Fuels'. 'Zero-Emission Shipping Fuels'.

5. Conclusion

The interdependence of civilian and military fuel infrastructure means that the energy transition will undoubtedly impact military fuel readiness. For this reason, this report identified and assessed challenges and opportunities of the civilian energy transition for military fuel readiness across the air, land and maritime domains as of 2025. Based on the analysis, the following five conclusions emerge:

1. **The most important feature of a military fuel is its alignment with military performance requirements.** Military fuels are judged based on availability, flexibility, logistical simplicity and battlefield performance, with upfront fuel cost taking a secondary role. Most European militaries use the NATO Single Fuel Policy, a framework that aims to harmonise fuel usage policies for all NATO Allies, focused on F-35 jet fuel, also known as JP-8 in the United States.
2. **Changes in civilian fossil fuel availability and logistics infrastructure necessitate a reassessment of military fuel readiness.** As the civilian market moves away from fossil fuels, the available supply as well as adequate infrastructure to move these fuels through Europe will likely deteriorate. This brings risks for military fuel readiness in the short and medium term. At the same time, the growing domestic alternative sustainable fuels market can strengthen the resilience of military supply chains and therefore mitigate some of these risks.
3. **The gradual adoption of domestically produced drop-in fuels can reduce dependence on oil imports, thereby enhancing supply chain resilience.** The most likely candidates for swift adoption are drop-in fuels that can be blended with fossil fuels, notable synthetic fuels and advanced biofuels. They meet performance needs, diversify supply, and fit existing military systems and fuel infrastructures without any changes.
4. **While it is in both the civilian and military sectors' a near-term interest to increase adoption of drop-in fuels, the scale of this industry has not yet kicked-in.** The growing maturity of synthetic and bio-based alternative fuels markets could offer medium-and long-term term opportunities for the military, provided that sufficient investments are made for scaling.
5. **Other alternative fuels such as synthetic and bio-based methanol and ammonia are not fit for military use.** Their low density, the associated requirements for new military hardware and heavy investment in new fuel infrastructure and logistics, and high toxicity and flammability make it unattractive for military consumption.



The Hague Centre
for Strategic Studies

HCSS

Lange Voorhout 1
2514 EA The Hague

Follow us on social media:

@hcssnl

The Hague Centre for Strategic Studies

Email: info@hcss.nl
Website: www.hcss.nl