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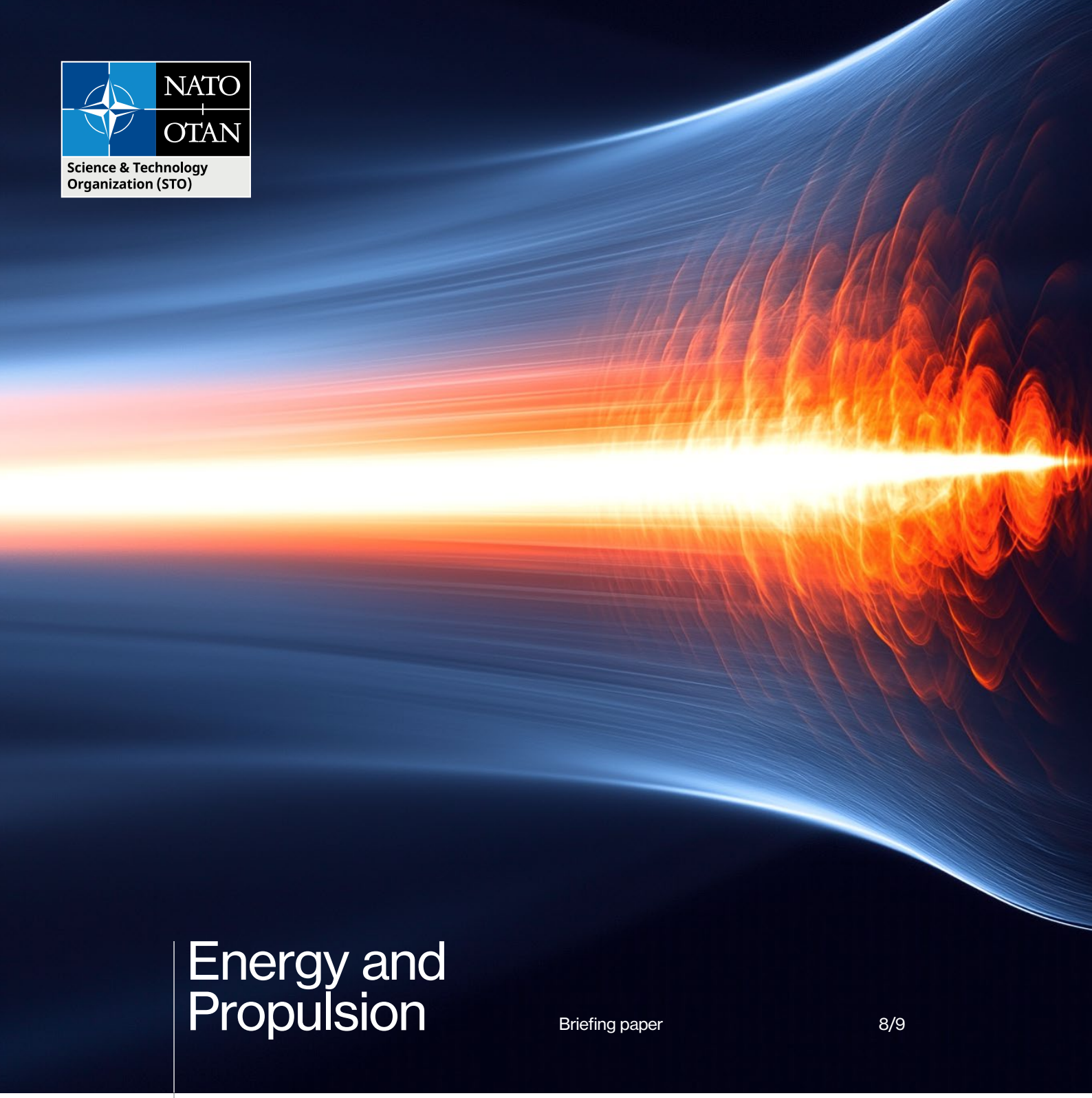

Energy and Propulsion

Briefing paper 8/9

Energy consumption trends indicate that global energy demand will increase significantly over the next 30 years, while many countries will reduce carbon emissions. Security and price of energy supplies are still at risk through geopolitical conflict, including fuel for military assets. The development of propulsion technologies, energy sources, advanced battery storage and transmission technologies is progressing. Simultaneously, climate change impacts are intensifying.

Implications

Economic Implications – Research and development for an eco-friendly economy is increasing, and is expected to drive greater use over renewables as they become more cost-effective and profitable. Government investment and large economies' strategies will drive a race to develop environmentally friendly technologies and address energy needs. These developments may require new regulatory frameworks, taxation and incentives.

Military Implications – Military operations have traditionally been energy-intensive and reliant on fossil fuels. With increasing competition and geostrategic challenges to global energy supplies, Allies have agreed to enhance energy security and invest in stable, reliable energy supplies and sources. Strategically, competition is escalating for access to rare earth elements, and cleaner ore processing capabilities needed for renewable energy technologies. Reliance on next-generation energy solutions will require the integration of renewable energy and battery systems into defence infrastructures and national power grids.

Societal Implications – The pace of renewable energy-source development will determine the speed and effectiveness of climate change solutions. Factors like clean air and access to water have far-reaching implications for human health and well-being. The transport sector will play a major role in developing newer, cleaner, more efficient propulsion technology. Access (or lack thereof) to clean, affordable energy could alleviate or exacerbate inequality and economic competitiveness. To meet these challenges and develop new energy technologies, it will be crucial to re-skill and up-skill the workforce.

Key Technology Areas

Power Generation – Clean energy generation is advancing rapidly due to technological advances mitigating the effects of climate change, rather than those focused on military applications. These technologies should be adapted to support NATO's climate objectives. Solar power is now economically competitive with fossil fuels due to increased research on thin-film flexible solar cells, for example. Biofuels using existing infrastructure are also promising, although the potential for environmental damage must be addressed. Nuclear power, despite reputational challenges, offers solutions such as Small Modular Reactors (SMRs) and accident-tolerant technologies (e.g. thorium-based molten salt reactors).

Storage and Transmission – Rising demand, reliance on intermittent sources and the limitations of dominant lithium-ion batteries are driving research into new energy storage technologies like lithium-sulphur or sodium-ion batteries, which may offer lower degradation and higher energy density. Supercapacitors provide energy storage without relying on electrochemical mechanisms, but still face significant limitations. Energy security for militaries is essential, as they rely on civilian power grids. As such, wireless power transfer and localised microgrids are expected to enable further improvements.

Propulsion – Vehicle electrification is key to the carbon-neutral energy transition – due to commercial innovation, electric ground vehicles are rapidly gaining market share. Electric aircraft prototypes, some of which are close to starting larger production, are in development. Space propulsion technologies, including chemical, solar, electric, and nuclear, are evolving rapidly to deliver cost reductions, increased endurance/reliability, and extended mission timespan. Combined-cycle engines (low-speed turbojets transitioning to high-speed scramjets) may also enable crewed hypersonic flight in the atmosphere.

Technology Convergence

Artificial Intelligence and Materials – Developments in energy storage, driven by novel materials such as graphene and exotic battery chemistry, as well as stronger lightweight materials, novel designs and advanced manufacturing (e.g. supercapacitors or 3D printing), will drive electrification or the use of green fuels (e.g. biofuels) in military operations. AI applications to support these designs and material developments and optimise energy usage will contribute to lower carbon emissions of NATO activities.

Biofuels and Space – In coming years, alternative fuels from biological sources (often plant-based) will be used in the aviation and shipping industries, as well as for specific military tasks such as fuelling autonomous vehicles or powering remote operating bases and assets. New space propulsion technologies (e.g. nuclear thermal propulsion and nuclear power) will support deep space exploration and extend the lifespan and capabilities of satellites. Space-based solar farms may also provide a new, sustainable source of energy.