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The Armed Forces of the Future

Can hydrogen ensure energy independence and contribute to the development of a new energy market?

Introduction[1]

National and European objectives to achieve climate neutral economies by 2045 or 2050 are leading to fundamental changes in our energy supply. Around the world, researchers are focusing on the replacement of fossil fuels.

The issue of energy independence for the Bundeswehr of the future is highly significant in view of likely changes in the energy infrastructure and propulsion systems concerning mobility. As a user of these systems and technologies, the military also depends on these developments and must continuously consider the implications for its strategies and the procurement system. One of Germany's focal points is the National Hydrogen Strategy.

This study focuses on whether alternative energy sources, and hydrogen (H_2) in particular, can be used by the Bundeswehr. We will analyze the entire field of military mobility including the energy infrastructure and show possible applications. In addition, we want to determine which contribution armed forces can make regarding the use and market development of regenerative energies and hydrogen in particular. Based on an analysis of current and expected developments in the industry and the field of research, and pursuant to the European climate objectives, the aim is to develop a strategic perspective for energy autonomy of the Bundeswehr from 2050 onwards.

Due to long service lives of military systems and the time needed to carry out procurement processes, it is important to closely monitor the transformation of the energy market from an early stage. In addition to this first contribution, the GIDS therefore plans to publish a series of further articles that will not only feature analysis of technological developments, but also cover possible applications for the Bundeswehr with regard to operating conditions, military logistics, interoperability and safety in handling.

When designing the armed forces of the future, from a military-operational point of view, it is also crucial to answer the pertinent energy-related questions.

1 The authors wish to thank the experts for their comments and suggestions.

The current situation – a changing energy market

Crude oil and natural gas today still count as the key resources for the global economic cycles. The military is also part of these cycles. Increasing reliance on technology, in particular, makes energy-intensive systems necessary that were so far mainly powered by these fossil fuels. Therefore, the ability to plan and conduct successful military operations is also increasingly linked to the energy management of the armed forces themselves.[2] It is well-known that, from a strategic and security-related point of view, this economic and military dependence on oil makes access to this energy source and stabilization of the oil markets a vital necessity.[3]

This circumstance is particularly relevant in light of current developments in the fossil energy market. The fall in oil prices after 2014, for example, led to a decline in investments in this market segment. Although capital investment gradually stabilized and slightly increased until 2019, it still hasn't returned to the level of 2014.[4] This does not mean we are calling into question the importance of these energy sources, because their supply must by all means still be ensured for a long period of time. It is natural gas, in particular, that should be seen as a longer-term bridging technology.

Especially in Europe, the production of crude oil and natural gas will decrease in the foreseeable future due to continued depletion of reservoirs. As a result, dependence on crude oil from crisis regions will increase. Natural gas imports from Western Europe will also become harder to accomplish. This development has been expected for many years, but it will accelerate if consumption continues to increase as projected while investment remains low, particularly in the area of exploration. The long time periods required for exploration and development of new reservoirs, ranging from ten to twenty years, make it likely that there will be shortages and price volatility or increases in the future.[5]

On the other hand, there is the worldwide ratification of the Paris Climate Agreement, which shifts the basic energy policy framework and will likely lead to changes in the logic described above. In this context, the assessment of the International Energy Agency (IEA) published in May 2021 is particularly striking. Based on the objectives of the Paris Climate Agreement for 2050, the IEA even calls into question the need for future exploration of new oil and gas fields.[6] According to the IEA, achieving the objectives will lead to a decrease in crude oil and natural gas consumption. This then presupposes the development of alternative energy sources.

These developments indicate the challenges the energy market will be faced with in the near future. Lacking investment in fossil resources and delays in switching from fossil fuels to renewable energies make shortages likely. It is therefore imperative to improve the energy independence of the armed forces.

2 Saritas/Burmaoglu 2016: 331–333.
3 Bayer/Struck 2021: 4; Saritas/Burmaoglu 2016: 334.
4 IEA 2018:156–163; IEA 2020b: 44; IEA 2021b: 277 f.
5 IEA 2018: 156–163.
6 IEA 2021a.

Energy in 2050 – hydrogen as a component of a sustainable energy economy

The framework of a future hydrogen market

Hydrogen is a key element in the transformation process of the energy market. In this context, the groundbreaking IEA paper entitled *The Future of Hydrogen*, compiled for the G20 Summit in Osaka in 2019, can be seen as a standard work of reference. This is also directly reflected in the G20 final declaration, which highlights the special importance of this energy source: 'We also recognize opportunities offered by further development of innovative, clean and efficient technologies for energy transitions, including hydrogen.'[7]

As a consequence, several G20 states have developed national hydrogen strategies, with governments emphasizing the fundamental importance of hydrogen for the energy transition of various industries, the heating market and, above all, for mobility.[8]
The National Hydrogen Strategy published by the German government in 2020 also points out the special significance of hydrogen for military applications, particularly in the transport sector:

> Mobility applications offer great potential for hydrogen uses. The transport sector must rely on technological progress if it is to reach the sector-specific climate and renewables targets. Hydrogen-based or PtX-based mobility can be an alternative option for those applications where using electricity directly is not reasonable or technically feasible. This includes military applications that must be able to ensure interoperability between allies.[9]

Hydrogen use, however, if intended to substitute fossil fuels within the mobility sector, to make energy-intensive industries more sustainable and to tap into the heating market, poses enormous challenges for the energy market.

It is expected that there will be a multiplication in the current demand for hydrogen and therefore also in its generation capacity. In its National Hydrogen Strategy, the German government assumes that the country's hydrogen demand in 2050 will be at least seven times higher than today.[10] Other estimates even suggest that the quantities required will be much higher.[11]

Within the industrial sector, the expansion of the existing hydrogen market is expected especially when it comes to energy-intensive companies, such as those producing steel and cement.[12] Mobility can be considered another main factor in this

7 G20 2019: 11.
8 Taibi/Miranda/Carmo 2020: 19–25; Bundesministerium für Wirtschaft und Energie [Federal Ministry for Economic Affairs and Energy] 2020: European Commission 2020; Secretary of State for Business, Energy & Industrial Strategy 2021; Government of the Netherlands 2020.
9 Translated from the German original: Bundesministerium für Wirtschaft und Energie [Federal Ministry for Economic Affairs and Energy] 2020:11.
10 Bundesministerium für Wirtschaft und Energie [Federal Ministry for Economic Affairs and Energy] 2020; European Commission 2020.
11 Robinius et al. 2020.
12 Bundesministerium für Wirtschaft und Energie [Federal Ministry for Economic Affairs and Energy] 2020: 2.

expansion.[13] In this area, hydrogen and its derivatives constitute an essential alternative to fossil fuels and, for many applications, also to electromobility. According to IEA estimates, the transport and mobility sector and the associated sustainable production of fuel could account for more than one-third of the projected global hydrogen demand in 2050. For 2070, the IEA even predicts a hydrogen demand of 520 million tons (2019: 75 million tons). Mobility is expected to account for 60 percent of this demand:[14]

> In the Sustainable Development Scenario, this situation changes, with global hydrogen demand increasing sevenfold to 520 Mt by 2070 [...]. The direct use of hydrogen in the transport sector for cars, trucks and ships accounts for 30% of hydrogen use in 2070, while around 20% of hydrogen is used in the production of synthetic kerosene from hydrogen and C02 for the aviation sector, and a further 10% is converted into ammonia as a fuel for the shipping sector, meeting almost half of all shipping fuel demand in 2070.[15]

This shows that hydrogen is seen as highly important for the mobility of the future.

The challenge: developing the hydrogen market

However, this comprehensive integration of an alternative energy source faces the challenge that the integration will be into an existing energy market where (fossil) energy technologies are already established. An economic policy that is open to technology, something that is often supported by economists also in the context of climate policy, could become an impediment to the market introduction of alternative energy sources:

> The assumption that an open competition among the different technologies will lead to achieving the objectives at minimal cost can only be maintained if these technologies are competing on equal terms from the start. It cannot be maintained if sophisticated and established technologies compete with those that are in relatively early stages of their development with high potential for cost reduction, for instance due to size effects or learning curve effects. In the long run, these innovative technologies often have the potential to achieve the prescribed climate objectives in a more cost-effective way than established technologies.[16]

In its study *The Future of Hydrogen*, the IEA therefore underlines the key role that government actors play in ramping up the hydrogen market.[17] The suggested course of action is to introduce government guidelines and policies that will make the expansion of hydrogen in the energy market economically efficient. Because the gradual ramping up of a hydrogen market in the industrial and transport sectors requires the development of transport structures and particularly also of demand structures. The energy sector is therefore facing the challenge of developing the hydrogen market without any clear

13 IEA 2020a, 2019; Robinius et al. 2020; Perner/Unteutsch/Lövenich 2018; Merten et al. 2020.
14 IEA 2020a: 110.
15 IEA 2020a: 110.
16 Translated from the German original: Kemfert/Elmer/Dross 2017: 485.
17 IEA 2019.

market mechanisms, because infrastructure projects can only attract investors if there are robust demand structures.[18]

It should be noted that government interventions in the energy market also pose a substantial risk to the economy. Government steering mechanisms may contribute to assets and investments being allocated to a technology that turns out to be less efficient and competitive than others. The resulting one-sided creation of demand and infrastructures could have a negative impact on the development of the energy sector.[19]

However, this risk still remains low with respect to hydrogen, because H_2 can be used directly as an energy source on a broad basis and is highly versatile when it comes to fields of application. For instance, hydrogen can also contribute to mobility by directly being used as fuel in suitable hydrogen combustion engines.[20] Hydrogen is already being used in combination with fuel cell technology in various applications.

In addition, so-called *green hydrogen* from renewable energy generation is one of the basic components for the process-intensive and expensive production of synthetic fuels (e-fuels). Synthetic fuels, which are likely to become necessary for energy-intensive applications, can be used in the existing infrastructure for oil and gas. Nevertheless, much like the production of *green hydrogen*, the cost of producing synthetic fuels still needs to be considerably reduced.[21]

Producing so-called grey *hydrogen* from fossil energy sources such as natural gas may become significant. However, the CO_2 storage via carbon capture storage (CCS) that will be necessary to make this process climate-neutral (blue hydrogen) can hardly be regarded as a permanent solution in terms of quantity. In view of the anticipated high volumes of CO_2, the CCS capacities seem very limited. Consequently, this production process must be seen as a long-term bridging technology. It is questionable whether the climate objectives can be achieved by 2050 and beyond by using such a technology on a broader and sustained basis.

Based on current knowledge, *green hydrogen* will thus play a key role in the future production and use of energy. The German government, the EU and scientific institutions are expecting a massive increase in hydrogen demand in the coming decades.[22] At present, however, the capacities for its production are limited. An expansion on the scale envisaged seems very ambitious. It would require massive investments in suitable technical facilities and, in view of the imports becoming necessary, especially also in the areas of transport and infrastructure.

It must be clear that for *green hydrogen* to play a central role, the competitive profitability of its value chain and usage will be a key element, i.e. in comparison to other energy production systems. After all, the ultimate goal is not to use a particular technology, but to consistently prevent emissions. Only full-cycle cost considerations of economic viability will show the extent to which investors can be attracted to a specific technology.

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18 Schulte/Schlund 2020; Kemfert/Elmer/Dross 2017: 484–486.

19 Kemfert/Elmer/Dross 2017.

20 Klell/Eichlseder/Trattner 2018.

21 Perner/Unteutsch/Lövenich 2018.

22 This is further reinforced by the envisaged energy generation from gas-fired power plants using hydrogen, see Bundesministerium für Wirtschaft und Klimaschutz [Federal Ministry for Economic Affairs and Climate Action] 2022.

Design of the hydrogen market and role of governments

The challenges outlined above give government actors a special role in the market developing of alternative energy sources. In this respect, the comprehensive approach suggested by the IEA seems promising. It envisages the ramping up of the hydrogen market to initially take place in *coastal industrial clusters* so as to align and expand demand and consumption on a regional basis. The IEA has identified the North Sea region as particularly suitable for the realization of such a concept.[23]

When the hydrogen market expands, however, even for such a market design the question will need to be answered how hydrogen can be made available to industrial clusters. Both the IEA report and the German government's National Hydrogen Strategy therefore underline the importance of hydrogen imports as the ramping up of this energy source continues, because the required renewable energies can be provided in conjunction with electrolysis plants, especially in sunny and windy regions.[24] Closer cooperation with countries in North Africa and the Middle East, for instance, could also lead to a new *OPEC for hydrogen* in the future.

These considerations also show fundamental economic and strategic implications: not only will the need to import energy sources remain, but it will even increase. Unlike crude oil, H_2 is a diverse energy source that could be directly used after importing. Existing value chains along industrial processes in Europe, such as those in the crude oil industry in the refinery process, would thus be eliminated to a considerable extent.

In developing a market design, the aspect of transport infrastructure is similarly important to the production itself. The authors believe that road transport, rail, and inland waterway transport play a special role in this context, because they allow increasing demand to be developed with the necessary flexibility, without the need for major investments in the start-up phase that cannot be justified from an economic point of view.[25] An extensive expansion of hydrogen pipeline systems or the rededication of existing natural gas pipelines and storage facilities for hydrogen can only take place after secure demand has been established within the intended hydrogen industry clusters.[26]

In order to build hydrogen demand structures, besides technology-independent penalization of fossil energy sources through measures such as CO_2 pricing, the IEA particularly emphasizes specific economic policy instruments: In addition to providing subsidies and incentives, such as those found in the German government's National Hydrogen Strategy, another key instrument is targeted demand development with the help of state actors and public projects. [27,28] In this respect, the armed forces could also play an important role.

23 IEA 2019: 177–182.

24 Bundesministerium für Wirtschaft und Energie [Federal Ministry for Economic Affairs and Energy] 2020: 4; IEA 2019: 191 f.

25 IEA 2019: 191.

26 Wang et al. 2020: 6.

27 Bundesministerium für Wirtschaft und Energie [Federal Ministry for Economic Affairs and Energy] 2020.

28 IEA 2019: 175–177, 181 f.

The Bundeswehr's potential in establishing a hydrogen market

The fact that armed forces have been able to make important contributions to the energy sector is demonstrated by the military's fundamental research on nuclear energy and gas turbine technology, which also had a decisive influence on the civilian sector. In the field of renewable energies, however, it is mostly civilian innovations that are being adopted by armed forces.[29]

Based on second-order effects, however, (energy) technologies and their related market sectors can also be driven by armed forces in areas other than direct defence innovation.[30] As a consumer of civilian technologies, the military procurement system provides important impetus for technological developments, especially in their early stages. As a lead and first purchaser of certain technologies, for example, the U.S. Armed Forces implement products in early phases of development that are expected to improve military capabilities. These stimuli for demand in the early stage of product development thus become an instrument of incentive control, because the companies involved are encouraged to make strategic investments in the further development of the technology. The associated market establishment of a technology or an energy source can therefore also increasingly become an economically attractive option for civilian companies.[31]

Due to its extensive network of facilities and large fleet with more than 30,000 civilian and military vehicles (including Bw FuhrparkService, the Bundeswehr's fleet management company), the Bundeswehr is the largest fuel consumer among Germany's federal agencies. The Federal Police, for instance, only operates about 7,000 vehicles. Considerable potential for hydrogen consumption in the armed forces can therefore be expected. Although the Bundeswehr's fuel consumption only amounted to about three terawatt hours in 2018[32], the potential consumption based on operational scenarios is likely to be much higher. With its almost 1,450 facilities and more than 33,000 buildings[33], the Bundeswehr could therefore become an important government instrument for ramping up demand within the above-mentioned market design, if it were to integrate hydrogen into its energy management.

To exploit the synergies between civilian market development and military applications, the potential uses of future military energy sources need to be analyzed with a view to transforming the energy sector at the nationwide level.

Hydrogen as a fuel for military mobility

The overall situation of the armed forces, especially regarding mobility, poses challenges for the integration of alternative energy sources. The Single Fuel Policy of the U.S. Armed Forces and its NATO allies only seemingly restricts the opportunities to diversify energy sources:[34]

29 Bayer/Struck 2021: 8.
30 Sempere 2018: 229; Soni 2020: 128; Bayer/Struck 2021.
31 Mowery 2010: 1236 f.; Schmid 2018: 597; Bayer/Struck 2021.
32 Deutscher Bundestag [German Bundestag] 2019: 7.
33 BMVg [FMoD] 2021.
34 National Academies of Sciences, Engineering, and Medicine 2021.

> restricting military users to a single fuel and thereby disincentivizing experimentation with alternatives, it has helped to create the mentality that petroleum fuels are the exclusive energy source in a forward environment. The Department of Defense [and its allies] needs to look past the single fuel concept and fully embrace the recommendations in its 2016 Operational Energy Strategy report to reduce the risks associated with the future operating environment through "innovation" and "diversification" of operational energy.[35]

This shows there have also been calls for innovation and diversification of energy sources within the U.S. Department of Defense. Accordingly, the U.S. Armed Forces are testing applications such as hydrogen and fuel cell powered UAVs, auxiliary power units (APUs), cars and armored vehicles.[36]

However, these diversification strategies must be pushed forward, and not just by individual NATO member states. The interoperability of the armed forces makes it necessary to pursue the development and implementation of sustainable energy systems such as hydrogen throughout NATO. This kind of holistic approach would also have positive effects on the global availability of these energy sources in the military context. It must therefore be the objective to further deepen cooperation among NATO countries in this respect. Such initiatives already exist between European allies in the area of infrastructures.[37]

The direct use of hydrogen as an energy carrier for the Bundeswehr in the future must therefore be seen as a long-term process, which is why an evaluation period up to 2050 was chosen. The long service life of military systems and protracted procurement processes make it necessary to look at options for introducing alternative energy and propulsion systems at an early stage. Accordingly, the procurement process must be oriented and adapted to a changing energy and fuel market as early as possible.
Particularly against the backdrop of new developments in the mobility sector, hydrogen could increasingly be used by military players as well, since there are developments in the area of propulsion systems already apparent today that suggest substantial advantages for military applications:

The military potential of hydrogen as an energy carrier is not fundamentally new, but was recognized early on by the U.S. Armed Forces, for instance in connection with fuel cell applications back in 2011.[38] In the Bundeswehr, hydrogen is also already being used in submarines, for example.[39] Fuel cells, in particular, offer direct operational benefits due to their reduced acoustic, visual and thermal signatures in comparison to conventional propulsion systems.[40]

When examining the comprehensive use of hydrogen in the armed forces, the objective certainly cannot be to only highlight operational benefits within the weapon systems in the narrower sense. What should also be pointed out are the implications for military energy systems and the associated logistics at home and abroad, for instance regarding the generation, storage, and transportation of the energy carrier.

Civilian developments, in particular, already demonstrate how extensively hydrogen can also be used for military applications. In the civilian marine sector, for

35 Kern et al. 2021; see also US Department of Defense 2016: 13 f.
36 Gross/Poche/Ennis 2011; Stroman et al. 2018; Zhou et al. 2021; Mayor-Hilsem/Zimmermann 2019.
37 European Defence Agency 2020.
38 Gross/Poche/Ennis 2011.
39 Krummrich/Hammerschmidt 2016.
40 Das 2017.

example, there are already dual fuel combustion engines on the market that allow tugs and ferries to be flexibly operated with hydrogen and conventional diesel.[41] Such concepts could be crucial especially in the early phase of military integration of new energy carriers, since they allow hydrogen to be used without initially giving up interoperability in the context of NATO's Single Fuel Policy.

Particularly within road haulage and for special machinery in the agricultural and construction machinery sector, hydrogen-based drive systems are an integral part of engine development by various German manufacturers. In this area, the battery technology used in electric mobility has currently reached its limits. Hydrogen combustion engines already have a similar performance level to conventional petrol or diesel-fuelled units. The difference in performance is currently around 20 percent and still has potential for optimization.[42] Besides the hydrogen combustion engine, which requires further development, the fuel cell is another important option for hydrogen-based drives within these sectors.

In civil aviation, a large aircraft manufacturer recently stressed the importance of hydrogen as an energy source for carbon-neutral air travel in short- to medium-range flights.[43] And manufacturers are also confident that hydrogen-based propulsion systems can be successfully implemented for these applications in the area of engine technology.[44] It must be clear, however, that all these promising developments have yet to be examined in more detail in terms of their usability and the Bundeswehr's required capability and performance profiles.

Challenges with H_2 as an energy source in military mobility

Notwithstanding the above, it is also important to take a more critical look at the use of H_2 as an energy source in military mobility. The key challenges of hydrogen are particularly apparent in military applications, with the low volumetric energy content and handling of the volatile gas still requiring further advances in storage technology.[45] However, it seems presumptuous to already anticipate the results of a research programme worth some nine billion euros being carried out as part of the National Hydrogen Strategy. The innovation drive initiated by the national and European hydrogen strategy should not be underestimated. Challenges, such as the need for innovative tank systems for hydrogen storage as well as transporting the gas in carriers, are being addressed with some very promising development approaches.[46] Besides liquid hydrogen transport (LH_2), which is already well-known, these include liquid organic hydrogen carriers (LOHC) as well as ammonia and methanol.

Defining limits for the use of hydrogen therefore seems premature at the present time. Accordingly, a strategy by the Federal Ministry of Defence[47] on sustainable energy systems in military mobility that is based purely on synthetic fuels can only be interpreted as a medium-term strategy, since these fuels can be integrated quite rapidly due to fewer infrastructural adjustments. It must be clear that, as things stand today,

41 BeH2ydro 2021; CMB.Tech 2021.
42 Schrank/Langer/Jacobson 2021.
43 Airbus 2021.
44 Dilba 2021
45 Environmental policy considerations must also be taken into account, since hydrogen combustion produces nitrogen oxides, for example.
46 Klell/Eichlseder/Trattner 2018: 137–139.
47 BMVg [FMoD]/Bundesministerium des Innern [Federal Ministry of the Interior] 2021.

synthetic fuels are likely to be needed as a substitute for fossil fuels, especially in energy-intensive applications such as combat aircraft, heavy battle tanks and certain naval vessels, because of their higher energy content.

Nevertheless, additional substantial investment in production facilities will also be necessary here in order to build up relevant capacities. This production infrastructure would also require hydrogen production based on renewable electricity generation because *green hydrogen* is part of the production chains of sustainable synthetic fuels (e-fuels). Given its simpler production process, hydrogen that is used as a direct fuel for combustion engines and fuel cells is a more cost-effective option.[48] Civil industry players in transportation, road haulage, coastal shipping, and short- to medium-range aviation may therefore consider hydrogen the most commercially viable option in the long term, especially if there are innovations in storage and engine technology. This will also point the way for the future types of fuel used by the Bundeswehr.

Hydrogen in Bundeswehr facilities – the Bundeswehr's contribution to the market ramp-up?

Besides the above-mentioned implications for the military mobility sector, the use of hydrogen also offers direct operational benefits for the management of facilities, provided the energy source is integrated into an overall concept for military energy management. Comparably short, renewable energy-based electrolysis processes might be used to implement decentralized energy generation systems in Bundeswehr facilities. These could be used to meet own needs for facility operation and the vehicle fleet in order to establish energy-autonomous locations. These considerations are already evident in the European Defence Agency's RESHUB project and in the Munich Mobility Research Campus operated by the Bundeswehr University Munich.[49]

Plans for energy independence such as these can have repercussions for the market ramp-up of hydrogen. This is beginning to become apparent, for instance, in the project of the European Defence Agency, where the Bundeswehr locations are intended to contribute to the national hydrogen infrastructure.[50] Especially together with a market ramp-up in the *coastal industrial clusters*, Bundeswehr locations and their vehicle fleets and facilities in the North Sea region could become important consumers of hydrogen and hubs for an initial market ramp-up. Furthermore, they could promote structures for transport and refuelling for the mobility sector.

In the first stage of the market ramp-up, the armed forces could therefore also be an important factor in terms of economic policy: As early adopters, they could not only increase their own energy independence, but also provide significant incentives for the development of demand and infrastructure in the hydrogen market. A key consideration in this respect are dual-use concepts, i.e. concepts allowing both civilian and military use of hydrogen in peacetime operation. For instance, hydrogen fuelling stations inside military facilities could be integrated into a civilian service station network.

48 Perner/Unteutsch/Lövenich 2018.

49 European Defence Agency 2020; Zentrum für Digitalisierungs- und Technologieforschung der Bundeswehr 2020.

50 European Defence Agency 2020.

Conclusion: New self-image for the armed forces

Bringing together these energy policy and military objectives will, however, require the Bundeswehr to develop a new self-image. The armed forces will need to see themselves as an actor within the energy and economic system. This will involve leaving the somewhat passive role as a consumer of technologies and energies and aiming to actively shape the national energy systems, also from the military perspective. The large vehicle fleet of over 30,000 vehicles (including Bw-FuhrparkService) and real estate operations make the armed forces an important energy consumer who could contribute to a market ramp-up, especially in the early stages of sustainable energy infrastructure development, together with other federal and state organisations. The Bundeswehr could therefore also serve as an instrument of economic policy to support the development of the hydrogen market. Involving military actors in infrastructure projects may enable the allocation of additional public funds to the defence budget, thereby theoretically contributing to the achievement of NATO's 'two percent target'.

Such an infrastructural integration of the armed forces, however, first requires a critical look at the Bundeswehr's future energy sources. In future, hydrogen and its derivatives will be a key component in achieving climate-neutral armed forces. In this context, a closer look should be taken at using hydrogen directly, as its integration is already becoming apparent today in civilian applications.

Current developments are on a promising path to making hydrogen usable as a military fuel. As shown above, this also offers military advantages. In certain applications, dual fuel solutions used for coastal shipping already have a similar performance level as previous propulsion systems. It follows that integration in these areas would also be possible in a military context. Engine and system manufacturers in aviation are also confident that hydrogen could be used as a climate neutral fuel for short and medium range applications. Leading European engine and system manufacturers in the special machinery sector for construction and agriculture, as well as in the bus and truck sector, have recently presented innovative drive concepts that also suggest integration into military systems, including those of the German army.[51] Besides transportation, light armored vehicles could also be focused on – both areas have a sufficiently large number of vehicles. Clearly, both areas need to be closely examined for their suitability regarding the capability and performance profiles of the Bundeswehr. This could potentially be done on the basis of pilot projects.

The presented developments are to be introduced in more detail in further contributions from GIDS in order to examine their possible usage for military applications. Moreover, the pursuit of future energy independence for the armed forces makes it necessary to take a closer look at hydrogen production and infrastructure. In addition to this analysis, the aim is to also consider the Bundeswehr's potential contribution to the design of a future hydrogen market.

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51 AVL/ZSW 2021; Airbus 2021; BeH2ydro 2021.

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