Energy Security: Operational Highlights

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Content

Editorial

By COL Romualdas Petkevičius (LTU-AF)
Director of the NATO ENSEC COE

When responding to security threats and crises, NATO Allies and partner countries must be able to deploy their forces rapidly and effectively. Technological innovation has always been critical for achieving military success. Matched with creative strategic thinking, advanced technology often made a difference. Military energy needs are changing as well as growing. More significant, the dramatic increase in electrical systems onboard military platforms is driving electrification of the battlefield. That and the need to reduce the logistic footprint are creating requirements for distributed and portable power generation, smart energy networks, improved energy storage, and wireless power transmission.

The share of renewables in the global energy mix should be more than double by 2030 to advance the global energy transition. Falling technology costs continue to strengthen the case of renewable energy. Solar panel costs have fallen by almost 90 per cent over the last 10 years and onshore wind turbine prices have fallen by half in that period. The global energy market slowly but surely moves towards a renewable-centered paradigm.

More clean energy means more solar panels, wind turbines, electric vehicles and large-scale batteries. At the same time it means more demand for the materials that make those technologies possible. In a sense we have now entered the "Rare Metal Age" as science and human ingenuity have allowed us unlocking of various magnetic, luminescent, heat resistant and conductive properties of a diversity of metals such as lithium, cobalt, indium, gallium, neodymium and dysprosium that are now delivering technological innovation.

Emerging or disruptive technologies and innovation in the energy sector play a key role in energy transition. The technologies impacting the new electricity system will be both – enabling and disruptive. Enabling technologies facilitate the integration of renewable energy generation technologies. Disruptive technologies by contrast have all of the process improvement possibility of enabling technologies, but disrupt current commercial models. The factor determining the degree to which renewable energy may become disruptive is the development of efficient and cost-competitive energy storage devices.

The NATO Energy Security Center of Excellence has also focused on "Smart Energy", as to enhance our armed forces' energy efficiency that means saving fuel – and this means spending less money on fuel. More energy-efficient equipment also means having to transport less fuel over long and often dangerous supply routes. This edition of Operational Highlights will underline the role of new energy technologies, especially emerging technologies (energy storage) and energy efficiency in the military. At the same time it will highlight that new technologies bring along new vulnerabilities such as cyber security. This last point has increasingly become a major concern in energy security as we have witnessed the recent use of cyber weapons against electric distribution grids and petrochemical plants. Energy security is no longer just about security of supply and price. The technologies used to drill and run fuel down a pipeline, control propulsion systems, generate and distribute electricity can be accidentally and/or maliciously disrupted electronically. In other words technology must now be seen as both an enabler and as a target.

This issue of Operational Highlights provides a timely overview of the emerging technologies in the power sector including energy storage and electro-mobility, focusing on exciting new trends in energy storage research and development. We also have a closer look at the strategic importance of rare earth minerals that are a critical for energy security. As well we touch upon how we can reduce the likelihood of cyberattacks against control systems used to monitor and manage our critical energy infrastructure. Lastly, we provide fresh insights on NATO initiatives in military energy efficiency.

Disruptive and enabling technologies in the energy sector

by Ms Marju Kõrts

Three primary drivers are transforming the global energy system: decentralization, digitalization, and decarbonisation. Together, these factors are shifting the world's power mix toward smaller, cleaner, and more intelligent technologies. Digitalization is a key amplifier of the power sector transformation, enabling the management of large amounts of data and optimizing increasingly complex systems. The growing importance of digitalization in the power sector is also a consequence of advances in two other innovation trends: decentralization and electrification. Decentralization is led by the increased deployment of small power generators, mainly rooftop solar photovoltaic (PV), connected to the distribution grid. Electrification of transport and buildings (heating and cooling) involves large quantities of new loads, such as electric vehicles, heat pumps and electric boilers. Technology is helping improve utilities' operational efficiencies through digitalization and the Internet of Things (IoT). On the other hand, networks are vulnerable to cyberattacks that many believe will become more prevalent and sophisticated.

This article will give an overview of the new emerging technologies in the power sector including energy storage and electro-mobility as the main drivers of decarbonisation of the energy sector that pave the way towards low carbon economy. It will also touch upon some trends in research and development related to energy storage.

1. THE NEW ENERGY LANDSCAPE AND THE CONCEPT OF DISRUPTIVE TECHNOLOGIES

Providing energy access while reducing emissions, major economies globally have committed to decarbonisation as a way of combating climate change effectively. To achieve this, future power markets will need to focus on implementing sustainable, low-carbon energy solutions and technologies. Currently energy is experiencing what some have termed a "Fourth industrial revolution", following those of steam, electrification and automation. Technology is powering renewable energy rise. The traditional model of large, top-down and centrally distributed energy production is being replaced by modular, consumer driven and evenly distributed power generation.

by Ms Marju Kõrts

Ms Marju Kõrts is an Estonian career diplomat who has hold several positions at the Estonian Ministry of Foreign Affairs. She graduated with her Masters degree in political science at Tartu University in Estonia. With the current function as the Estonian Subject Matter Expert at the Research and Lessons Learned Division of the NATO Energy Security Center of Excellence in Vilnius she focusses on the new energy technologies. At present she is conducting a research study "The use of LNG as an alternative propellant in the naval field" that will be launched this spring by the NATO Energy Security Center of Excellence. E-mail:marju.korts@enseccoe.org

Power generation technology is only one part of the energy transformation story. Stationary storage technology is improving and costs are falling steeply. New energy sources emerge, leading to a structural and permanent change in supply, demand and energy mix. For example, hydrogen could play a significant role in low-carbon future: counterbalancing electricity as a zero-carbon energy carrier that can be easily stored and transported, enabling a more secure energy system with reduced fossil fuel dependence. While electricity is proving comparatively easy to decarbonize thanks to the dramatic cost reductions and uptake of renewables, the other sectors (e.g transport, heat) must not be forgotten.

Around the world the pace of developing and introducing better, more efficient renewable energy technologies is accelerating. Renewables are becoming the go-to option for many countries in their transition towards secure, cost effective and environmentally sustainable energy supply. According to the Renewables 2019 Global Status Report – the Renewable Energy Policy Network's annual look at the market – recently revealed that, globally renewable energy is outgaining fossil fuel and nuclear capacity combined and now represents one-third of the world's installed capacity[1]. Once thought to be difficult to integrate into the grid, renewables are now serving to strengthen grid reliability and resilience.

Renewable energy from solar, wind and battery storage is grabbing a broader footprint by the day, along with microgrids[2] and other distributed energy sources (DER), enabling governments and the utilities to integrate those energy sources onto the grid. In this transformation process, the role of electricity will become more prominent and more central in the energy system.

The IEA report "World Energy Outlook 2018" highlights that increased penetration of variable renewable energy requires flexibility in the energy system which comes from 4 main sources: flexible power generation, flexible demand, energy storage, and smart interconnected grid infrastructure. As the need for flexibility increases, grid operators need to utilize each of the categories through resources such as residential demand response, long-term storage technologies or synthetic fuels for zero-carbon dispatchable power generation. Decarbonisation is only slowly taking hold beyond the power sector. Heating, cooling and transport are other areas in which fossil fuels are to be gradually replaced with renewables. This can be achieved either by using renewables directly - for instance, by using solar thermal collectors to heat a house, or by using renewable-generated electricity in other sectors. This transfer of clean electricity into other sectors, where it is used to reduce the amount of fossil energy required, is referred to as sector coupling.

As a result of energy transition, energy carriers will become increasingly interconnected. Cross sector coupling involves the integrated use of different energy infrastructures and vectors, in particular electricity, heat and gas, either on the supply side, e.g. through conversion of (surplus) electricity to hydrogen, or at the demand side, e.g. by using residual heat from power generation or industrial processed for district heating. On one hand, sector coupling calls for bringing more consumers to the grid to better utilize the already plentiful generation. Looking at the same system from another perspective, the heating sector and the automotive sector, for example, are mostly using energy resources. Outside electrification or using synthetic fuels such as hydrogen produced with renewable electricity, there are not many other alternatives to decarbonize these sectors[3]. Energy retrofit of the building sector[4] and other energy efficiency measures may reduce demand, but will not replace the underlying energy source. In order to decarbonize the energy sector we need to integrate more renewables to the grid and in this regards sector coupling is the key to a greater penetration of renewables in the energy sector, but it still has hurdles to overcome, both technically and on the market scale.

[1] 2019 Strategic Directions: Electric Report. Repowering the Power Industry.

[2] A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries acting as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid enabling it to operate with the grid or island-mode on its own.

Emerging or disruptive technologies and innovation in the energy sector play a key role in energy transition. Much of the technological innovation in the energy sector has been of an incremental nature[5]. Incremental innovations that accumulate over time can have large impacts. But what is striking about the energy sector since the turn of the centuries is the transformative nature of the changes that are taking place. An example of renewables innovation can be found in floating solar – known as "floatvoltaics" – in which photovoltaic (PV) panels are mounted on the surface of water bodies. With solar energy generation requiring large areas for PV panels to lay, floating solar systems present a solution that can address land acquisition issues effectively, which is particularly important in population-dense regions. Floatvoltaics on a hydro-electric dam reservoir offers easy access to power evacuation to the grid and a hydro-floating solar hybrid solution for improved grid performance. Electric vehicles (EVs) and electrified fleets – everything from buses to garbage trucks – are growing in numbers, pressuring power providers to accommodate charging demand. Technology with disruptive effects on markets and business models are gaining ground rapidly.

The concept of disruptive technologies was first introduced and defined by the American scholar Clayton Christensen in the 1990s, but it was later updated and called disruptive innovation with the recognition that new business models could have disruptive consequences regardless of technological change. The discussion around energy and disruption has often focused on the work of Tony Seba[6] and discussions of the clean disruption. Seba's work focuses on technology-based disruptions: the convergence of technologies, business model and product innovations that are disrupting the world's major industries including energy, transportation and infrastructure. It means that traditional business models are challenged because of the zero marginal cost aspect of solar and wind. There are no fuel costs as there is no need to pay additional costs to produce more energy like you do with coal, gas and uranium powered energy production. So renewables substantially reduce the wholesale costs of energy. The business model of 20th century was based around building large power stations producing a constant supply of energy in centralized systems. It was based, for the most part, around an active supply and passive demand. This arguably all being disrupted because of the decentralized process with smaller units around the country and intermittency factors. Renewables arguably enable new players to come to the fore, for example prosumers selling electricity at the household level back into the grid. For example, the Brooklyn Microgrid, a P2P energy trading[7] microgrid project in Brooklyn, New York enables to localize the energy industry by combining blockchain and microgrid technology. In this sense renewable energy and energy storage technologies is that they are disruptive to the traditional model.

The technologies impacting the new electricity system of the future come in two technologies - enabling and disruptive technologies. The distinction between them is curiously

[3] Van Nuffel, L. Study: "Sector coupling: how can it be enhanced in the EU to foster grid stability and decarbonisation", Brussels, November 2018.

[4] Energy retrofit is an energy conservation measure in an existing building also leading to an overall improvement in the building performance.

[5] Technical innovations can be classified according to whether they are "incremental", "radical" or "disruptive". A disruptive innovation is something that creates a new market and value network displacing existing markets and business models, a game-changer.

[6] Tony Seba "Clean Disruption of Energy and Transportation – How Silicon Valley Will Make Oil, Nuclear, Natural Gas, Coal, Electric Utilities and Conventional Cars Obsolete by 2030", 2014.

[7] Peer-to Peer (P2P) energy trading is the trading of energy from one person or entity (producer) to another person or entity (consumer), without the use of intermediary.

slim. Enabling technologies facilitate the integration of variable renewable energy generation technologies. Such technologies include, among others, storage batteries, technologies that enable the electrification of other sectors with renewable electricity, digital and ICT developments, and smart grid solutions. Smart grid is an electricity grid which includes a variety of operation and energy measures, including smart meters, smart appliances, renewable energy resources, and energy efficient resource. Electronical power conditioning and control of the production and distribution of electricity are important aspects of the smart grid. All of these developments bring new opportunities for integrating higher shares of renewables, as they enable new ways of operating and optimizing power systems. Disruptive technologies by contrast are such that have all of the process improvement possibility of enabling technologies, but do so in a way which disrupts current commercial models. The disruption comes from economics, it has to do with consumption of energy. For example, the objective of the Virtual Power Plant[8] (VPP) is to relieve the load on the grid by smartly distributing the power generated by the individual units during periods of peak load. The biggest VPP was established in Adelaide Australia in 2016 and it boosts grid stability, reduce power price volatility and support the expansion of renewable energy.

Innovation in energy storage represents the largest and most near-term opportunity to accelerate renewable energy deployments and bring us closer to replacing fossil fuels as the primary source to meet the world's continual growth in energy demand. Energy storage systems primarily offer value to power systems by absorbing power during periods with low demand and injecting power during periods with high demand. This technology is increasingly seen as disruptive technology as it is able to break through existing business models and create a whole new industry. It has the potential to eliminate the need for gasoline in cars, and can turn the relationship between citizens and energy.

For example, carmaker Tesla is having lot of success with the sale of its revolutionary electric vehicles (EVs), and has a plan to sell 500,000 EVs by the year 2020. With the rollout of a cheaper model, the company expects to reach more people, but a cheaper model is highly dependent on the price of the battery. This currently costs approximately one third of the price of the entire car, and will not drop until it is produced on a much larger scale. For this reason, Tesla has worked out a grand plan with Panasonic to build a "Gigafactory" in Nevada, for just such large scale battery production. The disruptive part of the idea lies in the longer term potential to move away from the current petrol engine. Meanwhile, other battery manufacturers are making similar plans, and the first mega-investments are expected to be made soon.

Beside car batteries, Tesla also wants to build larger batteries for households who want to store their solar-panel generated energy. Energy which then can be used to recharge their EV, and can be further used in the household. SolarCity is the company that will provide both solar panels and storage technology, and is led by Tesla director Musk.

The example of Tesla shows that energy storage has begun to play a wider role in energy markets, moving from limited and niche uses, such as grid balancing to play a larger role such as replacing conventional power generators for reliability, providing uninterrupted quality power, and supporting renewables integration. It is projected that storage will represent a core component of all new energy technologies moving into the future, as both utility-scale and domestic energy storage solutions become more price competitive, eroding the advantages of traditional energy sources. The traditional model of large, top-down and centrally distributed energy production is being replaced by modular, consumer driven and evenly distributed power generation.

The advantages of energy storage are manifold. Firstly, battery storage can be effectively used to tackle peak demand as it varies not only on a daily basis, but also seasonally and annually. Meeting the peak demand is costly, as utilities have to either invest in additional capacity by building new power plants, which are not always optimally run, or buy power from independent power producers during peak hours at higher prices compared to non-peak hours. On the other hand, grid-connected battery storage can effectively inject the required power into the grid at the right time to meet the demand. Power from battery storage will not only save the utilities from the above-mentioned challenges but also help in maintaining grid balance.

2. THE ENABLING TECHNOLOGIES: SMART GRID AND ENERGY STORAGE

Many factors will impact the pace and scope of the expansion of the renewable sources of energy. These include federal and tax credits in the United States of America, feed-in tariffs in the European Union, growing pressures of climate change, and a projected low-price environment of natural gas. But looking over the coming decades to 2035, the key obstacle and/or enabler will be the degree to which the grid system is modernized and digitized into a smart grid; in the longer term, advancement will depend on breakthroughs in cost-competitive energy storage. To effectively integrate growing amount of intermittent energy sources like solar and wind into the grid, smart grids are key.

A "smart grid" is a digitized infrastructure of the electricity system, transforming electricity systems much the same way that the smartphone transformed telecommunications from the use of landlines. It uses computer technology to create two-way communication between all nodes of the electricity network – supply, transmission, distribution, and consumption – creating a more efficient, reliable, and resilient system. Automated technology relays information from sensors and smart meters employed at home and offices, allowing the utility to adjust and control power flows in real time in each individual device, or in millions of devices, from a central location.

This automated system allows utilities to gauge shifts in demand in real time; more rapidly respond to power outages; and integrate intermittent sources of electricity like, solar, wind, and eventually electric vehicles into the grid[9]. The backbone of the future smart grid is artificial intelligence (AI), this technology will continuously collect and synthesize overwhelming amounts of data from millions of smart sensors to make timely decisions on how to best allocate energy resources. Additionally, the advances made from "deep learning algorithms", a system where machines learn on their own from spotting patterns and anomalies in large data sets, will revolutionize both the demand and supply side of the energy economy[10].

As a result, the large regional grids will be replaced by specialized microgrids that manage local energy needs with finer resolution. These can be paired with new battery technologies that allow power to continually flow to and between local communities even when severe weather or other outages afflict the broader power system.

For example, the Brooklyn Microgrid[11], a P2P energy trading microgrid project in Brooklyn, New York developed by LO3 enables to localize the energy industry by combining blockchain and microgrid technology. Peer-to Peer (P2P) energy trading is the trading of energy from one person or entity (producer) to another person or entity (consumer), without the use of intermediary. On one hand, this

[8] Virtual Power Plant (VPP) is a network of decentralized, medium-scale power generating units, such as wind farms, solar parks, and Combined Heat and Power (CHP) units, as well as flexible power consumers and storage systems. The interconnected units are dispatched through the central control room of the VPP, but nonetheless remain independent in their operation.

[9] Manning, R. "Renewable Energy's Coming of Age: A Disruptive Technology?" Atlantic Council, Issue Brief, December 2015.
[10] Wolfe, F. "How Artificial Intelligence Will Revolutionize the Energy Industry". Harvard University newsletter on Artificial Intelligence, 2017.

project will make Brooklyn more sustainable by incentivizing local home-owners and businesses to install rooftop solar. On the other hand, it will make Brooklyn more energy resilient as the microgrid can operate autonomously from the traditional grid, especially in the event of a weather incident such as Hurricane Sandy. The need for greater flexibility and mobility in the marketplace has opened the door to technologies such as blockchain that helps provide part of the solution, providing that real-time information in terms of power generation. The use of data has increased in tandem with the need for more technical solutions and the need for an ever-smarter grid.

Perhaps the factor determining the degree to which renewable energy accelerates and becomes disruptive is the development of more efficient and cost-competitive energy storage. Coupled with falling technology costs, particularly for lithium-ion batteries, energy storage is expected to play a key part in the global transition toward a more sustainable and reliable power grid. The primary drivers for storage are changing rate structure, electric vehicle charging integration, solar PV integration, resiliency/back-up power, and to some degree business model innovation.

A 2017 review of "deep carbonization" scenarios for the U.S. by power sector researchers found that scenarios with a high penetration of renewables require either a backup system of dispatchable resources or long-duration, seasonal storage technologies[12]. The only long-duration, seasonal storage technology currently proven viable at scale is pumped hydro storage. Areas of the world such as Norway, Wales, Japan and the U.S. have used elevated geographic features for reservoirs, using electrically powered pumps to fill them.

Based on their energy storage capacity, energy storage systems can be categorized as short-term and long-term energy storages. Short-term storage systems including the super-capacitator energy storage, flywheel energy storage and superconducting magnetic energy storage are explained in detail in part 2.1.1 of this article. The long-term storage systems could be subdivided into pumped hydroelectric energy storage (PHS), compressed air energy storage (CAES), battery energy storage, and hydrogen energy storage.

The entire energy storage market has significantly increased its presence in 2019. In recent months, the news from the storage industry has ramped up significantly. We have seen recent announcements of large battery storage projects, some as big as NextEra's Manatee Solar/Storage undertaking involving 409 MW and 900 megawatt-hours (MWh) and a 495 MW energy storage project from intersect Power that may be developed in Texas, U.S[13].

North-America, the Asia Pacific and Western Europe were the leading regions for deployed energy storage power capacity during the second quarter of 2019[14], with lithium-ion batteries remaining the fastest growing storage technology. Triggered by electric vehicles' development, battery technologies are progressing quickly. This progress is also benefiting the large stationary batteries used for grids or small individual batteries used for self-consumption.

The majority of investment today is in battery storage, and part of that is lithium-ion energy source of choice for new projects because of the falling prices. According to the recently published report from Rethink, global energy storage will grow from 6 GWh installed today to 635 GWh by 2030. It can be predicted that the Asia Pacific region, led by China, will dominate installations with 273 GWh, or some 43 percent of the total capacity, while Europe and the U.S. will account for about 31 percent of cumulative capacity. Lithium-ion batteries will remain the predominant storage technology over the next decade, spurred by the anticipated growth of the EV market. The top 10 battery manufacturers alone have planned some 510 GWh of annual global factory capacity by 2030, with 45 percent of global lithium-ion manufacturing capacity located in China, Europe and South Korea.

Energy storage technologies can be used in different sectors such as defence, heat and transport. The U.S example shows that battery storage technology can be successfully used in the military. The U.S largest stand-alone battery energy storage system is developed at Fort Carson army base in Colorado[15]. Battery storage can provide immediate, flexible power to military installations while reducing the carbon footprint, fuel demands and recurring costs of existing back-up generators. Storage technology has advanced to the point that large-scale installations can provide resilient power without straining defence budgets.

In the heat sector, high temperature heat storage can be used to increase flexibility of thermal power plants. Most prominently they are considered as flexibility option for solar power plants in order to be able to feed power into the grid also during times without sunshine.

The transport sector is likely to deploy a large-base of energy-storage systems in the future. With the anticipated increase in the adoption of electric vehicles (EVs), the trend is projected to increase demand for EV charging infrastructure on a global scale. This will likely lead to significant growth in the electrochemical energy storage systems market.

2.1 TYPES OF TECHNOLOGIES WITH THEIR SUB-TYPES UTILIZED FOR ENERGY STORAGE SYSTEMS

A range of energy storage technologies exist, each with different trade-offs for particular applications. However, pumped hydropower is still dominant form of installed power system energy storage worldwide. Although the cost of lithium-ion batteries has decreased significantly in recent years, their levelized cost of energy remains higher than the levelized cost of energy of pumped hydropower and other gravity energy technologies. Also, gravity energy storage technologies, including pumped hydropower, have two key advantages over electrochemical batteries (e.g. lithium-ion, lead-acid); (i) their capacity does not degrade each cycle and (ii) their power capacity is decoupled from their energy capacity[16].

Electricity storage technologies can be classified based on the underlying physical principles of the energy transformation process. Accordingly, four major categories are distinguished: (1) mechanical storage (including pumped hydro storage (PHS), compressed air energy storage (CAES), and flywheels); (2) electrochemical storage (including conventional batteries), advanced high-temperature batteries and flow batteries); (3) electromagnetic storage (including superconducting magnetic energy storage (SMES), superconductors and supercapacitators), and (4) thermal storage (including molten-salt technology, heat storage in tanks or rock caverns, cryogenic energy storage and ice-based technology).

Energy storage systems work by capturing the available form of required energy resource and store it for future use. In the past, electricity storage was mainly employed in the form of large-scale, bulk, centralized units providing fast response (batteries, flywheels). Today, there is an emerging interest in small-scale, decentralized storage and indeed, in the future power system electricity storage could fulfill a variety of functions and provide benefits to various stakeholders[17]. It might be connected directly to the trans-

[11] A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries acting as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid enabling it to operate with the grid or island-mode on its own.

[12] Ladislaw, S., Naimoli, S. "Transforming the U.S. and EU Electric Power Sectors: Workshop Report and Recommendations for Trans-atlantic Cooperation". Center for Strategic International Studies, Washington D.C (August 2019).

[13] Peter Kelly-Detwiler. "Energy Vault Receives 110 million USD From SoftBank for Gravity-Assisted Power Storage". Forbes, August 14, 2019.

[14] According to the data of the second report from the UK-based market research company "Rethink Technology Research".

[15] Smart Energy International newsletter. "U.S Army develops largest battery energy storage system", 23 August 2018.

[16] Morstyn, T., Chilcott, M., McCulloch, M.D. "Gravity Energy Storage with Suspended Weights for Abandoned Mine Shafts", Department of Engineering Science, University of Oxford. Applied Energy, April 2019.

[17] It refers to ancillary services that are all services required by the transmission or distribution system operator to enable them to maintain the integrity and stability of the transmission or distribution system as well as power quality. Ancillary services include frequency control, voltage control, spinning reserve, standing reserve.

mission or distribution grids, to renewable generators, or to consumers. Also electric vehicles technically can provide the different storage functionalities. Besides electric energy storage in the narrow sense, also thermal storage devices might see interesting applications at consumer level or in combination with large, remote concentrated solar power facilities. Thus, electricity storage can be located closer to generation or closer to load; it could be operated in a more centralized or in a more decentralized manner.

The following sections analyse the effectiveness, current status, and future scope of some of the major energy-storage technologies mentioned in Figure 1.

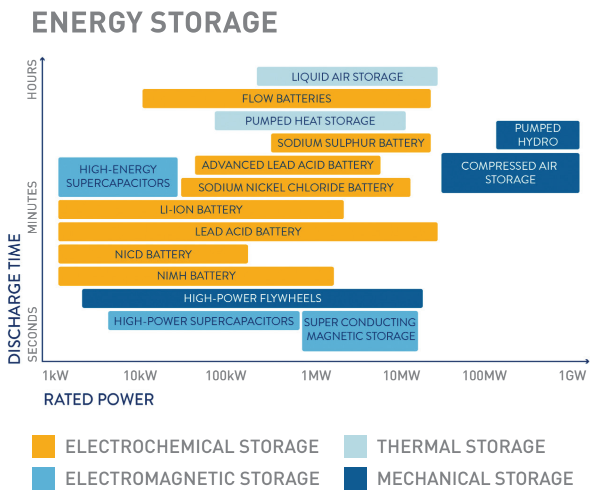


Figure 1: Types of energy storage technologies
Source: De Oude Bibliotheek Academy (2017)

2.1.1 MECHANICAL ENERGY STORAGE

Mechanical energy storage systems take advantage of kinetic or gravitational forces to store inputted energy. While the physics of mechanical systems are often simple (e.g. spin a flywheel or lift weights up a hill), the technologies that enable the efficient and effective use of these forces are particularly advanced. High-tech materials, cutting-edge computer control systems, and innovative design makes these systems feasible in real-world applications.

PUMPED STORAGE TECHNOLOGY

Pumped-storage hydroelectricity facilities (PHS) use energy input which is stored in the form of kinetic energy. Water is pumped to a higher elevation for storage during low-cost energy periods and high renewable energy generation periods. The relatively low energy density of pumped storage systems requires either a very large body of water or large variation in height. Recent innovations have allowed PHS facilities to have adjustable speeds, in order to be more responsive to the needs of the energy grid. Pumped hydro storage is the leading technology accounting for 97% of world's storage capacity, with a rated power of 159 GW, as it is cheaper and more technologically mature than any other storage methods available[18]. In 2018, pumped hydro storage was the most widely deployed storage technology on a large scale, accounting for over 85% of the total energy-storage systems market.

China has the largest rated power capacity of operational PHS plants with 32 GW, followed by Japan and the U.S., with 28.3 GW and 22.6 GW respectively. While pumped hydro systems currently dominate total installed power storage capacity, the cost of stationary batteries such as lithium-ion and flow batteries could fall up to 66% by 2030, in turn stimulating 17-fold growth in storage capacity.

Pumped hydropower is limited by the number of suitable locations since it requires large areas of land for an upper and lower reservoir, which must be separated in height. This has created interest in developing new forms of gravity energy storage, to capture the benefits of pumped hydropower without its land-use requirements. A particular technology patented by the U.S. Company Gravity Power is based on a large underground piston, which is lifted hydraulically to store energy, and then released to push water through a turbine. The cost of this system is primarily made up of excavations (approximately 57% of the total cost) and a reinforced concrete container to resist the load pressure (approximately 25% of the total cost)[19].

FLYWHEEL STORAGE TECHNOLOGIES

Flywheel energy storage systems use electric energy input which is stored in the form of kinetic energy. Kinetic energy can be described as "energy of motion", in this case the motion of a spinning mass, called a rotor, is a rotating mechanical device that is used to store rotational energy that can be called up instantaneously. This rotor is made spin under an enclosure with much less friction. In case of power requirements, stored kinetic energy in the flywheel is converted into electrical energy. Flywheel energy storage has major advantages such as fast charge capability, long lifecycle, and low maintenance requirements. Currently, flywheels for energy storage are utilized for applications in sectors such as power, aerospace, and telecommunications.

R&D activities are underway to improve the performance of flywheel energy-storage technology. For instance, research regarding development for new materials possessing low density and high strength, which will provide higher energy densities.

GRAVITY STORAGE TECHNOLOGIES

Most gravity storage concepts are based on the idea of using spare electricity to lift a heavy block, so the energy can be recovered when needed by letting the weight drop down again. For example, Advanced Rail Energy Storage (ARES) has developed a gravity based technology that will permit the global electric grid to move effectively, reliably, and cleanly assimilate renewable energy and provide significant stability to the grid[20]. ARES has combined proven electric railroad technology with modern electronics in an internationally patented system that has very low technology risk, growing markets, limited competition, and expected high returns to investors. ARES will use surplus wind/solar or other low-cost energy from the grid to move hundreds of tons of mass uphill on railroad shuttles, effectively storing thousands of megawatt-hours of potential energy to power a medium-sized city for several hours. Gravity is also the force underpinning pumped hydro, the most widespread and cost-effective form of energy storage in the world. At the same time pumped hydro development is slow and costly, requiring sites with specific topographical characteristics and often involving significant permitting hurdles. The proponents of newer gravity storage options claim that installation and deployment of their technology is quicker, easier and cheaper.

In 2018, Swiss/Southern Californian startup Energy Vault announced the commercial availability of its energy storage solution that is based on the principles that underpin traditional gravity-based pumped hydro plants. Its new technology combines fundamentals of potential and kinetic energy with a cloud-based software platform to operate a newly developed six-arm crane. The crane operation is automated and moves massive concrete bricks that provide the basis for the storage and discharge of electricity. The company Energy Vault also announced a technology and commercial partnership with CEMEX Research Group AG (Mexican cement and building materials manufacturer) that will focus on material applications which include the optimization of various concrete based composite materials that will support Energy Vault's system deployments globally. This cooperation contributes to the development of a new material that would be lightweight, durable (lasting 30 or more years), inexpensive and capable of incorporating multiple waste materials, such as used debris concrete, coal ash and industrial slag.

Energy Vault's technology was inspired by pumped hydro plants that rely on the power of gravity and the movement of water to store

[18] Whiteman, A; Esparrago, J.; Rinke, T.; Elsayed, S.;Arkhipova, I.; Strinati, C.; Alay,L.F. Renewable Energy Statistics 2017; International Renewable Energy Agency (IRENA): Masdar City, UAE, 2017.
[19] Morstyn, T., Chilcott, M., McCulloch, M.D. "Gravity Energy Storage with Suspended Weights for Abandoned Mine Shafts", Department of Engineering Science, University of Oxford. Applied Energy, April 2019.
[20] Cava, F., Kelly, J., Peitzke, W, Brown, M., Sullivan, S. "Advanced Rail Energy Storage: Green Energy Storage for Green Energy", Storing Energy with Special Reference to Renewable Energy Sources, 2016, pages 69-86.

and discharge electricity. The company's solution is based on the same fundamentals but replaces the water with concrete bricks. The large bricks are combined with Energy Vault's system design and algorithm based software, which calibrates the energy storage tower and electricity charge/discharge while accounting for a variety of factors including power supply and demand volatility, weather and wind. As a result, the company said that it can deliver all the benefits of a pumped hydro system, but at a much lower price, higher round trip efficiency and without the requirement for specific land topography and negative environmental or wildlife impacts. Energy Vault is partnering with India's energy giant Tata Power Company to construct an initial 35 MWh facility with an expected date of completion in 2019.

According to the founders of Energy Vault, the system operates about 90 percent efficiency, and delivers long-duration storage at half the prevailing price on the market at present. The idea is to bring something to the energy storage market, for the first time, will produce baseload power below the cost of fossil fuels. In order to achieve this goal, Energy Vault must succeed where several mechanical storage startups, with their own takes on seemingly simple technological solutions, have failed. A full scale Energy Vault plant, called an Evie, would look like a 35-story crane with six arms, surrounded by thousands manmade concrete bricks, weighing 35 metric tons each.

2.1.2 THERMAL STORAGE TECHNOLOGIES (INCLUDING MOLTEN-SALT THERMAL ENERGY STORAGE)

Thermal energy storage is achieved with widely differing technologies. Depending on the specific technology, it allows excess thermal energy to be stored and used hours, days, or months later, at scales ranging from the individual process, building, multi-user-building, district, town, or region. When energy needs to be stored, rocks, salts, water, or other materials are heated and kept in insulated environments. It is the most widely used method for thermal energy storage as compared to its available counterparts. It works by storing heat energy, which can be transformed into superheated steam. To run steam turbines in order to generate electricity. This technology is extensively utilized in solar thermal power plants in which molten salts are used as a heat transfer fluid and to store the excess amount of heat energy. Molten-salt thermal storage helps solar thermal power plants to function as a base load power plant. A well-known molten salt storage is typically associated with the Solana concentrating solar power plan in Arizona, USA.

One example of an experimental storage system based on chemical reaction energy is the salt hydrate technology. The principle of this technology is that energy is stored chemically by separating salt from water and then released by combining them again. In Europe, the Swedish company SaltX Technology is piloting a large scale plant with Vattenfall in Germany by using "salt hydrate" technology[21]. SaltX Technology uses patented nano coating of the salt, which is claimed to offer several advantages. One of them includes preventing the salt from becoming sticky and thus to retain its original single crystal form, which in turn increases the number of charge-discharge cycles it can undergo. In addition, salt is non-corrosive and also it is non-toxic and recyclable.

Another emerging potential competitor for longer duration storage is cryogenic storage (liquid air). England-based Highview Power began operating a pilot-scale 5 MW cryogenic energy storage facility near Manchester in June 2018. The technology uses electricity to chill and liquefy air at -160 degrees of Celsius, store the liquid air in insulated, low pressure tanks and later expose the liquid air to ambient temperatures to rapidly re-gasify the air, expanding it to 700 times its liquid volume in order to provide power to turbines. In July 2019, for example, Highview Power, a global leader in long-duration energy storage solutions, announced a contract with Nebraska-based Tenaska Power Services, the leading provider of energy management services and demand-side customers in the U.S to help develop up to 4 GWh of cryogenic energy storage plants in the U.S. over a two-year period[22].

Thermal storage can be as basic as storing ice for later use in air conditioning. Instead of generating electricity, making ice can shift power demand, especially to peak solar generation hours during the summer months, with the ice later used for air conditioning. California-based Ice Energy is currently installing 1,200 ice-energy systems under a contract with Southern California Edison (SCE). The systems will be centrally controlled to manage peak demand and load shifting.

Siemens Gamesa offers what it calls a cost-competitive technology, electric thermal energy storage. In this case, electricity is used to heat volcanic stones in an insulated container to up to 600 degrees. The heat is later converted to electricity using a conventional steam turbine, achieving a 45 percent round-trip efficiency. This technology could be used to retrofit fossil-fired power plants and the company plans to begin operation at a pilot facility later this year.

2.1.3 ELECTROCHEMICAL ENERGY STORAGE

Electrochemical energy storage systems have the potential to make a major contribution to the implementation of sustainable energy. Three important types of this storage system are rechargeable batteries, fuel cells and flow batteries.

BATTERY STORAGE TECHNOLOGIES

Storage batteries are rechargeable electrochemical systems used to store energy. They deliver, in the form of electric energy, the chemical energy generated by electrochemical reactions. There are three main types of conventional storage batteries used extensively today: the lead-acid batteries, the nickel-based batteries and the lithium-based batteries. Lead-acid batteries are the oldest type of rechargeable batteries and are based on chemical reactions involving lead dioxide (which forms the cathode electrode), lead (which forms the anode electrode), and sulphuric acid which acts as the electrolyte. Lead-acid batteries have high energy efficiencies (between 85 and 90%), are easy to install and require relatively low level of maintenance. In addition, the self-discharge rates for this type of batteries are very low, around 2 percent of rated capacity per months (at 25 degrees C) which makes them ideal for long-term battery storage applications.

The nickel-based batteries are mainly the nickel-cadmium (Ni-Cd), the nickel-metal hydride (Ni-MH) and the nickel-zinc (Ni-Zn) batteries. All three types use the same material for the positive electrode and the electrolyte which is nickel hydroxide and an aqueous solution of potassium hydroxide with some lithium hydroxide respectively. Typical operational life and cycle life of Ni-Cd batteries is also superior to that of the lead-acid batteries. Despite the above advantages of the Ni-Cd batteries over the lead-acid batteries, Ni-Cd and the rest of the nickel-based batteries have several disadvantages compared to the lead-acid batteries in terms of industrial use or for use in supporting renewable energy. Ni-Cd battery may cost up to 10 times more than the lead-acid battery.

The third major type of battery storage technology is the lithium-based battery storage technology. Lithium-ion battery storage systems represent one form of electrochemical energy-storage system. Globally, electrochemical energy storage market accounted for over 3,200 MW installed capacity in 2018, of which lithium-ion battery storage accounted for the dominant share. Lithium-ion batteries store power in the form of chemi-

[21] Engerati network newsletter. "Salt storage shows promise in Germany", 30 August 2019.
[22] Driscoll, W. "A non-battery year for advancing non-battery storage", PV Magazine, September 2019.

cal energy, offering major advantages such as low self-discharge rate, high round-trip efficiency, and longer lifetime. Research is ongoing to further enhance the amount of energy density for lithium-ion batteries. For instance, high-voltage electrolytes and silicon anodes are some of the techniques being looked at to further increase energy density of these batteries. Ongoing research in energy storage technology has resulted in reduced cost of lithium-ion (Li-ion) batteries and an increase in their performance. With this trend to continue, utility companies in future are expected to switch to large battery banks as an alternative to building new power plants.

Another type of electrochemical energy-storage system – sodium-based battery storage – is considered as a future alternative to lithium-ion based battery storage. The main reason for this move forward toward the sodium-based battery is simply because of sodium is one of the most abundantly available resources in the Earth's crust. In addition, sodium can be recovered from seawater. Moreover, chemical composition of sodium provides inherent protection to the battery in case of overcharging. This fact makes sodium-based battery storage safer than its lithium-ion-based counterpart.

One possible drawback is that sodium-based battery storage is expected to be physically heavier than lithium-ion-based battery storage. Nonetheless, R&D efforts are underway to commercialize sodium-based batteries in the near future owing to their aforementioned advantages. This option will provide low-cost storage facilities for large-scale solar and wind projects in the future.

Flow-based electrochemical energy storage systems have many advantages over the solid-state rechargeable batteries. The electroactive species involved in the electron transfer is outside the cell and makes battery capacity independent of quantity present in the cell package unlike solid-state rechargeable batteries. In addition, the electroactive species outside the cell not only increase the life of battery, but allow the flow battery capacity to be scaled up independently; this addresses the GW-scale energy storage required for grid power back-up. This drives the importance in flow batteries to be better solution for long-term energy storage, this is most likely the best means of storing the intermittent energy from renewables.

Flow battery is a type of rechargeable battery where electricity is generated by the ion exchange process between two electrolytes. The electrochemically active components in the electrolytes circulate against each other to generate a charge and are charge separated by a thin membrane and surrounded by a positive and negative electrode. The construction principle of a flow battery is based on directly converting chemical energy to electricity directly. Flow batteries developed based on this requirement are redox, hybrid, membrane less, semisolid, organic, metal hydride, and nano-network.

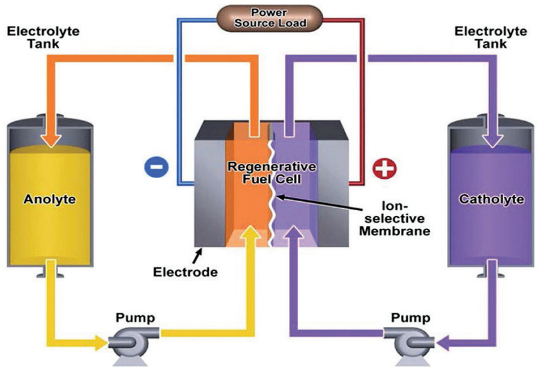


Figure 2. Flow battery consists of two tanks of electrolytes pumped against each other separated by a membrane.

Source: www.sciencedirect.com/topics/engineering/redox-flow-battery

The Redox flow battery is a type of rechargeable flow battery based on the principle of chemical reduction and oxidation in the package to store energy in liquid electrolyte solutions, which flow through negative and positive electrodes. Most popular and extensively studied redox flow batteries are Vanadium Redox Flow batteries[23].

SUPERCAPACITATOR STORAGE TECHNOLOGIES

Following Elon Musk's speech at Cleantech Forum 2011, there has been a lot of interest in supercapacitators and for sure the potential offered by nanotechnologies is keeping high hopes that at some point in the future, supercapacitators might reach a point where they equal the performance of batteries. Supercapacitators (or ultracapacitators) are very high surface areas activated capacitators that use a molecule-thin layer of electrolyte as the dielectric to separate charge. The supercapacitator resembles regular capacitator except that it offers very high capacitance in a small package. Supercapacitators rely on the separation of charge at an electric interface that is measured in fractions of a nanometer, compared with micrometers for most polymer film capacitators.

Energy storage is by means of static charge rather than of an electro-chemical process inherent to the battery. While comparing the key parameters of Li-ion batteries and supercapacitators, it shows that one of the key benefits of the supercapacitator is its extremely high cyclability, meaning that it can be charged and discharged virtually an unlimited times. For systems designers having to power systems in harsh environments, supercapacitators will operate in very low to high temperatures without degradation, which is not the case for batteries. On the downside supercapacitators self-discharge from 100 to 50 percent in 30 to 40 days, whereas lead and lithium-based batteries self-discharge about 5% during the same period, but technology is improving daily and supercapacitators are becoming better. For example, Skeleton Technologies, the European market leader for ultracapacitators and energy storage systems for transportation and grid applications will supply ultracapacitator systems to power Škoda trams in Mannheim Germany[24]. The ultracapacitator system recuperates the braking energy of the trams and uses it for re-acceleration, saving energy and decreasing costs. This project in Germany is further proof that ultracapacitators will be the key enabler for smart city transportation systems in Germany and across the globe.

2.1.4 HYDROGEN STORAGE TECHNOLOGIES

One of the technologies to store excess energy produced by renewable energy sources is generation and storage of hydrogen. The system includes the major components of an electrolyser, hydrogen storage tank, and a fuel cell. The excess from the renewable sources (e.g. solar and wind) is directed towards an electrolyser to generate hydrogen by electrolyzing water into hydrogen and oxygen. Hydrogen-based energy storage system is one of the promising technologies favorable for long-term large-scale energy storage applications. While receiving rapidly-growing attention, hydrogen-based energy storage solutions for such applications areas yet to be further developed. Only 7 projects were reported to be operational globally by 2016, having a combined capacity of just over 7 MW. According to a recent report published research in August 2017, the hydrogen-based energy storage and technology market reached 3.6 billion USD in 2016 and is expected to reach around 5.5 billion USD by 2021[25].The round trip efficiency today is lower than other storage technologies. Despite this low efficiency the interest in hydrogen energy storage is growing due to the much higher capacity compared to batteries (small scale) or pumped hydro and compressed air energy storage.

POWER-TO-HYDROGEN (OR OTHER FUELS)

It is another established technology, at least for installations of modest scale. Hydrogen that is produced using electrolysis can be stored and used later to generate electricity

[23] Dinesh, A., Olivera, S., Venkatesh, K, Santosh, S.M., Priya, M.G, Asiri, A, Muralidhara, H.B. "Iron-based flow batteries to store renewable energies", Environmental Chemistry Letters, February 2018.
[24] www.skeletontech.com/news/skeleton-technologies-ultracapacitators-to-power-skoda-trams-im-mannheim
[25] Biswas, R. Hydrogen Storage: Materials and Global Markets; bcc Research: Wellesly, MA, USA, 2017.

via fuel cells. This is a potential long-duration energy storing option at least three small industrial installations have been announced over the past year, all using the proton exchange membrane (PEM) electrolysis technology to produce "green hydrogen" by using solar or wind power to electrolyze water into hydrogen and oxygen. The resulting hydrogen may be stored in pressurized vessels, while it waits use in fuel cells. As the hydrogen storage is separate from the electrolyzed units there is no technical limit to hydrogen storage capacity.

While PEM and other electrolysis technologies are well-established, achieving economies of scale is challenging. Hydrogen technology may need to expand its foothold across a range of markets, scaling up and driving costs down before it can become a cost-competitive storage option. The scaling-up process has already begun. In February 2019, Hydrogenics Corporation announced plans to build 20 MW PEM electrolyzed system in Canada for the company Air Liquide. Also last February, a framework contract for a 30 MW electrolysis project in Switzerland was announced by a division of Norwegian-based hydrogen company Nel ASA. Another possible storage solution is to use green hydrogen to manufacture ammonia. Japan's JGC Corporation has reported an efficient method of converting hydrogen to ammonia, which can later be combusted to generate electricity.

2.1.7 HYBRID ENERGY STORAGE

Hybrid energy-storage systems combine several different energy-storage technologies to form a single energy-storage system. The potential of these systems is the advantage of better reliability and availability, as well as an increase in overall efficiency.

Currently, some of the types of hybrid energy-storage systems under pilot-stage implementation are thermal/battery, battery/battery, and ultracapacitator/battery. For instance, a utility in Bremen, Germany contracted with AEG Power Solutions in 2018 to build a hybrid energy-storage system. This system will combine electrochemical and thermal energy-storage technology, with the goal of aiding the utility's grid-frequency regulation.

In October 2017, the utility company RedT provided a hybrid energy-storage system to Monash University in Australia[26]. This system utilizes battery/battery type of hybrid energy-storage system that leverages a vanadium-based flow battery and lithium-ion based battery. In this system, vanadium-based flow battery provides majority of power, while Li-ion battery provides power during a surge in power demand.

2.2. ELECTRO-MOBILITY AND ITS POTENTIAL ROLE AS STORAGE OPTION

In the energy sector, we witness a new phenomenon – the convergence of different technologies. Technology convergence is the integration of a number of disparate technologies or functions into a single integrated system. The internet and digital convergence are classical examples of this. A new wave of energy innovation is remaking the transportation, electricity and manufacturing sectors.

In particular, the electric mobility revolution is gaining pace. Besides the integration of renewable electricity generation the most active field of development for electricity storage systems is the electrification of the transport sector. The demand for especially lithium-ion battery systems rises rapidly due to the introduction of plug-in hybrid and full electric vehicles. Electric vehicle (EV) sales (both battery-electric and plug-in hybrids) surpassed 2 million units in 2018, a 58 percent growth over the previous year. In Norway, EV sales grew 40 percent in 2018, with nearly half of all passenger sold being electric that year (Elektrek, 2019). The switch to electricity is not just happening with cars. Electric buses are making large-in-roads, particularly in China, where some cities have converted their entire public bus fleet to electricity. For

[26] Engerati network newsletter. "Hybrid battery system: the best of both worlds", 18 September 2019.

instance, Shenzhen has over 16 000 electric buses in operation (The Guardian, 2018). Together with advancement in energy storage technologies and the convergence of different technologies across different sectors, it paves the way for a radical transformation in the next decades.

This transition is also linked to the electricity sector for two reasons. Firstly, the increased demand fosters mass-production of batteries which causes decreasing battery prices which also helps to introduce storage systems in the electricity grid. Secondly, the battery storage systems of the traffic sector can also be used as grid storage during times when the vehicles are plugged-in for charging. The link between these two sectors causes major transitions in the traditional world of utilities as automobile manufacturers start to produce their one "green" electricity for their electric vehicles fleet. On the other hand, utility companies start getting involved in the mobility sector as they deploy the charging infrastructure and develop business models for electricity supply for e-mobility. Both trends result in a closer link of these two important branches of industry. For example, in 2016 the world's first fully commercial vehicle-to-grid (V2G) hub was opened in Denmark in co-operation between global automotive manufacturer Nissan, multinational energy company Enel, and California-based company Nuvve, a leading V2G services provider[27]. With V2G technology, electric vehicles will play an integral part in the energy management systems of the future. This technology helps enhance grid stability, further enabling the integration of renewables into the generation mix.

Battery technology is an area of constant innovation. To meet the future needs of our society, a huge improvement in the performance of batteries is key, with new designs that need specific purpose. Although batteries were initially a simple technology their development has been slow compared with other areas of electronics. A major research hurdle lies in finding suitable materials for electrodes and electrolytes that actually work well together without undue compromise to other aspects of a battery design.

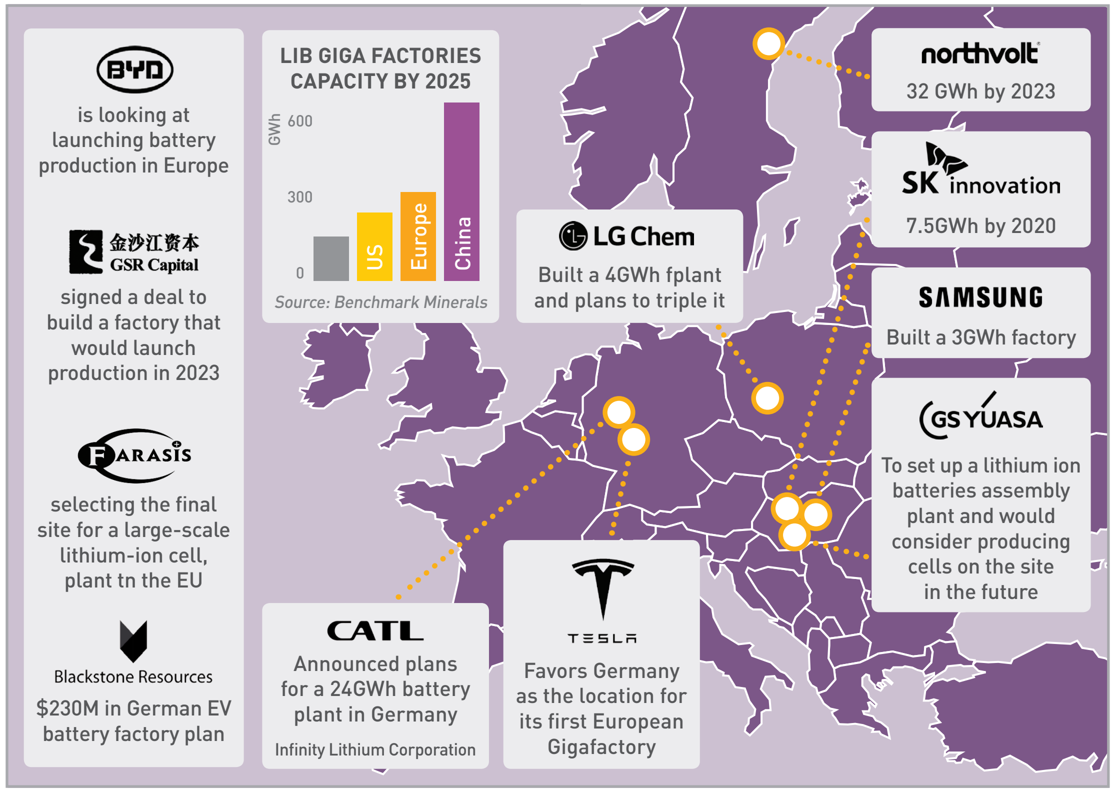
With the need to cut down on fossil fuels, automotive companies have all been making a push into electric cars. For example, Volkswagen and BMW have invested a lot in the development and production of electric cars and therefore the European owned car makers are investing in the Swedish start-up Northvolt to build a battery farm to rival Tesla's gigafactory in Europe. It is planned to produce 16 GWh from the plant annually, but once fully operational, it will be one of Europe's larger battery cell factories and produce 32 GWh worth of capacity annually. For example, in mid-2018, battery production at Tesla's Gigafactory 1, reached an annualized rate of rough 20 GWh. The plan is to build another factory in Germany in the near future. Although reports show that China is ahead when it comes to battery production.

According to Bloomberg data, based on planned and existing production plants, 80% of global capacity for lithium-ion batteries is likely to be in Asia, and most of it (69%) in China. The risk is that, particularly brewing trade dispute between China and the US that this will create problems for European car manufacturers. There are already factories being built in Hungary and Poland by Asian actors. Amid the risk of falling behind, the EU under the Horizon 2020 program has set aside 1 billion USD for battery projects and financing building facilities and the European Investment Bank. For example, in May 2019, EIB committed 350 million euros in a loan to Northvolt for the building of Europe's home-grown gigafactory for lithium-ion battery cells. However, it is not the only battery project in the EU. French battery-maker Saft, Polish Umicore and the Swedish renewable battery manufacturer Nilar are some of them.

To sum it up, the storage developments have

[27] Biswas, R. Hydrogen Storage: Materials and Global Markets; bcc Research: Wellesly, MA, USA, 2017.

A Number of New Lithium-ion Factories Planned in Europe



Modified from: Infinity Lithium Corporation 2019

shown that battery storage is not the only game in town. Other technologies that are capable of long-term storage are also moving forward.

3. CONVERGENCE OF TECHNOLOGIES IN THE ENERGY SECTOR

With the implementation of disruptive technologies we can see a new trend, convergence of different technologies, e.g. energy systems and mobility assets help each other. Electric vehicles can be used as a decentralized energy resource and provide new, controllable storage capacity and electricity supply that is useful for the stability of the energy system. In markets where regulation allows EVs to be used as a source of flexibility, energy players start betting on this vision, with cars working as "batteries on wheels."

For example, in a pilot project in Denmark, Enel and Nissan set up the first vehicle-to-grid (V2G) commercial hub: by selling frequency regulation services for system balancing purposes to the Danish transmission system operator (TSO), a car can generate around €1,500 in annual revenue. New business models are possible, where the drivers and fleet operators of EVs could play as producer-consumers of energy services, such as vehicle-to-everything (V2x) and smart charging. These new energy services will create additional opportunities for revenue sharing between the vehicle owners and the energy suppliers that would reduce the total cost of ownership of the EVs and accelerate their market penetration. There will be a need to augment existing and build new grid infrastructure in order to accommodate charging EVs. As EV batteries grow in scale and mileage increases, the deployment of fast-charging infrastructure is anticipated to be key to drive faster EV adoption. Another significant impact of EV growth will be the scaling of energy storage. The demand for batteries driven by the growth of EVs will continue to transform the battery supply chain, reduce energy storage costs, and accelerate its adoption.

At the same time, energy is changing, as we are moving toward energy systems that are cleaner and increasingly decentralized, with energy generated, stored, and distributed closer to the final customers, with renewables and storage technologies. At the same time, digitalization will allow customers and electricity system operators to control, where, when, and how electricity is being used and new business models to emerge. And finally, new and more energy uses are going to be electrified – mobility being one of the critical ones.

The next decade in transportation is expected to dramatically change due to three major trends – electrification, autonomous driving, and the shared economy. The exponential technological progress, combined with disruptive social dynamics, make forecasting the speed and magnitude of change difficult. This is the position we find ourselves, where the automotive sector is concerned. According to the forecasts, 60 percent of car manufacturers intend to have some form of autonomous vehicle on the market by 2025, but back in 2016 only 1 percent of all vehicle sales came equipped with any form of autonomous driving capability. Currently only 5 percent of cars sold around the world have electric vehicle powertrains. However, we at present know that 50 percent of the new models developed up to 2021 will have this facility. We are also seeing massive consumer shifts in the areas of in car connectivity and shared mobility. All these abovementioned changes will transform the way transport consumers, fleets, and companies consume energy. Passenger vehicles, buses, and delivery trucks are all rapidly becoming electric, and local heavy trucking is expected to follow. While global electric vehicle forecasts vary, the consensus is that EV will grow significantly over the coming decades. This growth in EVs will substantially impact electricity ecosystem. The increase in electricity demand will provide new opportunities for electricity suppliers, but unique EV requirements can create overloads on local grids. In the future, EVs will also cost significantly less per mile than vehicles with internal combustion engines for personal use – by as much as 40 percent – and could also reduce congestion and traffic incidents.

Hydrogen and fuel cell technologies offer greater personal choice in the transition to a low-carbon economy. That is also the reason why hydrogen and fuel cells are seeing a resurgence in interest: large-scale production of fuel cell vehicles has begun, and hundreds of thousands of homes are now heated and powered by fuel cells[28]. By 2030 it is anticipated that the number of hydrogen refueling stations will increase across China, the United States, Japan and South Korea from the current figure of 1,000 up to 8,500. Battery powered electric vehicle exhibit higher overall efficiency as long as they are not too heavy due to large battery sizes, making them ideally suited for short-distance and light vehicles.

The transformations happening in the fields of energy and mobility are inevitable, influenced by market factors and megatrends that are virtually unstoppable. Their convergence is the opportunity. The energy sector will have to accelerate the path toward a cleaner, more digitalized and decentralized system, yet one that is more connected and customer centric. The mobility sector will have the opportunity to develop new business models based on service and sharing models, and the new uses and services associated with EVs as decentralized energy resources. The convergence of IoT, software, Big Data[29], analytics

[28] Staffell, I., Scamman, D., Velasquez Abad, A., Balcombe, P., Dodds, P.E, Ekins, P., Shah, N., Ward, K.R. "The role of hydrogen and fuel cells in the global energy system", Energy &Environmental Science Journal, 2019, 23

[29] Big data is a term often used to describe sets of data characterized by high volume, high velocity, and high variety, and for which the use of advanced analytical tools is required in order to process data into actionable information by identifying patterns, trends, and relationships.

and the growth of renewables is revolutionizing the energy system. A new energy world is emerging, in which digitally enabled services allow opportunities for increased savings and greater efficiencies. Blockchain technology has gained significant levels of attention across several industries and is believed to be a disruptive technology. At its core, Blockchain technology is a ledger that is shared, replicated, and distributed. It can be used to manage and record transactions across multiple network participants, on which the transactions can be triggered based on predefined conditions. These core characteristics of this technology seem to be well-fit to accelerate the digitalization, decarbonisation, and decentralization trends transforming energy industry. Artificial intelligence is another technology that is in its early stages of implementation and poised to revolutionize the way energy is produced, transmitted, and consumed.

4. CONCLUSIONS

The energy sector is in the midst of a major global transformation that is primarily being fueled by multilateral efforts focused on decarbonizing the global economy to address climate change and a shift toward an increasingly clean, intelligent, mobile, and distributed energy ecosystem. Linear value chains supporting one-way power flow from centralized generation to end-customers will give way to a more sustainable, highly digitized, and dynamic energy system.

Disruptive technologies will be a key factor of the energy sector over the coming years. There are two other factors as the carbon agenda and increased customer engagement. The energy dilemma – affordability, safety and security – can be dealt with by the growth of renewables as well as improved electric vehicles infrastructure, demand driven smart meters and blockchain which contribute to the move toward a decentralized energy system.

However, increased renewables will also present challenges, since while sources like wind and solar are stable, they can also be intermittent and less reliable. The governments face a significant challenge in creating a dynamic energy market that can successfully accommodate the spectrum of green and disruptive technologies into the energy generation mix. If this is going to be achieved, innovative disruptors in the market have a key role to play. In much the same way technology and innovation has had transformative effect on sectors such as retail, so it can have a similar effect in the energy sector.

Disruption in the energy industry is happening at many levels, and the huge increase in renewables over recent years, innovations in technology and consumers taking a much more active interest, are going to have a huge impact on the sector. It is a landscape that is shifting continually and the goal posts can change very rapidly.

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The strategic importance of rare earth minerals for NATO, EU and the United States and its implications for the energy and defense sectors

by Ms Marju Kõrts

ABSTRACT

Rare earth materials such as cobalt and lithium have become a cornerstone of global government initiatives aimed at improving energy efficiency, increasing renewable power generation capacity and reducing greenhouse gas emissions. Rare earth minerals are a critical aspect of energy security and independence, both directly affecting national security. Furthermore, it is their applications in clean energy technologies and defense systems that have brought global attention to rare earth elements. Due to the growing economic and the persistent strategic importance of these sectors, continuous access to these resources is strategically important. The current global production and the availability of several critical metals is insufficient for a transition to a renewable energy system. However, the distribution of rare earth elements over the world is uneven. The supply chain of rare earth metals is overwhelmingly controlled by China that dominates the mining, processing and manufacturing of the metals. This has some negative effects which became obvious during the 'rare earth crisis" lasting from 2010 to 2012, when a territorial dispute between China and Japan escalated into a trade embargo.

This article highlights the risks of strategic vulnerability of the western countries due to the Chinese monopoly on rare earths and discusses possible mitigation measures in the international context.

1. RARE EARTHS AND CRITICAL MINERALS AS GEOPOLITICS OF UNEQUAL DISTRIBUTION

With the increasing concerns about climate change and reliability of supply of fossil fuels, growing attention has been drawn to the introduction and implementation of renewable energy, and emerging technologies such as photovoltaics, fuel cells, and wind turbines. As a consequence, the raw materials are required for these technologies, which are indispensable or can hardly be substituted, have become the focus of concern. Among these materials, rare earths (referred to as REEs) have become critical and important.

Strategic minerals also known as critical minerals is a broad-based category that constitutes various minerals and elements, the majority of which are minor metals. Geographic availability of domestic supply often defines which minerals are deemed critical for any particular country or region. Critical minerals include compounds that are economically important and subject to risks of supply. In this article, the term "minerals" includes metallic and non-metallic elements and minerals (sensu stricto), which in most cases are compounds of elements. Critical minerals include the rare earth elements (REEs) used for building wind turbines, magnets and new battery types. Other uses are for special alloys (e.g tungsten, rhenium, and niobium), chemical catalysts (e.g rhenium, platinum-group elements or PGEs) and for renewable energy generation and storage (e.g indium, lithium, cobalt, vanadium, and gallium).

Rare earth elements (REEs) are a group of 17 chemical elements that occur together in the periodic table. The group consists of yttrium and the 15 lanthanide elements[1]. To date, more than 250 rare earth minerals have been discovered containing rare earth elements. The concentration of rare earth elements in minerals ranges from 10 to 300 ppm (parts per million used as a unit of concentration)[2]. The challenge lies in discovering REEs that can be mined and processed economically.

Despite the fact that chemically these elements have been lumped into one group, they are often divided into groups of "light" and "heavy", as defined by their atomic number. The distinction generally indicates their geological occurrence, light being more abundant, heavy being less so. Scandium is found in most rare earth element deposits and is sometimes classified as a rare earth element. All rare earth elements are metals, often referred to as "rare earth metals". These metals have many similar properties, and often are associated in geologic deposits. They are also referred to as "rare earth oxides" because many of them are typically sold as oxide compounds.

REEs are indispensable and non-substitutable for emerging technologies due to their unique physical and chemical properties. Historically, REEs were widely used for metallurgy, petroleum, textiles, and agriculture. As knowledge and development expanded, a broad range of applications that rely upon their chemical, catalytic, electrical, magnetic, and optical properties emerged, especially in many high-tech applications. The REEs are used in very small quantities and act as so-called technological spice metals in catalysts, alloys, magnets, solar systems and computers. During the past twenty years, there has been an explosion in demand for items that require rare earth metals. Many rechargeable batteries are made with REEs compounds and the demand for batteries is driven by the demand for portable electronic devices such as cell phones, portable computers, and cameras. The volatile nature of wind and solar energy creates a problem for utility companies that need to match the amount of energy supply at all times to the amount of demand. Storage technologies, including batteries, offer a way to maintain the supply-demand balance by drawing electricity from the grid when renewable energy are abundant and sending it back when demand picks up. Compared to other technologies, lithium-ion batteries are lightweight and compact with high storage capacity for their size. Looking ahead, improvements in redox or flow batteries are making them an increasingly promising option for stationary applications.

Rare earth elements are essential for the defense sector. The military uses night-vision goggles, precision-guided weapons, communications equipment, GPS equipment, batteries and other defense electronics. Rare earth metals are key ingredients for making the very hard alloys used in armored vehicles and projectiles that shatter upon impact. Alternatives to rare earth metals in some defense applications can be found; however, those substitutes are usually not as effective and diminish the performance of military material.

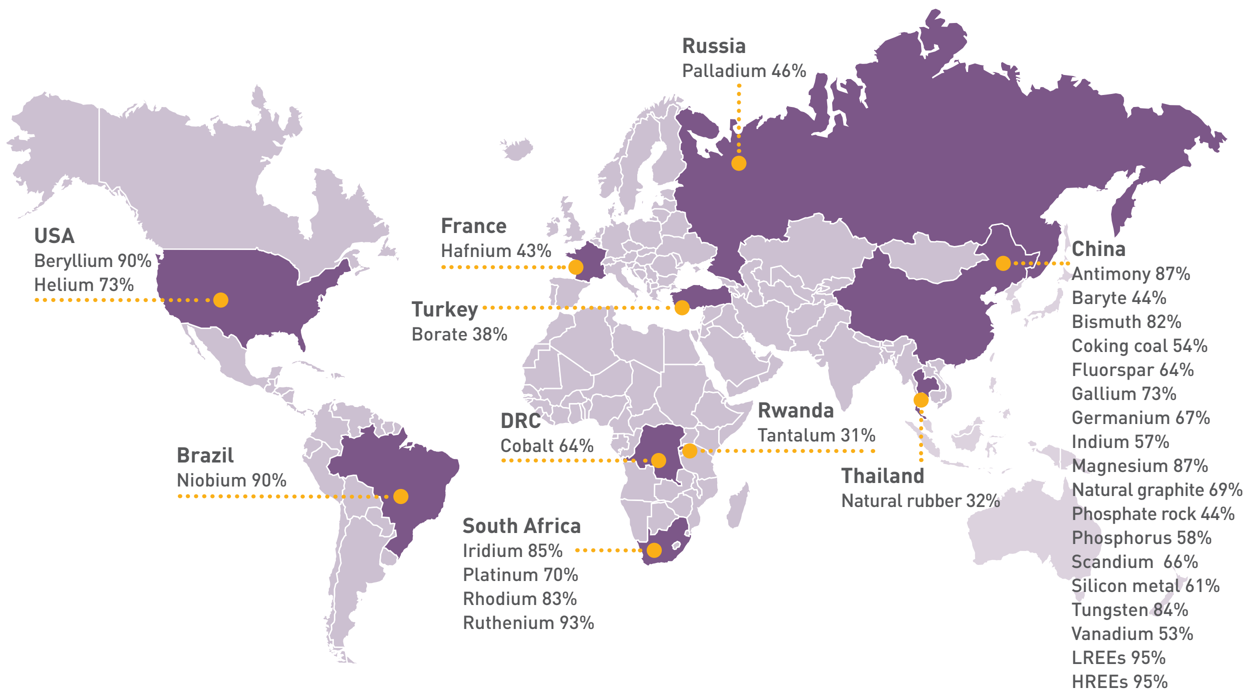
To meet the rapidly rising demand, production of most minerals has significantly increased over the past few decades. However, production of many high-demand minerals is concentrated in just a few industrialized countries, mainly in China and Malaysia[3], creating increased risk of price spikes and supply disruptions. Due to its dominant role in the field of technology metals, it is crucial to understand China's political and economic ambitions and the drivers of its behavior. China today produces at least 80 percent of antimony, bismuth, gallium, magnesium and tungsten, and more than 65 percent of natural graphite,

[1] Lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium.
[2] Yufeng Chen and Biao Zheng "What Happens after the Rare Earth Crisis: A Systematic Literature Review". Sustainability 2019, 11, 1288.
[3] https://minerals.usg.gov/minerals/pub/mcs

germanium and scandium[4]. It is well-known that China possesses most proven reserves of REEs. Concurrently, it is the largest exporter and consumer of rare earths in the world. China has supplied more than 90 percent of the world demand in past decades. Consequently, the rest of the world, including the United States, Japan, and the European Union has developed a strong reliance upon the exploitation and exportation of China's rare earth minerals, which make them concerned about the risk of the supply of rare earths in view of the dominant position of China in the world market of rare earths. In 2010, China decided to implement a stringent exportation policy, which directly resulted in a surge of the price for rare earth products. If mineral supplies from China were suddenly interrupted, other Nation's economy and national security could be threatened. There has also been a growing recognition that mineral scarcity can hamper the speed of key technology development.

The underlying driver for both lithium and cobalt demand is the electric vehicles revolution, which is gathering pace. Cobalt is a cathode material in lithium-ion batteries that needs addressing urgently as it has a risky supply chain partly due to geopolitical issues. Half of the world's current cobalt reserves lie in the Democratic Republic of Congo (DRC), and the country is expected to account for about 70 percent of global supply by 2020[5]. Ominously, the DRC has a history of being exploited for its natural resources, first by the Belgium colonial regime, then mining corporations and foreign powers that were deeply involved in the First and Second Congo Wars. The Second Congo war broke out in 1998, and officially ended in 2003 when a Transitional Government took power. It was the widest inter-state war in modern African history that directly involved 9 African nations (e.g. Namibia, Zimbabwe, Angola, Chad, Uganda, Rwanda, Burundi and etc.) as well about 20

Countries accounting for the largest share of global critical minerals supply



Modified from: European Commission (2018) Report on critical raw materials and the circular economy. [https://publications.europa.eu/]

armed groups and earned the epithet "Africa's World War". The militia groups are still involved in ongoing insurgencies and conflicts with resource extraction fueling militia violence and weapons purchases. Most of the cobalt in the DRC is located in the former Katanga province (which was split into Tanganyika, Haut-Lomami, Lualaba and Haut Katanga provinces in 2015) in the country's far south. Katanga's rich resource wealth has driven political events in the DRC for decades. For instance, Katangan secessionists were heavily involved in the 1961 killing of Patrice Lumumba, the Congolese independence leader and the DRC's first prime minister.

Geopolitics and economics of rare earth metals is not only about China: Brazil is the world's dominant producer of niobium and, the United States produces over 90 percent of the world's beryllium. Production of platinum group metals is concentrated in Russia (palladium) and South Africa (iridium, platinum, rhodium and ruthenium), while Australia and Turkey are significant producers of specific metals such as neodymium and boron respectively. Europe and the U.S. are overwhelmingly dependent on China, which is in a position to control global supply – a position that could be easily abused[6].

According to the United States Geological Survey, the most recent estimate of the total world reserve of rare earths is approximately 140 million tons. China with 55 million tons and India (35 million tons), hold over 2/3 of the world REE reserves while the United States have 13 million tons. Although the United States have significant reserves, their demand for minerals far outweighs domestic supply as it has only one U.S domestic production plant. This means that the U.S. depends on China, a nation with its own rising demands for the minerals. China supplies about 80 percent of the rare-earth elements imported by the United States. The dominance of China as a global supplier of many technology minerals and the Chinese government's ability to constrain supply has shifted the focus of the debate to the international trade dimensions of this challenge.

In the current trade dispute between the United States and China since 2018, rare earths have been brought into play by the Chinese as a possible means of pressure. The dominant position of China in these strategic commodities constitutes a structural market problem with technological and security implications for western industrialized countries. While China may not be cutting off rare earth minerals yet, it is not afraid to show that all options are on the table. Without a reliable domestic supply, the U.S. must rely on rare earths from China to supply their industries of strategic importance. Although there are different alternatives in terms of technological innovations (recycling, substitution, re-use and recovery of critical minerals), it is difficult to substitute these metals within a specific application due to their unique properties. Another option on the basis of the U.S example will be to rebuild their rare-earths industry in order to increase its domestic supply, but it would take at least 10 years. That may leave enough time for China to win a trade war against the U.S., during which - China's de facto monopoly on the production of rare earths will help it to control the productivity of the U.S. high-technology sector.

The U.S, Japan, the European Union and South Korea have all been keenly focused on securing mineral supply for their domestic industries through a range of political initiatives. These efforts included World Trade Organization (WTO) dispute resolution mechanisms[7], as well as, research and development investment in finding alternatives. Generally, the risk of price spikes and supply disruptions may change over time as a result of geopolitical shifts, rapid increases in demand, or happen due to other supply chain factors. The focus has also shifted towards

[4] Mineral Commodity Summaries, United States Geological Survey (USGS), 2018 and Deloitte Sustainability, BGS, BRGM and TNO, Study on the review list of Critical Raw materials, European Commission, June 2017, pp. 44-45

[5] Ross, Nick. "The cobalt boom: recharging trouble in the Congo" Foreign Brief (10 September 2017).

[6] Johnson, Keith, Groll, Elias "China Raises Threat of Rare-Earths Cutoff to U.S" Foreign Policy (21 May 2019).

considering strategic stockpiles of minerals from internal sources, an approach that goes as back to the Cold War era strategies of material security. The potential solutions may include diversifying mineral supplies, developing substitutes for materials and technologies that use specific minerals, increasing recycling, and ensuring that critical minerals are efficiently used.

2. DEMAND AND SUPPLY OF CRITICAL MINERALS

A low carbon future will be significantly more mineral intensive, for example global demand for strategic minerals such as lithium, graphite and nickel will skyrocket by 965 percent, 383 percent and 108 percent respectively by 2050 according to the latest report by the World Bank[8].

The future demand for REEs is forecast to be primarily driven by the demand for permanent magnets, with a smaller (but still increasing) demand for the other key REE sectors (catalysts, glass, polishing, and LaNiH batteries). For example, in the energy sector, the development of wind power (requiring several REE's) and domestic energy storage (mainly requiring cobalt and natural graphite) are expected to drive up the critical mineral demand in the coming decades (Figure 1). Magnets in wind turbine generators are a mix of iron, boron and REEs which improve their performance. Smaller and lighter permanent magnets generators that require less REEs are being adopted across Europe (e.g. German company Enercon developed a gearless design for wind turbines that is REE free). The largest concern pertains to so-called permanent magnets from the rare-earth elements neodymium and dysprosium. Dysprosium allows magnets to maintain their magnetic properties when operating a high heat.

The ever increasing demand for smaller and more powerful portable devices, and the trend towards "all electric vehicles" is fueling the future of battery technologies. The latest estimates from McKinsey's Future Mobility Initiative[9] suggests that global electric vehicle production will increase from 3,2 million units in 2017 to 13 to 18 million units by 2025 reaching 26 to 36 million units in 2030. As cobalt is a by-product of copper or nickel and so its supply also depends on demand of these parent materials. A recent deal between the South Australian state government and billionaire Elon Musk's Tesla to build the world biggest lithium-ion (Li-ion) battery is a prominent example that portends a boom of cobalt mining.

MINERAL COMMODITIES	USED IN	BIGGEST PRODUCERS
Beryllium	Wind energy	Brazil, China, Madagascar, Mozambique, Portugal
Cobalt	Batteries, energy storage, electric vehicles	The Congo, Biggest refiner China
Gallium	Solar power systems	Biggest refiner China
Germanium	Solar power systems, fiber-optic cables	Canada, China, Finland, the Congo
Indium	Solar power systems	China (50%), Belgium, Canada, Japan, South-Korea
Graphite	Battery technology, electric vehicles	China (67%), India, Brazil
Lithium	Battery technology	China, Australia
Niobium and Tantalum	Energy storage	Brazil (90%), Canada
Rare earth elements	Clean energy applications	China (90%), Australia
Selenium	Solar power systems	Japan (51%), Belgium, Canada, Japan and the United States
Tellurium	Solar power systems	China, Sweden
Vanadium	Battery technology	China, Russia, South Africa

Figure 2: Mineral commodities most frequently used in wind energy, photovoltaic or battery technologies. ***Modified from: Schulz et al. (2017), Jorgensen (2002).***

In nine out of twelve cases listed, China plays a significant part either as a producer or as a refiner of the mineral. These mineral commodities were identified as critical minerals for the United States.

There are notable industry efforts to lower the cobalt content of batteries, but if electric vehicles are to make up a significant share of the fleet, cobalt will remain in demand and risks associated with its supply will persist[10]. Despite some attempts to develop alternative technologies, such as Toyota's work on sodium solid-state batteries[11], the importance of cobalt in rechargeable battery electrode production is not expected to diminish. The battery industry already consumes approximately 42 percent of global cobalt production and it is expected to increase significantly over the coming years due to the rise of industrial-use batteries, including commercial power-storage facilities, household energy-storage units and electric vehicles[12].

To prevent supply shortfalls, the focus of numerous research projects is on the development of alternatives to replace cobalt in electric vehicles batteries. The automotive industry aims at reducing the amount of cobalt per battery. Through the development of solid-state battery cells, fuel cells or redox flow cells, the industry hopes for an alternative that works with less cobalt.

Although consumption and demand for REEs will change with technology, many of the current geographic, social, economic and geopolitical questions associated with natural resources exploitation remain: where are these resources situated, who holds the keys for production, and are there risks of supply shortages?

2.1 SECURING ACCESS TO CRITICAL RAW MATERIALS AND CRITICALITY

For decades energy security has been high up on the agenda of politics and defense. For fossil fuels the issues of supply threats, international relations, and security have been extensively analyzed in energy policy. Currently the global energy security focus shifts from fossil fuel supply and the Middle-East region to rare metals and China, leaving the world vulnerable to new geopolitical dependencies.

Criticality of raw materials is, however, all a matter of degree, and the criticality of any given mineral at any time is both dynamic and context specific. The definition of criticality derives, on one hand, from the concentration of raw materials in certain geographic areas, and on the other hand, the impossibility of replacing them with similar materials in the production process. Supply options include developing new sourcing strategies, end of life recycling, and increasing production of the material (through either new mining operations or processing yield improvements). Demand option solutions include materials and manufacturing optimization, material substitution and system substitution.

Recycling critical metals seems to be a good

[7] World Trade organization (WTO). DS509: China – Duties and Other measures concerning the Exportation of Certain Raw Materials.
[8] World Bank. The Growing Role of Minerals and Metals for a Low Carbon Future (2017).
[9] McKinsey/Bloomberg New Energy Finance. An Integrated Perspective on the Future Mobility (2016).
[10] Olivetti, E.A, Ceder, G., Gaustad, G.G. and Fu, X. Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. Joule.1 (2), pp. 229-243.
[11] These batteries (a form of lithium-ion battery) are often considered to represent the next big leap in battery technologies, and are likely to be in use in the foreseeable future. They are potentially suited for a large variety of applications: energy storage, electric vehicles and portable electronics.
[12] Conca, James. "Energy's Future – Battery and Storage Technologies". Forbes (26 August 2019).

solution to supplement growing demand. It can also help reduce the need to search for new source of battery materials. Cobalt, for example is fully recyclable and roughly 15 percent of the U.S. cobalt used is from recycled scrap today. In the European Union, recycling of rare earths is high on the agenda. According to a 2018 report, 39 million of Euros from EU funds have been spent on research and development of rare earths recycling in the last decade. Although there are two important factors (technological complexity and the availability of secondary material) that determine the uncertainty concerning recycling. Technical complexity relies in the fact that materials are often combined and alloyed to enhance and create functional properties. This in term makes them difficult to separate and recover. For example, the Belgian company Umicore, a global leader of recycling manages to recover only 8 of 25 critical metals from a smartphone. Although recycling is a good solution to supplement growing demand, it is technologically complex due to the small size of some of these components, which makes recovery costly and time-consuming. The use of waste materials is a new resource for critical minerals and poses an opportunity to recycle.

A combination of innovations, breakthrough in R&D, and public incentives will be needed to secure the long-term availability of these critical natural resources. These include the development of new, resource-lean technologies that would provide the same functionalities but with the use of much less resources, e.g. the development of nanotechnologies is offering such possibilities for a wide range of applications.

GLOBAL RESPONSES AND SUPPLY OPTIONS

The shift to low carbon energy will produce global opportunities in different continents with respect to a number of minerals. In Asia, China enjoys the global dominance on metals, both base metals and REEs that are required to supply technologies in carbon concentrated future. This applies both to production and reserve levels even when compared with resource rich developed countries (such as Canada, the United States and to a lesser extent Australia). When China started to strengthen its protection of rare earth resources, some nations immediately took action to reduce the Chinese domination in the rare earth sector. Countries with own resources of rare earths have ramped up their domestic production of rare earths (e.g. Lynas Corporation in Australia). This company has a mining concentration plant at Mount Weld, Western Australia and a refining facility in Malaysia.

THE EUROPEAN UNION

Much of Europe's industry is heavily dependent on international markets to secure the raw materials it requires. The European Commission has launched the "European Raw Materials Initiative[13] which was adopted in 2008, followed by the "European Innovation Partnership on Raw Materials" in 2012.[14]

Within the context of the "European Raw Materials Initiative", the European Commission has published several lists of critical materials. The first was published in 2011 and identified 14 materials as being critical for European society and welfare. So far the list has been revised twice in 2014 and in 2017, and the list of critical raw materials was expanded to 61 materials. Nine new materials (six abiotic and three biotic) were added, and 15 rare earth elements and five platinum group metals (with the exception of osmium) were now analyzed separately. Figure 1 highlights the key world producers for the metals and minerals identified as being critical to the EU's economy. The issue of critical materials is not about being resource independent, but rather focuses on the diversification of supply. A home supply (strategic storage) of rare earths is also an aspect of the raw materials initiative. Since 2010 the EU has funded projects for the exploration of rare earth deposits. At present, three REE projects are currently being explored or being technically and economically assessed, and have reached an advanced stage of exploration and development (pilot beneficiation and extraction studies; pre- and/or final feasibility studies). These include Kvanefjeld and Kringlerne, in South Greenland, the Norra Kärr, in Sweden[15]. The REE-reserves for each of the abovementioned projects could potentially secure European REE supply for decades to come. However, it should be stressed that no mining company is obliged to sell their product to domestic or near-by market. To sum it up, despite promising discoveries of potential mines, market conditions and price volatility is preventing them from launching production.

THE UNITED STATES

With China currently controlling 90 percent of the world market, the U.S. economic and national security depends on China for rare earth imports. As one of the largest consumers of metals and minerals, the U.S. Department of Defense uses as much as 750 000 tons of minerals each year. Thus, the U.S. government has recognized the strategic importance of rare earths for America's economy and military. Namely, the present administration has taken steps to reduce the dependency on China, including regulatory relief and other measures to enable the identification and development of critical resources on U.S soil. In addition, the U.S. has recently launched the Energy Resource Governance Initiative according to which it will share mining expertise with other countries. For example, the U.S. will team up with Canada and Australia to help countries around the world develop their reserves of minerals like lithium, copper and cobalt. This is a part of a strategy to reduce global reliance on China for materials crucial to high-tech industries. In June 2019, the U.S Commerce Department recommended immediate steps to boost U.S domestic production of "critical minerals", by providing low-interest loans to mining companies and requiring defense companies to "buy American".

AUSTRALIA

In 2019 Australia published its critical minerals strategy "Critical minerals in Australia: Review of Opportunities and Research Needs". According to this report, Australia has the potential to become a major global supplier of critical minerals. It is one of the world's principal producers of several major mineral commodities including bauxite, coal, copper, lead, gold, ilmenite, iron ore, nickel, rutile, zircon, and zinc. Although some critical minerals are mined as primary products, many critical minerals are extracted as companion products from general mineral production. Considering Australia's leading expertise in mining and processing as well as its extensive mineral resources which are likely to contain critical minerals, there is potential for Australia to develop into a supplier of critical minerals. Australia's opportunity to develop into a leading supplier of critical minerals is significantly affected by a number of factors, including geological studies dedicated to assessing and facilitating the discovery of critical mineral resources. There is also a need for new mining technologies and services to economically extract critical minerals.

In order to overcome China's global REE market dominance new strategies and new investments are necessary. On the long run, some new technologies may reduce the need for rare earths in many current uses, such as for example in nanotechnology. However, in the near future rare earths still possess a pivotal position in modern industry and economy. Therefore, sustainability of rare earths supply remains a complex challenge for western nations.

2.2 OVERVIEW OF THE CRITICAL MINERALS MARKET: THE MAIN SUPPLIERS AND POSSIBLE CONSEQUENCES OF CHINA'S DOMINANCE

[13] COM (2008) 699 Final, "The raw materials initiative – meeting our critical needs for growth and jobs in Europe". This strategy involves a) assessing the risk of shortage in the supply of critical minerals, with the view to promoting diversification of the sources and imports of raw materials; b) supporting R&D in products' and processes' substitution efforts and c) formulating European policy proposals in the framework of the European 2020 industrial and knowledge base economy.

[14] European Commission (2012) focusing on the reduction of import dependency, improving supply conditions from European and other resources.

[15] Antoine Monnet, Amar Ait Abderrahim "Report on major trends affecting future demand for critical raw materials" (2018)

The main characteristic of the global rare earths market is that it is considered a complicated niche market. Its financial volume is about 8 billion dollars, a fairly small sum compared to the iron, aluminum or zinc industries[16]. In addition, it is a rather complicated industry.

Manufacturing these products requires cutting-edge technology in order to separate and purify the rare earth elements mixed together in the ore and to produce magnetic alloy according to the specifications of industrial users. This requires leading edge research in metallurgy and materials science, areas in which research is particularly strong in Asia. For many sensitive raw materials, in the supply chain that runs from geological expertise, upstream to mining operations, metallurgy and materials science, downstream, the step of criticality lies in the phases of metal extraction and purification and in the production of semi products. Today, much of the cutting edge experience in metallurgy is found in Asian countries. The key factor here is the extraction and processing expertise and technology that is increasingly owned and controlled by China.

The absolute quantity of rare earth elements needed in consumer products is relatively low, and the price is governed by the dominant Chinese producers. Rare earth elements are not standard raw materials traded like iron ore, gold and copper; on exchange markets. REEs are traded on so-called OTC markets[17] with direct agreements between a few buyers and sellers[18]. Consequently, it can be difficult for a new player to gain a market share. A specific example is the bankruptcy of the vertically integrated American producer Molycorp in 2015 as the company was unable to generate profits following the price drop of rare earth elements after 2011[19].

CHINA'S EVOLVING MONOPOLY

Over the last decades, China has sought to take advantage of its rich deposits of rare earths by supporting technological innovation and economic development in a wide range of sectors, from space to defense and energy. It achieved its leading rare earth position through a series of aggressive actions such as attempts to acquire any physical mining territory and mining companies available. China has purchased mines outside its own territory, most notably in Australia and Africa[20]. Between 2005 and 2017 China invested 58 billion USD in the sub-Saharan African mining and energy sectors. Despite currently falling commodity prices, China continues to be a leading investor in the global mining industry.

RARE EARTH ELEMENT PRODUCTION

(Metric tons - rare oxide equivalent)

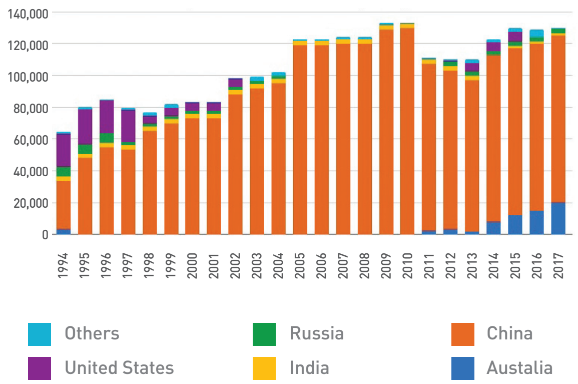


Figure 3 – Rare Earth Element (REE) production by nations between 1994 and 2017[21]: China's (red bars) dominance in the production of rare earth elements between 1994 and 2017 is evident. The United States (purple bars) were a significant producer through the 1990s, but low-priced materials being sold by China forced mines in the United States and other countries out of operation. As China limited exports in 2005; and prices increased rapidly in 2009 and 2010, mines in Australia and the United States became active again.

[16] Seaman, J. Rare Earth and China: Review of Changing Criticality in the New Economy (Policy Center for the New South/Center for Asian Studies 2019)
[17] OTC – over the counter.
[18] Report on "Innovation-critical metals &minerals from extraction o final product – how can the state support their development". Growth Analysis 2017.
[19] The Molycorp Silmet plant is now opened by Neo Performance Materials and is still in operation.
[20] King, Hobart.M. REE-Rare Earth Elements and their Uses. Link: https://geology.com/articles/rare-earth-elements/ Last accessed: 26.06.2019
[21] Graph by Geology.com using data from the United States Geological Survey.

During the same time, China's lax regulation and cheap labor virtually pushed international competitors out of the market, thereby gaining almost complete market dominance. The combination of these factors demonstrates the long-term strategy of the Chinese government to gain global control of the REE market.

The liberalization of global trade and investment, and China's liberalization in particular allowed globally acting companies to establish subsidiaries or cooperative enterprises in China. In turn, it allowed Chinese companies to acquire technological know-how in the rare earth sector from abroad. This not only enabled China to become the dominant upstream producer of rare earth oxides, but also to increasingly dominate the value chains of some rare earth applications such as NdFeB magnets. These magnets were commercially introduced in the early 1980s and they are widely used for many different applications (e.g wind turbines, electric cars). In the wind sector, NdFeB magnets are used by a number of turbine manufacturers to enable "direct drive" systems that are lighter and require less maintenance, a feature that is particularly attractive for offshore usage. Whereas 23 percent of today's wind turbines use rare earth containing magnets, the figure is expected to grow to 72 percent by 2030[22].These special high-performance magnets are produced outside of China only in Japan. The few remaining European magnet producers have almost relocated all of their manufacturing facilities to China, where they can obtain the rare earths materials much cheaper. The Chinese share in global magnet production is estimated at more than 80 percent. From the ore to the final product, China is and remains for many REEs a monopolist on several levels.

Until 2010, very little attention was paid to the concentration of rare earth production in China. Supply and trade in the raw materials were seen as stable and, the associated risks of market concentration were simply overlooked. From July 2010 on, China set stringent quotas on REE exports: 30 000 tons per year, compared with the estimated 55 000 tons of non-Chinese demand. When coupled with the alleged embargo on Japan from September to November 2010, supply risks suddenly became clear to western nations.

In recent years, China has rapidly adopted a strategy of venturing further up value chains and not simply being a cheap supplier of raw materials. China has used concerted efforts to lead entire value chains. As of 2017 a cluster of more than 200 companies working throughout the value chain from extraction and refinement to the production of permanent magnets, special alloys, batteries, and magnetic sensors exists in the city of Baotou, a hub for the extraction of light rare earth elements in China. The focus of the Chinese government is on becoming the leader of five value chains for rare earth elements: permanent magnets, polishing powders, luminescent materials, materials for storing hydrogen gas, and catalytic converters. Close co-operation between industry, universities and research institutions combined with large-scale state funding has been the key to this development. This not only challenges the European and American manufacturing industries, but also poses a risk to western nations defense industries, which depends on critical metals.

Recent trends[23] indicate that China's share of global rare earth mineral production has fallen slightly as a handful of new rare earth mines have become operational outside of China. However, while China's share of the mine production has fallen, its share of downstream value adding capacity to convert rare earth mine outputs in oxides, metals, alloys and magnets has continuously expanded. This shows China's growing focus on dominating the downstream where profit margins are greater and activities are environmentally cleaner.

For a producer bringing online a new rare earth mine outside of China in the coming years – be it in Greenland, Canada, Australia or anywhere else – there is high probability that these rare

[22] WindEurope, "Research and Innovation Needed to Provide Substitutes for Rare Materials Used in Turbines" WindEurope News, 2018, www.windeurope.org
[23] Adams Intelligence. "Rare Earth Elements: Market Issues and Outlook Q2 (July 2019).

earth mine outputs are being further processed in China's value chain. This, leaves the producers and end consumers subject to a higher degree of market opacity and uncertainty.

To sum it up; unless the rest of the world starts investing in critical downstream linkages to take rare earth mine outputs and upgrade them into market-desired materials, such as NdFeB magnets, all end-users outside of China will remain reliant on and vulnerable to China's monopoly. This will be at least true for the foreseeable future – irrespective of how many mines are brought online elsewhere.

3. STRATEGIC IMPORTANCE OF THE RARE EARTH MINERALS FOR THE ENERGY AND MILITARY SECTORS IN NATO

3.1 A NEW ENERGY PARADIGM

Battery storage is transforming the global electric grid and is an increasingly important element of the world transition to sustainable energy. Firstly, carbon neutral sources, like wind turbines, solar PV are variable renewables. Due to the volatility of the renewable energy, the energy grid based on renewables cannot answer to the spikes in demand very quickly. Simultaneously, battery technologies are getting better, recently Jack Goodenough, the inventor of Li-ion battery, came out with a new fast-charging battery technology that uses a glass electrode instead of a liquid one, sodium instead of lithium, and may have three times as much energy density as lithium-ion batteries.

In addition to batteries, we do have other technologies for storing intermittent energy such as thermal energy storage, which allows cooling to be created at night and stored for use the next day during peak times. Salt is gaining ground as a contender for thermal energy storage. Salt storage as one form of energy storage is not a new technology, but these technologies are receiving much renewed attention and appear to have a promising environmental performance. Salt storage produces no emissions during operation and more than 99 percent of the overall weight of the battery materials can be recycled (the steel, the copper and aluminium). Recycling sodium and sulphur remains a challenge, however. The major drawback for molten-salt technologies is that they need to operate at a high temperature (300-350 degrees Celsius).

In the molten form it is now commercially available for the storage of heat from concentrated solar power on timescales of days. In the dry form on the other hand, the technology is still emerging, with the potential to open the way of storage on timescales of months and to support the integration of high levels of renewables. For example, Swedish company SaltX Technology is a pioneer of this "salt hydrate" technology and is piloting a large-scale plant with Vattenfall in Germany. In this case the pilot plant with a 0.5MW power output/input and total storage capacity of 10MWh was commissioned at Vattenfall's Reuter combined heat and power plant in Spandau, Berlin earlier this year[24].

At present, the most widely used storage method is pumped hydro storage, which uses surplus electricity to pump water up to a reservoir behind a dam. Later, when demand for energy is high, the stored water is released through turbines in the dam to generate electricity. Currently around 96 percent of storage is pumped hydro and of the remaining 4 percent, by far the biggest share is lithium-ion. They are the fastest growing form of battery on the worldwide market, with the potential to dominate the market in the short term. The global battery market could be worth 250 billion euros per year from 2025 onwards according to the European Commission[25], and batteries are likely to play a key role in decarbonizing the road transport sector. Storage capacity in Europe will reach 5.5 GWh by 2020, according to the European Market Monitor on Energy Storage released in March 2019[26]. New growth drivers will emerge as the Clean Energy Package[27] is enacted and we can expect E-mobility to become a significant new application for stationary energy storage to support the charging infrastructure. At the global and EU level, lead acid technologies are expected to still prevail in 2025 in terms of volume, but the lithium-ion market is expected to become greater in terms of value from 2019 onwards. The use of lithium-ion battery is expected to accelerate in the near future. Their design is likely to evolve during this time, but scientists believe that they may soon reach their performance limits in terms of energy density. Thus, in addition to efforts to develop future evolutions of lithium-ion, the quest is now on to identify potential alternatives that offer better performance with an improved environmental profile[28].

At the same time, the system is changing and due to the seasonal nature of the renewable energy, seasonal storage that last for weeks and months is required. Technology such as compressed and liquefied air energy storage, or flow batteries are needed. The innovative projects like balloons in the sea, using gravity, carbon nano-tubes or ultra-capacitators – we will see a lot of technology evolving in the next few years[29]. Solid-state batteries, for example those being developed by French battery maker Saft, are a promising future technology, since they will have energy density and less risk of spontaneous combustion. As well, there are other gravity-based energy storage systems like Advanced Rail Energy Storage that uses surplus wind and solar energy to move millions of pounds of rock uphill in special electric rail cars that roll back downhill, converting this gravitational potential energy to electricity that goes out onto the grid. We need large, stable and long-lasting utility-scale chemical battery storage to deal with rapid intermittency in both generation (renewable energy) and demand (rapid changes in use throughout the commercial day).

The latest technology to emerge is the vanadium redox battery, also known as the vanadium-flow battery. These batteries are fully containerized, nonflammable, compact, reusable over semi-finite cycles, discharge 100 percent of the stored energy and do not degrade for more than 20 years. Redox flow batteries are well suited for stationary energy storage as they can store energy for a long time and release it quickly when needed. They are durable with a long lifespan (in terms of both cycle life and calendar life), efficient, and have reasonable capital costs. In future they can replace lithium-ion batteries as the predominant energy storage battery technology for stationary applications[30]. Besides the earth's crust has much more vanadium than lithium, e.g. on yearly basis twice as much vanadium as lithium is produced each year.

In particular, energy storage will be critical in the coming years for military specific innovation, electric grid security and clean energy development. For example, the Otis Air National Guard base on Cape Cod, Massachusetts boasts the military's first wind-powered microgrid. The installation, which includes one wind turbine, a diesel generator, and battery storage, can power the base for up to 120 hours in the event of an outage. The project was funded in part by the state of Massachusetts (U.S.) with the aim to develop renewable energy on military bases[31].

To sum it up, the mineral requirements for the deployment of solar panels (mainly silicon, indium and gallium) should become less

[24] Engerati network's newsletter. "Salt storage shows promise in Germany" (30 August 2019).
[25] Battery 2030+ Initiative focuses on the future battery technologies that are essential for electric vehicles, clean mobility, renewable energy storage, and a range of emerging applications (including robotics., medical devices, and aerospace)
[26] EASE. "European Market Monitor on Energy Storage" (March 2019). Link: www.ease-storage.eu/category/publications/emmes
[27] Based on the European Commission proposals published in November 2016, the Clean Energy for all Europeans package consists of 8 legislative acts (e.g the recast of renewable energy directive, amending the directive of energy efficiency to name some of them). After political agreement by the Council and the European Parliament in 2018 and early 2019, enabling all the new rules to be in force by mid-2019, the EU countries have 1-2 years to transpose those directives into national law.
[28] European Commission/Science for Environment Policy. "Future Brief: Towards the battery of the future". Issue 20 (September 2018).
[29] Clerens, Patrick. "Storage is the backbone of the energy transition". EASE newsletter (30 August 2019).
[30] Weber, A.Z, Mench, M.M, Meyers, J.P., Ross, P.N, Gostick, J.T. and Liu, Q. Redox flow batteries: a review. Journal of Applied Electrochemistry. 41 (10), pp.1137-1164.
[31] Nexus Media. "US military Bases using Solar, Wind &Battery Storage for Energy Security (17 November 2018).

critical by 2035 due to improvements of material efficiency. Thus, the rare earth minerals (REEs) will be the prime enablers of the global energy transition and its low carbon technologies and systems. This also means that global production of rare earth minerals used in solar panels and wind turbines must grow twelvefold until 2050[32].

Important drivers to monitor in this sector include policies to further reduce carbon dioxide emissions, incentives for distributed power generation, power and storage requirements related to the deployment of electric vehicles[33].

3.2 THE NATO'S DEFENSE SECTOR

Securing the supplies of critical minerals is vital for NATO members and its allied partner countries not only from an economic, but also from a security point of view. The western allies' military sector increasingly relies on dual-use equipment and depends on globalized supply chains. Military equipment for the modern battlefield includes communications technologies, robotics and computer systems. Military technology will continue to change rapidly and will be increasingly shared with NATO members and partners[34]. Defense supply chains are therefore less distinct from those in the broader economy, and the dual-use nature of a broad range of assets means that many supply chains are more international than ever. Moreover, "higher risk of and uncertainty about supply disruptions owing to the fragmentation of global supply chains[35] can further threaten assured access to critical minerals. Much of today's defence equipment is purchased directly from civilian vendors and designed to meet both civilian and military needs. Since these civilian technologies are also used in the military sector, they have a strategic importance for the functioning of increasingly networked high-tech armies. For example, an American submarine of the Virginia class requires about four tons of rare earth materials, an Arleigh Burke class destroyer more than two tons, and an F-35 fighter jet more than 400 kilograms. Further areas of REE use are aerospace engineering, surveillance systems and lasers. The more sophisticated the military equipment becomes, the more diverse is the demand for rare earths for the armed forces in the future. This is a trend that no army of NATO countries can deny, however, a present, NATO's import dependency on China's rare earths is nearly 100 percent.

4. INCREASED INTEREST IN CRITICAL MATERIALS AVAILABILITY – NATO, THE U.S. AND THE EU

For rare earths materials, NATO countries and the rest of the world depend on China. Based on recent trends of Chinese exports and in compliance with the evolving strategic priorities of China, it becomes obvious that China will cease to export rare earth materials and actually become a net importer of these materials within the next few years[36]. The United States Geological Society estimates that China controls only 60% of the rare earth minerals distributed around the planet. Therefore, the rest of the world has some options at its disposal, including the exploitation of rare earth oxide mines in the U.S., Australia and Canada. But even with alternate sources of elements, the supply chain required to convert these materials into usable material is currently non-existent outside China. This lack remains a main issue for producing for example future NATO weapons system (e.g. the next generation precision-guided munitions that can be carried and operated by both conventional manned platforms and autonomous Unmanned Aerial Vehicles (UAVs)[37].

According to the most recent U.S Geological Survey Mineral Commodity Summary 2019, the U.S. is 100% dependent on foreign supply for 20 metals and minerals, and 50% or more dependent for another 43 metals and minerals. That is nearly half of the naturally occurring elements on the Periodic Table. Such deep dependency is the main concern expressed in the President's Executive Order on Critical Minerals, issued in December 2017. The strategic problem of critical minerals dependency was raised most recently when the Commerce Department released a report requested by President Trump to investigate the U.S. access to rare earths in case of an emergency. According to the report, the United States is heavily dependent on critical minerals imports.

If China (and/or Russia) were to stop exports to the U.S. and its allies for a prolonged period – similar to China's rare earth embargo in 2010 – an extended supply disruption could cause significant shocks for the NATO allies.

Although other countries like France, Estonia, and Japan also have some rare earth deposits, much of their production is sent to China as concentrates for refining.

In Europe, the situation is as worrying as it is in the U.S. The European Union is entirely dependent on imports of rare earth supplies, most of them coming from China. For many raw materials, the EU is absent from the upstream steps of the value chain. To access these raw materials, the EU member-states have no other choice than to import the concentrates or the refined materials from other countries to feed their industries and markets.

In this context it can be asked what possible solutions are available for the U.S., Europe and other western countries. Finding suppliers other than China is essential, and in reality alternatives do exist, although the price of rare earth from China is less expensive. Rare earths are also sold by Brazil, Russia, Australia, Burundi or the United States. A significant rise in the global price would make mining in those countries feasible. Some rare earth minerals can even be profitably produced from recycling. The measures to reduce China's dominance at the rare earth market require a realistic assessment of the resources, the economic, political and geostrategic constraints and development of joint approaches.

Even in the hypothetical absence of China's erratic political behavior, the market of rare earths would always be prone to wild fluctuations due to its small size. To cope with this challenge, western allies need to obtain an accurate, and up-to-date picture of this comparatively small and non-transparent commodities market. It would be desirable that the western allies get a clear idea of how strongly China dominates the field. NATO planning circles and defense sector politicians need to obtain the full picture of which raw materials and components for which weapon systems are provided by which companies and which mines, processors and suppliers they depend. This would allow to assess existing and future procurement risks along the long and complex value-added chains. However, this knowledge is still lacking.

For NATO, the EU and other nations, long-term cooperation between industry and politics within the nations and at a European and transatlantic level would be desirable. The US, the EU and Japan could intensify their ongoing commodity dialogues and expand the security and armament policy dimensions. So far, little attention has been paid to the American-Japanese commodity dialogues between politics, economics and science. Australia as a country with a still functioning rare earth production should be included. The aim of this dialogue format should consider developing rare earth deposits outside of China, to keep them alive, and to bring at least some of the value chain back to the Western allied nations.

This means that e.g. the EU should classify

[32] Van Exter, P., Bosch, S., Schipper, B., Sorecher, B., Kleijn, R. "Metal Demand for Renewable Electricity Generation in the Netherlands: Navigating a Complex Supply Chain" Metabolic, Universität Leiden, Copper (2018).
[33] Antoine Monnet, Amar Ait Abderrahim "Report on major trends affecting future demand for critical raw materials" (2018).
[34] Parthemore, Christine, "Elements of Security: Mitigating the Risks of U.S Dependence on Critical Minerals" Center for New American Security (June 2011).
[35] Ibid.
[36] "Impact of Scarcity of Materials on Military Structural, Mechanical, Propulsion and Power Systems" (NATO Science and Technology Organization 2017).
[37] LtC Francesco Esposito. Precision-guided Munitions of the Future and the Related Challenges to NATO. Joint Air Power Competence Center's Publications (2019).

this market as being of high strategic importance and re-position itself with a coherent, inter-ministerial raw materials and industrial strategy[38]. In Germany, the so-called *"Rohstoffallianz"*[39] was already trying to set up a purely private industrial consortium of leading German companies to jointly buy raw materials on the world markets. This commodity alliance was founded following the last high price phase in 2011/12, but ended in 2015. The participating companies were no longer interested, because the prices for rare earths and other raw materials declined and the German government had not supported the project from the onset - a missed opportunity to better position Germany as an attractive industrial location in case of future raw material crises.

With so much at stake, it is imperative that the western nations develop methods to acquire a secure, long-lasting source of rare earth elements. A further option is to substitute critical minerals of unreliable supply with easier to find materials, and recycling, in which even products like cellphones and iPods can yield small quantities of rare earth elements.

Other countries relying heavily on rare earth elements, such as Japan and South-Korea are scrambling to secure future supplies. Japan, as a huge manufacturing hub of high technology equipment, has been carefully monitoring the rare earth industry and trying to come up with solutions to protect its own needs. Japan should strengthen its relationships with current supply countries and also pursue new frontiers. Efforts are underway to extract elements from lower quality resources. Lithium, along with materials such as vanadium and uranium, is present in seawater in small concentrations. Researchers have recently developed a method for extracting these materials from seawater. Japan is increasingly looking to secure further resources supplies from Australia, with focus on rare earths, to stem the dominance China has on the market.

The U.S. could use Japan as a role model and pursue joint ventures with other countries with known rare earth reserves. Another effort might be to seek alternative methods to extract rare earth elements. For example, the U.S and other countries might invest in and promote the research and development of cost effective methods of recycling. More than 80% of rare earth materials could be recycled by, better handling of the manufacturing and recycling of products. Today all lead-acid car batteries must be returned to recycling centers to remove the lead, and it is possible to use those same centers to recover other critical materials for recycling, including magnets from electric vehicles' motors.

[38] Ibid.

[39] Raw material alliance.

CONCLUSIONS AND OPEN QUESTIONS

The first step in addressing the issue of critical materials for sustainable energy applications is to examine resource scarcity from the perspectives of both supply and demand. Increasing worldwide adoption of renewable energy technologies and growing electrification of transport will require one to two orders of magnitude larger and more complex systems than presently exist in order to generate, store, and distribute this energy. However, these new technologies are dependent on various metals, including lithium and cobalt. Availability of other metals (e.g. silver) is deemed even more critical, but for cobalt the researchers find that with assumptions of a global clean energy transformation, cumulative demand for cobalt for period until 2050 can exceed known global resources by almost 200 percent. Understanding cobalt criticality and availability is necessary as lithium-ion battery demand is projected to increase exponentially throughout the next decade. Due to the projected increase in demand over the coming decade, lithium-ion batteries will continue to be the largest end-use sector of cobalt. With expected lifetimes between eight and twelve years and high cobalt recovery rates at end of life, electric vehicles lithium-ion batteries will provide a significant source of secondary supply for cobalt. Due to relatively high recycling rates (up to 50%), recycling programs of small consumer electronics may also play a future role in secondary cobalt supply? Short-term projections indicate that battery recycling is not currently economically or systematically developed to make an impact on cobalt supply up to 2030. Despite this tendency, recycled cobalt from used batteries will be a significant source of cobalt in the long term, potentially matching 70 percent of primary supply by 2030[40].

Critical metals have many applications besides solar and wind energy. Neodymium and praseodymium are crucial components in electric vehicle technology. The next critical question will be which metals will experience strong increases in demand. The answer remains far from clear, for the ways in which metal demand will increase depend on both inter-technology choices, such as the balance between wind and solar power, and intra-technology choices, such as the balance between onshore and offshore wind. Another unsolved question is future choice between different types of solar PV cells, and the extent to which vehicles become fully electric and what types of batteries will dominate in industrial production.

Other triggers for alarm are high dependency levels coupled with strongly concentrated reserves and actual production in certain countries. The raw materials identified as critical have changed according to the demand and supply structure of the industries. One possible solution is to mitigate future supply shortages and technological bottlenecks is to create a European value chain for rare earth elements. However, this is associated with a considerable risk as a result of Chinese dominance because China could use its market power and strong government protection to outcompete any European value chain that is able to compete with the state controlled Chinese cluster.

The recent trade dispute between the U.S and China highlighted the dependence of the United States on China. It was a wake-up call at the international level that concerted efforts are required to reduce the dependency and strategic vulnerability on China. This is a global challenge, impacting many geographical regions and cutting across different industries. To solve it requires international political cooperation and increased technological efforts.

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Securing the industrial internet of things:

Policy considerations for reducing cyber risks to industrial control and safety systems[1]

By Mr Óscar Recacha Ortega*, Mr Vytautas Butrimas**

ABSTRACT

This report explores ways through which we can reduce the likelihood of cyber-attacks against control systems used to monitor and manage our critical infrastructure such as in the energy sector. The main purpose is to convey the need to raise awareness on the importance of securing our control systems, to review the technologically based vulnerabilities by taking a look back into recent history, and to give policy makers and security practitioners recommendations to strengthen these critical systems from threats emanating from cyberspace.

KEYWORDS

cybersecurity, cyber-attack, industrial control systems (ICS), critical infrastructure, industry, Industrial Internet of Things (IIoT), intelligent electronic device (IED) and SCADA.

1. INTRODUCTION

Technology has entered in almost every as-


By **Mr Óscar Recacha Ortega**, and
Mr Vytautas Butrimas, NATO ENSEC COE

Mr Oscar Recacha Ortega studied at Campus Universitario Duques de Soria (Universidad de Valladolid) in Spain and in 2018 was an intern at NATO Energy Security Center of Excellence.

Mr Vytautas Butrimas is a cybersecurity consultant who has worked from 2016 until January 2020 as Cybersecurity Subject Matter Expert for the NATO Energy Security Center of Excellence in Vilnius. He has contributed to various reports on cybersecurity and critical infrastructure (for OSCE, EU ENISA, IEA, NATO and other international organizations), published articles and have been an invited speaker at various conferences and trainings on Cyber Security and defence policy issues. In 2019, he completed a cyber risk study of the NATO Central Europe Pipeline System.

* Intern in 2018 at NATO Energy Security Centre of Excellence, Institution, Šilo g. 5A, LT-10322 Vilnius, Lithuania
** NATO Energy Security Centre of Excellence, Institution, Šilo g. 5A, LT-10322 Vilnius, Lithuania
E-mails: Oscar.Recacha@gmail.com; Vytautas.Butrimas@enseccoe.org

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pect of our lives. Its constant development has simplified and added powerful enablers to the way we live. It is time-saving and cost-effective, and it has provided us with the capacity of instant communication, tearing down the distance barriers that seemed insurmountable before. The evolution of PCs into intelligent small devices in conjunction with the expansion of the Internet, is ushering in a world where ubiquitous computing is becoming a reality.[2] In 'Click Here to Kill Everyone,' Bruce Schneier says, 'We no longer have things with computers embedded in them. We have things with computers attached to them.'[3] A good example of this is the automobile. Depending on the model, they can have from 30-50 processers embedded in its systems, permitting them to control their steering, braking, and throttle control.[4]

The so-called Industry 4.0 - considered to be the 4th Industrial Revolution[5] - is changing the way humans live.[6] Autonomous machines are now communicating with other machines. Thus, humans no longer need to do all the work manually on site. This has both good and bad sides. On the one hand, there is improved efficiency and lower costs; on the other hand, fewer humans are in direct control of the process, which makes it more necessary to have faith that the machines will have the sufficient embedded intelligence to work properly and safely without constant human intervention.

A key new enabling component is the Intelligent Electronic Device (IED) which is more frequently found in various applications and environments from the home and small office to manufacturing. The interconnection of these devices via Internet and/or over closed internal networks allows for remote management and control of an activity or process. If one such device, such as a surveillance camera or a smart home thermostat carries data to the owner's smart phone over the Internet, we call this device part of the Internet of Things (IoT). To be more specific 'IoT is a distributed network system that typically employs the internet/cloud for some aspect of its communication and usually includes sensors/control systems, a storage component, a compute component, a user-interface component, and possibly gateways.'[7] Outside of the consumer sector, these devices have similar but more serious functions in terms of supporting an industrial process and safety. For example, if a sensor on a gas pipeline sends information about flow rates or pressure to a control centre remotely monitoring and controlling fuel flows over a wide geographic area, we can refer to this device as part of the Industrial Internet of Things (IIoT). IIoT is what makes connectivity possible for the remote management and control of industrial operations such as in power generation and oil refining found in complex and geographically distributed environments. However, the application of these connected devices interacting with each other over wide areas raises reliability and safety issues. As opposed to consumer IoT, IIoT's security, latency, and applications issues make cloud use (over the Internet) more difficult to integrate and less practical due to the complexities of the manufacturing or industrial environment.[8]

But we should not be blind about the numerous benefits that high tech has given to

[2] Kagermann, H., Whalster, W., and Helbig J. "Securing the future of the German manufacturing industry: Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Final report of the Industrie 4.0 Working Group," trans. Joaquín Blanco and Helen Galloway. April, 2013: 15. http://alvarestech.com/temp/tcn/CyberPhysicalSystems-Industrial4-0.pdf. Accessed July 24, 2018.

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[5] Also known as the Industrial Internet of Things (IIoT) discussed later in this article.

[6] Marr, B. "Why Everyone Must Get Ready For The 4th Industrial Revolution." Forbes. April 5, 2016. https://www.forbes.com/sites/bernardmarr/2016/04/05/why-everyone-must-get-ready-for-4th-industrial-revolution/#29334d5f3f90. Accessed July 19, 2018.

[7] Wong, W. "What's the Difference Between Consumer and Industrial IoT?" Electronic Design. September 21, 2016. https://www.electronicdesign.com/iot/what-s-difference-between-consumer-and-industrial-iot. Accessed August 1, 2018.

[8] Ibid.

us. With every innovation, potential vulnerabilities also come along. The omnipresent connectivity amongst devices nowadays is a double-edge sword that presents a serious quandary: if you can use the new Information Technology (IT) and communication technologies to remotely monitor and manage an industrial or process control system used to produce and distribute electricity, so can an adversary.

Since new information and communications technologies have become the foundation that supports commerce and our daily activities, the potential consequences of a maliciously motivated and/or unintentional alteration, not to mention a successful attack against it, can result in physical damage to property, environment, and loss of life. Therefore, Safety and Cybersecurity are important factors of concern as these technologies are further developed and applied.

When we think about the worst-case scenarios that could possibly take place, it turns out that the bulk of them involve industrial systems. In the 'Industrial Internet of Things Volume G4: Security Framework,' it is stated that 'A successful attack on an IIoT system has the potential to be as serious as the worst industrial accidents to date (e.g. Chernobyl and Bhopal), resulting in damage to the environment, injury or loss of human life.'[9] And the IIoT encompasses a myriad of critical industries such as: nuclear, chemical, manufacturing, energy, oil and gas, water and wastewater, to name but a few. Hence the urgent need for implementing an effective industry-specific policy framework upon which all the security measures must be harmonised.

This report will explore ways to reduce the likelihood of cyberattacks against control systems used to monitor and manage our critical infrastructure. This will be done by raising awareness on the importance of securing our systems, to state the present vulnerabilities and to give policy makers and security practitioners recommendations to strengthen the stated vulnerabilities in the future.

2. WHAT IS CRITICAL INFRASTRUCTURE AND WHAT ARE THE SECURITY CHALLENGES?

Critical infrastructure (CI) refers to both physical and cyber-based systems (along with their assets) that are so vital and essential that the disruption, incapacity, or destruction of such systems would have a debilitating impact on the state's health, safety, security, economic well-being, or any combination thereof.[10] Attacks on CI target Industrial Control Systems (ICSs). ICS is a collective term used to describe the integration of both hardware and software with network connectivity that allows us to remotely monitor and control sensitive processes characteristics of critical infrastructure. Were attackers to find and exploit existing vulnerabilities in the ICS, the operation of CI could be severely degraded or completely disrupted, resulting in damage to property and even loss of life.

Having briefly described the technical parts of an industrial control system, it is important to understand some of the cybersecurity challenges. There are three main concerns in defending a critical control system from a cyber-attack:

First, we have to understand that the addition of cyber threats to ICS is something relatively new. It was not present at such a scale some twenty years ago when many of these systems were designed and put into the field. Since the threat of a cyber-attack from the outside - from cyberspace - was not a major security concern, designers and operators rarely considered the fact that all these devices will be increasingly remotely accessi-

[9] Schrecker, S., et all. "Industrial Internet of Things Volume G4: Security Framework" Industrial Internet CONSORTIUM. September 19, 2016: 16. https://www.iiconsortium.org/pdf/IIC_PUB_G4_V1.00_PB.pdf. Accessed July 24, 2018.

[10] Radvanosky, R., and Brodsky, J. "Handbook of SCADA Control System Security." CRC Press. May 10, 2016: 3 - 5. https://universalflowuniversity.com/Books/Computer%20Programming/Software%20Security%20and%20Privacy/Handbook%20of%20SCADA%20Control%20Systems%20Security.pdf. Accessed August 1, 2018.

ble and subject to external attacks one day.[11] Furthermore, leaving aside the problems of maintenance, improvement, or management that these devices present, we should remind that these IED's, were designed to reliably perform a simple task and do it reliably in manufacturing or outdoor environments for many years without frequent replacement. For this reason, their technical powers are limited in comparison to the computing power found in an office PC. For example, one device used to monitor control processes in a pipeline has about the same computing power as a notebook pc purchased in 1992. It has a 32Mhz CPU and 4 megabytes of RAM.[12] It also uses an insecure decades old communication protocol (Modbus) where anyone can learn how to use by downloading the field technicians' user manual from the Internet.[13] A simple anti-virus scan, for example, could consume the available computing resources of this and other IEDs and degrade or even deny its functions. For example it could slow down the device's communication of critical data to a control station. There are many IED's (sensors, actuators, PLSC's and drives) that are used to remotely monitor and control the movement of trains on a railway line or fuel in a pipeline of several hundred kilometres in length. A sensor based alarm about a train approaching on a track or a sudden increase in pressure on a pipe, if delayed, can result in serious consequences. A good example is an unresponsive gasoline pipeline control system (SCADA) which contributed to an explosion of the Bellingham pipeline in 1999[14].

While new and more capable devices are available, the implementation costs could be cost-prohibitive for an enterprise to replace them all at once. It can be hard for a security practitioner to justify spending to upgrade security in an industrial environment since there have been few reported incidents and things seem to be working just fine. Thus, vulnerabilities are present that an actor can exploit that would not normally be present in an IT environment office where the cyber threat has long been understood and steps taken to address them.

Secondly, one of the primary characteristics of industrial systems today is their extensive connectivity. The current trend towards increasingly autonomous devices with added computing power and communications capability brings a new challenge —making sure the ability to remotely monitor and control a system is secured. If you lose the ability to communicate with all the devices working in the system there will be trouble. This is exactly the situation that developed in the December 2015 cyber-attack on control systems of three power distribution companies in Ukraine which resulted in a quarter of a million people being deprived of electricity in the wintertime.[15] This will be further discussed later.

The last and perhaps most important challenge is addressing the lack of understanding on what really needs to be protected and from what kind of cyber threats. It is not fully appreciated that an exhaustive and thorough evaluation of operational risk is essential in order to determine what critical assets and processes need to be protected. What is important is that if a contract is won to secure a critical industrial operation, the company needs to have the expertise in the operational technology employed by the customer. For example, an IT company that was used to auditing data centers was invited by an electric power company to test their control networks that are used to monitor and control substations. The company did a simple network scan to see what was on the network and knocked out all the relays which needed to be reset by hand (several hundred of them) in order to get the control back and restore normal operations.[16]

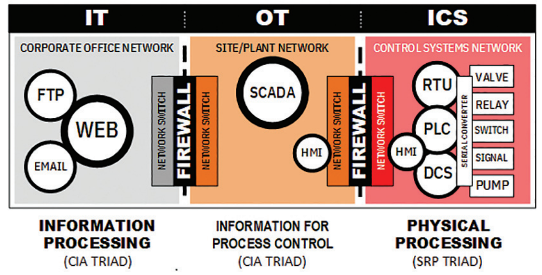


Figure 1. Protecting critical infrastructure is not just about protecting the enterprises IT assets in the office or "SCADA". Industrial control systems (ICS) and IED's (PLC's, Relays and Switches) are found closest to the physical process. Shown with permission of Bob Radvanovsky http://icsmodel.infracritical.com/

3. EXAMPLES OF CYBER-RELATED ATTACKS AND INCIDENTS ON CRITICAL INFRASTRUCTURE

In this part, we will discuss the principal sources of concern that are illustrated in a few selected cybersecurity cases: Stuxnet, Ukrainian ICS, and Trisis.

A) Stuxnet

First made public in 2010, this malware is considered to be one of the first publicly known cyber-weapon's developed and delivered to its target by a state. For the first time ever, a malware was capable of expanding beyond the digital layer, causing real-world physical damage to an industrial process.[17] It was most significant in that instead of attacking an office computer or server, it targeted an industrial control system which succeeded in taking away the view and control of a critical process from the operator. For the first time a doubt was introduced for operators of critical infrastructure: 'can we trust what our engineering systems are doing and telling us?'

Even though no one has publicly admitted to the Stuxnet operation, the creation, exceptional flawless development, and subsequent launching of Stuxnet is widely attributed by some analysts to governments seeking to 'derail or at least, delay the Iranian nuclear program.'[18]

Although no official numbers have been released, it is estimated that Stuxnet destroyed over 984 enriching centrifuges, resulting in a loss of 30% of production.[19] Stuxnet opened Pandora's box for a new type of war beyond anybody's imagination at the time - cyber warfare.[20] The success of this novel kind of high tech and intelligence operation which used cyber means to achieve a physical result and the lack of international reaction and prosecution were surely noticed and conclusions made by the cyber institutions of other states. For example, after Stuxnet the hacking community took notice and courses and workshops on attacking SCADA systems soon appeared at hacker conferences such as BlackHat.[21]

B) Ukrainian ICS

Having been targeted multiple times since

[11] Schrecker et all. "Industrial Internet of Things Volume G4: Security Framework," 16.
[12] SCADAPack 4203, Schneider Electric Brochure http://download.schneider-electric.com/files?p_enDocType=Brochure&p_File_Name=SE-DataSheets-SCADAPack4203-A4-TBU-v24.pdf&p_Doc_Ref=SCADAPack+4203+Datasheet+%E2%80%93+A4. Accessed August 16, 2018.
[13] Chipkin, P."Modbus for Field Technicians." Chipkin Automation Systems. 2010 http://www.chipkin.com/files/liz/MODBUS_2010Nov12.pdf. Accessed August 16, 2018.
[14] Determines Probable Cause Of Pipeline Rupture in Bellingham, Washington, NTSB 10/8/2002 News Release https://www.ntsb.gov/news/press-releases/Pages/Determines_Probable_Cause_Of_Pipeline_Rupture_in_Bellingham_Washington.aspx Accessed August 20, 2018
[15] Lee, R., Assante, and M., Conway, T. "Analysis of the Cyber Attack on the Ukrainian Power Grid." E-ISAC. March 18, 2016. https://ics.sans.org/media/E-ISAC_SANS_Ukraine_DUC_5.pdf. Accessed July 23, 2018.

[16] Weiss, J. "Are the Good Guys as Dangerous as the Bad Guys – an Almost Catastrophic Failure of the Transmission Grid." CONTROL. November 2, 2017. https://www.controlglobal.com/blogs/unfettered/are-the-good-guys-as-dangerous-as-the-bad-guys-an-almost-catastrophic-failure-of-the-transmission-grid/. Accessed on August 17, 2018.
[17] Zetter, K. "An unprecedented look at Stuxnet, the world's first digital weapon." Wired. November 3, 2014. https://www.wired.com/2014/11/countdown-to-zero-day-stuxnet/. Accessed August 1, 2018.
[18] Fruhlinger, J. "What is Stuxnet, who created it and how does it work?" CSO. August 22, 2017. https://www.csoonline.com/article/3218104/malware/what-is-stuxnet-who-created-it-and-how-does-it-work.html. Accessed August 1, 2018.
[19] Holloway, M. "Stuxnet Worm Attack on Iranian Nuclear Facilities." Stanford University. July 16, 2015. http://large.stanford.edu/courses/2015/ph241/holloway1/. Accessed August 1, 2018.
[20] Ivezic, M. "Stuxnet: the father of cyber-kinetic weapons." CSO. January 22, 2018. https://www.csoonline.com/article/3250248/cyber-warfare/stuxnet-the-father-of-cyber-kinetic-weapons.html. Accessed August 1, 2018.
[21] Assessing and Exploiting Control Systems (Course description). https://www.blackhat.com/us-15/training/assessing-and-exploiting-control-systems.html. BlackHat. Accessed August 16, 2018.

the conflict in the east of the country broke out in 2014, the attacks against the Ukrainian CI that took place in 2015 and 2016 are the most notorious. Evidently, the situation of instability and turmoil that Ukraine is currently undergoing, makes this troubled country the ideal laboratory where an adversary can — without fear of retribution— experiment and develop cyber-attacks and perhaps apply the results to achieve a political objective at the same time.

In December 2015, three power companies underwent highly coordinated cyber-attacks which resulted in circuit breakers at over 30 substations being opened remotely while the operator watched his hijacked control screens in disbelief.[22] The next part of the attack activated previously installed malware which acted to 'brick' the serial-to-ethernet devices used to communicate between the central control room and the substations on the grid. This resulted in a 'lost SCADA' situation giving the operator no choice but to send technicians out in the field to restore the functions of the substations. In completing their attacks and in order to make the work of the recovery operation more difficult, the attackers erased the control work stations hard drives. The attacks caused more than a quarter of million people to go without electricity.

Ukraine suffered the second attack on its ICS nearly a year after when part of Kiev, the capital city of Ukraine, experienced a power failure. The complexity of the malware was quite impressive and it marked an advancement in capability by adversaries.[23] However, it appears that the attackers restrained themselves, for according to one commentator they clearly could have caused more harm.[24] Perhaps it was just more an experimentation and testing?

C) TRISIS/TRITON/HATMAN

In August 2017, a cyber-attack targeted the safety systems of an important petrochemical plant in the Middle East. Although it is believed Saudi Aramco was the victim of the attack, the evidence is far from conclusive and it still remains officially unknown.[25] The malware deployed has been named in different ways, such Trisis, Triton, or HatMan depending on which security expert is writing about it.

This is the fifth publicly known ICS-tailored malware, but it is the first ever to target Safety Instrumented Systems (SIS). This is an event of significance and worth a digression.

The intentional attempt to compromise a safety system represents a serious escalation of the cyber threat to critical infrastructure. Control and safety systems are used in an industrial process to protect property and most importantly, people from serious harm resulting from an industrial process that has gone outside of set parameters. These parameters are used to program an automatic response in the SIS to bring a system back to a safe state when changes in temperature, flow rates, pressure, frequency, or other system state indicators exceed pre-set levels. These are the systems that automatically respond to open or close valves on a gas pipeline when pressures or flow rates go beyond pre-set parameters. These are the systems that automatically shut down a nuclear reactor when something goes wrong with the monitored critical industrial processes as for example occurred at the Hatch nuclear power station in 2008 when a software upgrade was interpreted by the SIS as an adverse event (lack of data on the reactor cooling system) causing the shutdown of the reactor.[26] If something is done to intentionally neutralize

[22] "Watch How Hackers Took Over a Ukrainian Power Station." filmed December 2015, video, 1:27. https://www.youtube.com/watch?v=8ThgK1WXUgk. Accessed August 17, 2018.
[23] Dragos. "CRASHOVERRIDE Analysis of the Threat to Electric Grid Operations." Dragos. June 12, 2017. https://dragos.com/blog/crashoverride/CrashOverride-01.pdf. Accessed July 24, 2018.
[24] Zetter, K. "Everything we know about Ukraine's power plant hack," Wired. January 20, 2016. https://www.wired.com/2016/01/everything-we-know-about-ukraines-power-plant-hack/. Accessed July 24, 2018.
[25] Groll, E. "Cyberattack Targets Safety System at Saudi Aramco." Foreign Policy. December 21, 2017, https://foreignpolicy.com/2017/12/21/cyber-attack-targets-safety-system-at-saudi-aramco. Accessed July 18, 2018.
[26] Krebs, B. "Cyber Incident Blamed for Nuclear Power Plant Shutdown." Washington Post. June 5, 2008, http://www.washingtonpost.com/wp-dyn/content/article/2008/06/05/AR2008060501958.html Accessed August 16, 2018.

Figure 2. The importance of Safety Instrumented Systems and consequences of their failure are illustrated in the Deep Water Horizon oil drilling platform explosion. For some reason all safety systems that could have avoided this disaster failed.

Source: https://en.wikipedia.org/wiki/Deepwater_Horizon#/media/File:Deepwater_Horizon_offshore_drilling_unit_on_fire_2010.jpg"

the functions of these systems, serious harm can result if a system state exceeds set parameters. It is like disabling the breaks and seat belts of an automobile traveling down a highway without the knowledge of the driver. Nothing immediately bad will happen to the driver of the car but if there was a sudden need to stop or turn the steering wheel the consequences could be most serious. In other words, safety systems are the last line of defence provided by automated technologies to save us from having to deal with something 'going boom in the night.'

What is of most concern is that this attack almost succeeded in fully compromising safety instrumented systems made by Schneider Electric's. These and similar SIS devices are used in many industrial plants around the world. If the perpetrators have developed a technique against the equipment of Schneider Electric, they can in theory apply the same technique in any of the plants that use this or similar equipment. While the cyber-attack was directed at a specific version of the device and software, the potential escalation for disruption of Trisis is unsettling.[27]

Trisis/HatMan had in many ways a 'game-changing' impact for the future cybersecurity of ICS. The fact that it specifically goes after the last line of defence tells us that adversaries are growing not only wiser but are willing to overlook the physical consequences of their acts. For this reason, HatMan should be taken as major wake-up-call for the need to

[27] Perlroth, N. and Krauss, C. "A Cyberattack in Saudi Arabia Had a Deadly Goal. Experts Fear Another Try." New York Times. March 15, 2018. https://www.nytimes.com/2018/03/15/technology/saudi-arabia-hacks-cyberattacks.html. Accessed July 15, 2018.

defend against and manage this destabilising behaviour in cyberspace.[28]

4. SHEDDING SOME LIGHT ON CYBERSECURITY MYTHS AND MISCONCEPTIONS

What do these case examples tell us about the problem of protecting ICSs from cyber-attacks and incidents?

Myth Nr. 1: 'We are safe, our critical systems are not connected to the Internet'

The belief that no one would ever notice your system or try to attack it because it is too technically difficult or because it is isolated is false. In 2014, two ICS engineers decided to test the assertion that there are no critical infrastructure devices that are visible on the Internet in a test called 'Project Shine'.[29] They added engineering search terms to the search engine 'Shodan' and the results were surprising. According to one of the researchers, 'The sheer number of devices exposed and the wide geographic area these devices were located in was staggering.'[30] As demonstrated in this project, the hard-fact is significantly different. The operators sometimes are not aware that they have devices on the network that are indeed visible from the Internet. They may forget to close a temporary connection or allow a remote connection to a vendor who has a compromised computer. Some enthusiastic Industry 4.0/Industrial Internet of Things[31] vendors offer cost savings and efficiencies by providing a solution which integrates office, control system, and safety instrumented systems.[32] Problem is if one has a link to the Internet, both the control and safety systems are put at risk. Thinking that you are safe if your critical systems are isolated from the Internet is not sustainable. There is always an 'open window' or 'unlocked door' to cyberspace that will be missed.

Myth Nr. 2: Industrial Control Systems are engineered to be safe and cannot be intentionally harmed

The belief that ICS is protected from external threats by being built according to high engineering standards and have safety systems to protect them against catastrophic failure is simply not true. The manipulation of the laws of physics also need to be considered.

The Idaho National Laboratory (INL) in the United States in a 2007 experiment called 'Aurora', executed a deliberate remote cyber-attack on a diesel generator used in power plants to demonstrate if a cyber-attack could wreck large rotating equipment. The test demonstrated that rapidly disconnecting and reconnecting a generator to the grid, but out of phase - via physical or cyber intrusion of control systems conducted maliciously or unintentionally - could have serious effects on systems operations including physical damage.[33] It must be remembered that the Aurora vulnerability is neither a 'virus' nor a 'design flaw', but comes from the laws of physics that if manipulated intentionally will result in physical damage.

5. POLICY CONSIDERATIONS FOR REDUCING CYBER RISKS TO INDUSTRIAL CONTROL AND SAFETY SYSTEMS

There are lessons learned based on measures to improve the safety and reliability of control systems in the context of today's dynamic cyberspace environment. However, it is important to remember the words of Andy Bochman:

> 'Here's the brutal truth: It doesn't matter how much your organization spends on the latest cybersecurity hardware, software, training, and staff or whether it has segregated its most essential systems from the rest. If your mission-critical systems are digital and connected in some form or fashion to the internet (even if you think they aren't, it's highly likely they are), they can never be made fully safe.'[34]

Keeping the above in mind here are some recommendations:

To develop a plan for implementing cybersecurity practices

Within the enterprise, the first step in cybersecurity for any organization is to perform a risk assessment and impact analysis of their operations. The result of this work should clearly indicate which critical assets need to be protected and from what cyber threats. Once this information is available then it should be possible to answer the last question in the risk analysis - how to protect chosen assets from the identified threats in the most cost-effective way.[35]

Resources for security are scarce, especially in the private sector where allocations for security or other kind of improvement need to be approved by management who in turn need to answer to the stockholders. It is hard to get approval for financing measures to improve cybersecurity when things seem to be running just fine. On the other hand, even if one does appreciate the importance of assessing the risks, if it is not done comprehensively the results may be disappointing when an unforeseen incident takes place that was never considered. For example, if the main threat is determined to be from cybercrime the measures taken to defend against on-line crime will fall short in defending against a state resourced and executed cyber-attack. The determination of risk is challenging. Think of the story of the 'Three Little Pigs'. In the end, only one of them judged the threat correctly (possibility of an attack from a wolf) and took the appropriate protective measures to secure the chosen asset (the house) by building with bricks.

This effort at risk analysis will allow for the development of a contingency plan that 'allows for the safe operation or shutdown of operational processes in the event of ICS compromise. These plans should include the assumption that the ICS is actively working counter to the safe operation of the process.'[36]

Another advantage in taking the time to answer the three questions is that the security practitioner will be fully prepared to provide clear and comprehensive answers to management on why a security measure needs to be funded and implemented. A useful tool to apply when funding requests have to compete with the requests coming from other parts of the enterprise.

When developing something new include security in the design process from day one

Ensuring security by keeping the design and/or implementation method a secret is called security through obscurity (STO).[37] The applicable counter-measure ought to be security by design that is, the application of security

[28] Dragos. "TRISIS Malware. Analysis of Safety System Targeted Malware." Dragos. December 13, 2017. https://dragos.com/blog/trisis/TRISIS-01.pdf. Accessed August 1, 2018.
[29] Rashid, F. "Project SHINE Reveals Magnitude of Internet connected Critical Control Systems." Security Week. October 6, 2014, https://www.securityweek.com/project-shine-reveals-magnitude-internet-connected-critical-control-systems. Accessed July 17, 2018.
[30] Ibid.
[31] List of IIoT benefits by a major ICS vendor can be found here: https://www.uruman.org/sites/default/files/articulos_congreso_10/iiot_-_industrial_internet_of_things_by_honeywell.pdf. Accessed July 31,2018.
[32] Integrated Control and Safety, Siemens: https://www.industry.siemens.com/topics/global/en/safety-integrated/process-safety/safety-integrated-systems/integrated-control-safety/pages/default.aspx. Accessed August 1, 2018.
[33] Swearingen, M. et all. "What You Need to Know (and Don't) About the AURORA Vulnerability." POWER. September 1, 2013. http://www.powermag.com/what-you-need-to-know-and-dont-about-the-aurora-vulnerability/ Accessed July 31, 2018.
[34] Bochman, A. "Internet Security." Harvard Business Review. April 27, 2018 http://alertlogic.qa.hbr.org/2018/04/internet-insecurity. Accessed on August 16, 2018.
[35] Butrimas, V. "In seeking to protect industrial control systems are we clear about what is being threatened and from what threats?" SCADASEC MAGAZINE. November 8, 2016. http://scadamag.infracritical.com/index.php/2016/11/08/in-seeking-to-protect-industrial-control-systems-are-we-clear-about-what-is-being-threatened-and-from-what-threats/. Accessed July 28, 2018.
[36] ICS-CERT. "Cyber-Attack Against Ukrainian Critical Infrastructure," February 25, 2016. Homeland Security. https://ics-cert.us-cert.gov/alerts/IR-ALERT-H-16-056-01. Accessed July 26, 2018.
[37] "Security through obscurity (STO) is a process of implementing security within a system by enforcing secrecy and confidentiality of the system's internal design architecture. Security through obscurity aims to secure a system by deliberately hiding or concealing its security flaws." https://www.techopedia.com/definition/21985/security-through-obscurity-sto. Accessed July 25, 2018.

measures from the very beginning rather than patched on later after the system has been implemented or put out as a product to sell in the market. A good example is the Windows operating system. It was sold throughout the world to consumers for years before the CEO Bill Gates wrote that famous e-mail in 2002 ordering his employees to make the security of its products top priority.[38] By then it was too late to redesign Windows from scratch. So, this is one of the reasons why all Windows users the world over spend time each month waiting for the latest security patch or update to install on their computing device at home or work. Putting security into the beginning of the design process can be hard, as it may increase the development cost and contribute to further delay in putting the product out to market. Not a good thing to say to management and to the stockholders. However, it will lead to cost savings in the long run in terms of safer systems and better company reputations.

An effort must be made to think whether a new IT feature is needed for the new equipment. Will the new feature also introduce a new exploitable vulnerability that can be used in a malicious cyber-attack? If so, then safety features need to be added to the device and instructions provided on how to best configure the device in the particular operational environment. However, the additional security may also add to the cost that would make application of a large number of sensors for a pipeline of thousands of kilometres cost-prohibitive. Not all of the new functionalities and connectivity options offered as 'selling features' by manufacturers are needed (for example adding an IP address to an aquarium thermometer or thermocouple.)[39] Adding unnecessary features that need more security can be costly and even cost-prohibitive. Instead, a return to a simpler non-digital or 'hard-wired to the device' analogue approach may, when compared to the rising security costs for adding digital technologies, be the most cost-effective means to reduce complexity and security management overhead.[40]

The creation of an Industrial Security Operations Centre (ISOC)

In addition to the operators of critical infrastructure assigned with watching over the day-to-day operations of an industrial process, a new section needs to be created with the task of monitoring and reacting to malicious or unintentional changes in process flows, equipment performance, and data flows that go beyond expected norms. Namely an Industrial Security Operations Centre (ISOC). The intent would be to establish a monitoring capability that could detect a malicious intrusion within 24 hours. It is not enough to look after the cybersecurity of the business side of the facility; the security needs of the manufacturing plant operations on the plant floor also need addressing. This will also demand resources in personnel and funding, but the benefits must be weighed against a dynamically changing cyber threat environment. Arguments for or against the creation of an ISOC will come from answering the three critical questions discussed above.

To start a dialogue about cybersecurity between the operator and vendor

The operator of a pipeline, power generation and distribution facility, water utility, or any larger manufacturing enterprise needs to engage in a dialogue with their equipment vendor/service provider about security. Operators, for example, need to ask the vendor about the manufacturers' security practices: is the customer notified when software patching is performed? Are there any 'backdoors' placed by the manufacturer on the equipment that allows outside access to it? A good example is Schneider Electric's openness about the HatMan malware and disclosing what they knew at a recent security conference.[41] To get started the customer needs to inform the vendor of the security needs and requirements that apply specifically to their operation. A good dialogue between the operator and vendor/service provider will do much to reduce the likelihood of unpleasant surprises at product installation and system start time.

Be careful about implementing Industry 4.0

The arguments for the benefits from increasing digital complexity in manufacturing and industrial environments[42] as have become associated with the so called 4th Industrial Revolution, also known as Industry 4.0,[43] are difficult to question. However, there are some concerns that need addressing when considering going down this path. For one, it must be understood that there are security implications - regardless of the perceived attractive cost benefits and increased efficiencies - for increasing the level of automation by introducing more device self-configuration in respect to different situations.[44] The challenge to determine whether there has been a cybersecurity incident will be very high when a self-configuring Industry 4.0 device makes a change. The question may arise: how to tell whether this change is legitimate or malicious?[45]

The tendency to integrate safety, control, and business networks into one network in spite of the advantages in lower overhead and savings is to be resisted and if implemented, wisely managed.[46] Take some time to explore the implications of Industry 4.0 before jumping into the movement and make sure that the ability to know and manage what is in your critical systems is not diminished.

Take the time to find out the cause of failure: it's a great learning tool

In looking back at the question raised at the beginning of this article and cyber myths just discussed, it does not seem prudent to go back to business as usual after a failure in energy infrastructure. Regardless of whether the outage was caused by a cyber-attack, technical failure, or management error the event should be taken as an opportunity to take a long look at the security of our increasingly vulnerable critical infrastructures. This on the other hand, may not be an easy task for an operator of a real-time system producing and distributing electricity or sending fuel down a pipeline to stop operations to conduct a cyber forensic investigation. Before doing this, there are several issues that need to be considered such as safely shutting down a system and making sure services continue to be provided to customers.

Get the IT and Operational Technology (OT) security people to work together as a team

An integrated approach to cybersecurity that takes into consideration not only the IT priorities of Confidentiality, Integrity, and Availability, but also the OT concerns for Safety and Reliability needs to be developed. This means that the contribution of information and communication technology specialists who deal with cybersecurity in the office needs to be part of the system risk evaluation and design process performed by control system engineers. The IT guy who may not understand what his OT colleague is doing needs to make his security concerns known to the OT guy and the OT guy needs to take some time to listen to the IT guy. A wide range of risks needs to be evaluated and accounted for if we are to avoid and defend against future failures in the

[38] Gates, B. "Trustworthy Computing." Wired. January 17,2002. 12:00 pm. https://www.wired.com/2002/01/bill-gates-trustworthy-computing/. Accessed July 31, 2018.
[39] 1732E ArmorBlock Dual-Port EtherNet/IP 4-Point Thermocouple and RTD Input Modules. September, 2012. http://literature.rockwellautomation.com/idc/groups/literature/documents/in/1732e-in005_-en-e.pdf. Accessed August 2, 2018.
[40] Brodsky, J. "Remember why ICS happened in the first place." SCADASEC MAGAZINE. August 14, 2018 http://scadamag.infracritical.com/index.php/2018/08/14/how-ics-security-shoots-itself-in-the-foot/ Accessed August 16, 2018.

[41] Kling, A. and Forney, P. "TRITON – Schneider Electric Analysis and Disclosure," filmed January 2018 at S4 Events, video, 25:51, https://www.youtube.com/watch?v=f09E75bWvkk&feature=youtu.be. Accessed August 2, 2018.
[42] Read "World Energy Investment 2018." International Energy Agency. July 2018. https://www.iea.org/wei2018/. Accessed August 2, 2018.
[43] Known in the United States as the Industrial Internet of Things (IIoT).
[44] Watch "Brave New Industrie 4.0" presented by the man who analysed Stuxnet, Mr. Ralph Langner. https://www.youtube.com/watch?v=ZrZKiy2KPCM. Accessed August 2, 2018.
[45] Ibid.
[46] Here is one manufacturer proposing to do just that by integrating safety systems. Selega, R. "How to remain safe and profitable during Industry 4.0." ABB Conversations. January 23, 2018. https://www.abb-conversations.com/2018/01/how-to-remain-safe-and-profitable-during-industry-4-0/. Accessed August 2, 2018.

critical infrastructures our societies depend upon so much for their well-being.

Finally, the engineers trying to defend these systems need some help. They cannot be expected to defend in isolation systems that are targeted by a state with all its technical and intelligence resources. It is not a fair contest. Very similar to the kind of contest between a High School soccer team and a FIFA championship team. Without significant help the outcome is certain that the school team will lose. What is needed to counter the odds, is an international institution based upon a legal framework developed by cyber knowledgeable politicians and diplomats working together with professionals from the engineering community. In questions where the need is recognised and where it really matters, states have banded together and signed international agreements and conventions. This has been especially so, for example, with prohibiting the use of weapons of mass destruction. One possible model that can be referenced for dealing with the production and use of cyber weapons by nation-states is the International Convention on Chemical Weapons.[47] Still perhaps remembering their use in World War I and in recognition of the advances in technology that could facilitate the use of chemical weapons and amplify their potential for harm, a convention entered into force in 1997. Over 190 nations have signed it, representing most of the world's population. Associated with the agreement, the Organization for the Prohibition of Chemical Weapons (OPCW) was created to monitor and report on implementation of the Convention.[48]

This would be a concrete proposal for one confidence building measure for states to follow in cyberspace. In this way, the monitoring institution would act as a lever of soft pressure on states putting them in the spotlight of world opinion as a violator of an international agreement which they have signed.

6. CONCLUSION

In the digital world we live in, automatization has increasingly taken a larger and crucial role in industrial operations. Remotely controllable robots and machines have come to replace humans. The running of major enterprises is now dependent upon a connected network of many devices that communicate more and more with each other than with their human managers. Since current societies rely on services from a safe and available critical infrastructure, securing their control devices and safety systems is a vital part of the work to ensure the well-being of the economy and society of a nation. Several technical measures have been proposed in this report that can be implemented with the help of IT and OT security professionals and engineers. Nevertheless, this effort should not just be left to the technology professionals to worry about. The increased pervasiveness of the technologies applied combined with their international dimension requires a much larger, multi-disciplined, and coordinated approach. The improvement of the ICS's security ought to be the product of a common effort between engineers, private sector, and governments.

What's more, we can be sure that past and present attacks, being largely unanswered by the international security community, will serve as blueprints (even provide encouragement as an effective, cheap and deniable means to an end) for future malicious cyber activities directed against the industrial control systems that keep critical infrastructure up and running. Together, we need to work on developing systems that will be safe and reliable and to cooperate and share information among the community of interest. This is vital in order to deal with future advanced and persistent cyber threats that jeopardise the safety and availability of critical infrastructure we all depend on for our everyday activities and lives.

[47] Chemical Weapons Convention. Organization for the Prohibition of Chemical Weapons. http://www.opcw.org/chemical-weapons-convention/. Accessed on August 1, 2018.
[48] The Organization for the Prohibition of Chemical Weapons. https://www.opcw.org/about-opcw/ Accessed on August 1, 2018.

Pulling the Thread for U.S. Air Force Mission Assurance

by Mr Mark A. Correll

ABSTRACT:

As the operating environment becomes ever more dependent on energy – and therefore susceptible to its interruption – the USAF is becoming increasingly cognizant of the need to better identify, assess, and mitigate these vulnerabilities to ensure mission success under a wide range of threat and hazard conditions. The process creates pathways to best integrate technologies to protect and enhance Enterprise readiness and lethality by assessing how an energy denial of service may jeopardize mission success.

MISSION THREAD ANALYSIS

As United States Air Force (USAF) core missions increasingly depend on larger and more complex and intertwined networks, the USAF exposure to risks from energy system interruptions also increases. A significant storm or well-orchestrated physical or cyber-attack on an installation or the national grid could cripple an installation's electrical system, compromising the USAF's ability to conduct its missions. It is vital for the USAF to mitigate the threat of energy interruptions to operations and improve the resilience of defense installations and surrounding areas as a means to guarantee availability of Enterprise capabilities. As the operating environment becomes ever more dependent on energy – and therefore susceptible to its interruption – the USAF is becoming increasingly cognizant of the need to better identify, assess, and mitigate potential vulnerabilities to ensure mission success under a wide range of threat and hazard conditions. Through its Mission Thread Analysis (MTA) process, the USAF is reshaping how energy security is understood within a mission context.

Through an MTA, the USAF expands the scope of how it identifies key assets that could lead to unacceptable mission impacts in a denial of service event. This process provides leaders with the information they need to account for and address potential mission gaps. The first key step to this analysis is decomposing the mission into core functions, tasks and capabilities, and engaging key stakeholders from across a mission's "kill chain".

Second, an MTA links these assets to the electrical grid to examine potential vulner-

by **Mr Mark A. Correll**

Mark A.Correll is the Deputy Assistant Secretary of the Air Force for Environment, Safety and Infrastructure, Headquarters U.S. Air Force. Washington D.C. He provides executive leadership on all matters pertaining to formulation, review and execution of plans, policies, programs and budgets for Air Force built and natural infrastructure, environmental, safety and occupational health programs.

abilities from grid-level disruptions. An MTA challenges participants to realize the interconnected nature of their missions and how inherently distributed enabling systems, like energy, support a variety of missions and functions. By breaking down functional silos among different mission components and bringing attention to how these components are linked together at an energy level, the USAF can better recognize and manage risks.

Third, an MTA helps leaders understand potential compromises to mission success that may be introduced through dependencies on internal and external partners. These identified areas of susceptibility can prompt discussions with industry partners to ensure mission needs and requirements are properly defined and communicated to those upon whom the USAF depends. Through this process, the USAF can shed light on how its mission capabilities may be tethered to shared energy assets.

Ultimately, the USAF is prioritizing energy resilience investments by pursuing solutions that can most effectively advance mission assurance within a budget-constrained environment. The MTA process helps identify where investments should be made and encourages collaboration with industry and other partners. From there, the USAF can better assess which technologies – traditional or disruptive – might best reduce identified mission assurance gaps. Doing so maximizes the impact of limited resources to both enhance Enterprise resilience and retain an operational edge. This analysis approach, coupled with additional efforts the USAF is pursuing to explore disruptive technologies, like wireless energy transmission, or cutting edge business models, like Energy-as-a-Service, are helping put the USAF at the forefront of tackling energy resilience from multiple angles.

The threat environment is changing, so embracing new approaches and polices to tackle energy assurance must come first in order to maximize the benefits of those energy technologies that are and will disrupt the current marketplace. By implementing processes like an MTA, organizations can make smarter investment decisions into technologies, processes, and risk management approaches that enhance energy security and system resilience. Understanding the USAF operates within a larger network of domestic and international partners, it's important that companies and organizations across the globe similarly take a step back and evaluate their analysis approaches and policies to ensure they are aligned with the changing threats and hazards to mission from energy interruptions.

Though the USAF is pursuing opportunities to temper potential resilience gaps in the electrical system with more robust analysis approaches and policies, it recognizes it cannot solve every problem on its own. Such considerations need to be institutionalized throughout the U.S. Department of Defense and its industry partners, but also within key international military alliances like NATO. Only through cross-cutting recognition of the interrelated susceptibility to energy interruptions can the full picture of how technologies can be best used to reduce collective risk be understood.

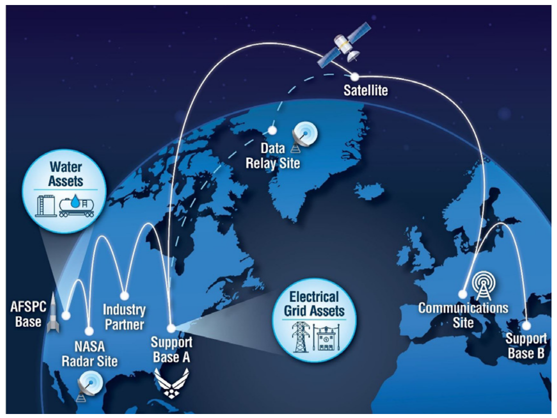


Figure 1: USAF missions rely on a system-of-systems network geographically distributed across the globe. A denial of service to systems such as energy and water that enable this network could have impacts that ripple across the mission. The USAF is tackling this challenge with an innovative approach to enhance enabling system resilience.

Source: USAF 2019

NATO's Experience in the Field of Energy Efficiency for Armed Forces

by Mr Andrea Manfredini

Officially, the road to energy efficiency in NATO began in 2012, during the Chicago Summit, when the Allied Heads of State and Government agreed that NATO should work "towards significantly improving the energy efficiency of our military forces". Then they declared at the Wales Summit in 2014 to "continue to work towards significantly improving the energy efficiency of our military forces, and [...] note the Green Defense Framework". Two years later, the Warsaw Summit contained a similar paragraph on energy efficiency with some additions: "...we will further improve the energy efficiency of our military forces through establishing common standards, reducing dependence on fossil fuels, and demonstrating energy-efficient solutions for the military". The last Summit held in Brussels, in July 2018 read that "...we will also further improve the energy efficiency of our military forces, including through the use of sustainable energy sources, when appropriate".

As we can see, although with different levels of sensitivity, the issue of energy efficiency has one of the focus points over the past seven years. At this stage, the following questions arise instinctively: how have these policy guidelines mentioned above been translated within NATO both, at both the strategic and the operational level? Can we consider the Alliance as efficient from an energy point of view?

It could be argued that some initiatives have been done within NATO from a bottom-up approach only, for the purpose to further push this topic among the Allies. The main purpose of this article is to list the most relevant examples of such ventures. It also reflects the author's opinion that what has been done so far is only the beginning and quite far from - considering NATO forces as being energy efficient.

SMART ENERGY TEAM (SENT)

This initiative has the merit of being the first to take stock of the situation within NATO immediately after the Chicago Summit Declaration. Its results are still current today:

by Mr Andrea Manfredini

CDR Andrea Manfredini (ITA Navy) is Head of the Doctrine and Concept Development Division at the NATO Energy Security Centre of Excellence (NATO ENSEC COE) in Vilnius. E-mail: andrea.manfredini@enseccoe.org

reducing fuel consumption in the military is an operational imperative. Energy efficient solutions will not only save money when less fuel is used, but can above all save soldiers' lives, and help improve the mobility, as well as the resilience and endurance of military forces.

Following the Chicago Summit Declaration, a proposal for the establishment of a Smart Energy Team (SENT) was submitted to nations. The project had to be funded for two years under NATO's Science for Peace and Security (SPS) Program. The SENT concept was approved by all Allied nations through the Political and Partnerships Committee (PPC) in October 2012. According to the concept, SENT was established as an interdisciplinary ad-hoc group of experts from various relevant fields. It was tasked to generate cross-cutting knowledge and contribute to the integration of energy efficiency related issues into the NATO Defence Planning Process, and in the medium and long term, integrating Smart Defence. The roles and goals of SENT included an examination of how reducing the energy requirement can shrink the logistical footprint, thus improving operational capabilities, minimizing the potential environmental consequences of NATO military activities and reducing force protection requirements. SENT's most important goal was to identify and highlight the best practices and opportunities for multinational smart energy projects within the Smart Defence framework and SPS Programme. Finally, SENT sought to identify and extend the pool of energy experts within NATO, which in turn was expected to result in proposals or incentives for more multinational NATO energy efficiency activities. During the preparation of the SENT concept, it was concluded that for now the focus would be on activities to advance energy efficiency for land operations. This pertains especially to power generation and management as well as to soldier power which had lagged behind the advances made for naval and air force capabilities. The final report on SENT was delivered on 6th of May 2015.

THE SMART ENERGY LIBGUIDE

This useful online library on energy topics in the military was created in 2011 and is still maintained and update by the Emerging Security Challenges Division at NATO Headquarters. It serves as an information sharing platform.

SMART ENERGY TRAINING AND ASSESSMENT CAMP (SETAC)

SETAC is a sustained effort to build Smart Energy capabilities with the aim to make NATO's armies more resilient and effective by reducing the fossil fuel dependency of deployable field camps while securing the interoperability of NATO's missions. One of the ideas to improve energy efficiency on military bases is to create a test base facility in which troops can train and energy used is measured: new technologies and energy management tools can then be applied to measure the differences in power usage and requirements. This training and assessment camp must be complementary to the already existing test camps of several nations. The expected goal of this initiative is to gain more detailed information about the use of utilities like energy and water on a manned compound, and to test new systems to improve energy efficiency. The dependency on fossil fuels might decrease significantly by testing new techniques and in making troops more aware of the importance of energy reduction.

This initiative lead by NATO Headquarters Emerging Security Challenges Division (ESCD) has not yet aroused a high level of interest among nations, probably due to the lackluster definition of the objectives and on how these should be concretely achieved. Support for interoperability in the field of energy efficiency is a point that deserves attention, although to date, beyond any declarations, solid results have not yet materialized. Up until now, the participation of the "SETAC flag" in the CAPABLE LOGISTICIAN exercises both in 2015 and 2019 at the moment does not seem to have marked significant progress at the doctrinal level.

There are two projects under the SETAC's umbrella that are funded by SPS:

1. Harmonized energy monitoring & simulation tools;

2. Innovative Energy Solutions for Military Applications (IESMA).

HARMONIZED ENERGY MONITORING & SIMULATION TOOLS

Making an interoperable energy monitoring kit and energy simulation tool available, a harmonized data collection and analysis approach is going to be developed in order to help generate a common multi-national understanding of deployed camp energy flows to promote energy reduction initiatives.

This ongoing project, led by Canadian researchers at CanmetENERGY addresses the energy saving challenge by developing a harmonized, interoperable solution for NATO organizations, members and partner nations, to better monitor, predict and ultimately identify suitable energy reduction strategies for deployed camps. It is a multi-national collaborative effort, to collect deployed camp energy consumption and energy efficient technology data to support the development of a universal deployed energy simulation tool. The main research thrust of the project is to evaluate and forecast the power and energy requirements and/or savings of a deployed camp. To achieve this, two interrelated sub-projects are underway, both of which also include training to ensure the successful transfer of equipment:

a. Development of an interoperable, portable and non-intrusive energy monitoring kit. This supports harmonized collection of deployed camp energy consumption and energy efficient technology data;

b. Development of a deployed camp energy simulation and energy prediction tool, validated with the multi-national deployed camp energy data collection initiative.

INNOVATIVE ENERGY SOLUTIONS FOR MILITARY APPLICATIONS (IESMA) CONFERENCE AND EXHIBITION

In line with the NATO mandate of raising awareness of energy developments with security sector implications, IESMA is a forum that brings together military experts from academia, industry and the defence to exchange experiences and discuss the implementation of emerging energy technologies in the military sector.

This is a bi-annual event organized by the NATO ENSEC COE, the first of which took place in 2011, with the aim of providing a platform - in the form of a conference and an exhibition - for information exchange on best practices, policies and technologies in the area of energy efficiency in the military domain. Experts across the world discussed the cutting-edge technical energy developments, material and non-material aspects, and their relevance for the military operations. The exhibition provides an opportunity for private enterprises, militaries, Ministries of Defence (MoDs), universities, organizations, and agencies to display the latest energy technologies and systems that could improve energy efficiency during military operations and which could also enhance practical cooperation between military, industry and academia. Over the years IESMA has become a recognized platform for bringing together the military, academia and industry, as well as governmental representatives from the capitals and from NATO's command structure. IESMA events allow them to update each other on material and non-material solutions and to initiate cooperative activities.

HYBRID POWER GENERATION AND MANAGEMENT SYSTEM (HPGS)

The HPGS generates stable electric power wherever it is needed, being able to use renewable sources, battery storage and, if required, conventional diesel generators.

The deployable modular HPGS is a prototype of a power generator which uses both renewable energy sources (wind and solar) and conventional fuel generators with energy storage and management solutions. It consists of two diesel generators, a photovoltaic array, a wind turbine, and an EMS including a battery pack and power electronics. It is capable of supplying to different types of camps and infrastructure, and can be easily transported and deployed as required, because all components are housed in 20 feet ISO containers. This project was initiated in 2015 by NATO ENSEC COE with the drafting of specifications, requirements and an operational energy usage scenario definition. The HPGS was funded by the Canadian Government in order to the increase the relevance of energy security in the Baltic Sea Region. After its launch it was formally transferred to the Lithuanian Armed Forces in February 2016 in order to be used and tested in NATO multinational exercises and trainings, as well as in military installations and barracks. The testing period of this system during military exercises has demonstrated that with HPGS troops can improve their energy efficiency and ultimately reduce dependence on fossil fuels. All these benefits are enablers for enhancing the operational effectiveness of forces, through the maximization of autonomy, increasing the availability of assets, strengthening resilience, as well as reducing the logistic footprint. The HPGS is an intelligent Energy Management System (EMS), which allows surplus energy coming from different types of sources to be stored in its battery pack for future use.

The project's goals have been to verify and to demonstrate the advantages of using a hybrid power generation system in a Deployed Force Infrastructure (DFI) environment and to analyse whether a HPGS would be beneficial for military use by saving fuel and increasing energy security. More than two years of usage and testing has given the NATO ENSEC COE the opportunity to define the system's advantages as well as weaknesses. A complete analysis is presented in a final report, which is downloaded from the NATO ENSEC COE website.

For more information about the HPGS project, download the NATO ENSEC COE report regarding the experimentation phase: https://enseccoe.org/data/public/uploads/2019/03/phase-1-report-hpgs-performance-analysis.pdf

ENERGY MANAGEMENT IN MILITARY ENVIRONMENT (EMMEE)

One tool for achieving energy efficiency is energy management, which the NATO ENSEC COE recognize as an instrument that can be implemented in the immediate-short term, with low economic impact, and which can be standardized for interoperability.

As large users of energy, it is believed that the armed forces of NATO nations could benefit greatly from the application of a standardized approach to energy management. The EMMEE project takes a case study approach and compares energy use at operational camps before and after the implementation of the principles of a "militarized" version of the ISO 50001 energy management handbook. It is expected that the benefits for the military of using a standardized approach include: a) improvements in safety for military personnel; b) reductions in energy resource consumption; c) reductions in logistical burdens related to the supply of energy; d) financial savings; e) improvements to environmental protection. The principles of the militarized version of the ISO 50001 handbook promote the efficient use of energy through improvements in three key areas; organizational management (or, to use a more military term, Command and Control – C2), technological application, and behavior change. The results of the case studies are expected to demonstrate the possibilities for the future development of energy efficiency related concepts, standards and doctrine.

SYSTEM ANALYSIS AND STUDIES (SAS) – RESEARCH TASK GROUP 119

The overall objective of this ongoing activity is to contribute to energy security within NATO, NATO Nations and Partner Nations, by sharing information and approaches to enhancing energy efficiency, and promoting best practices amongst NATO nations.

The overarching objective of SAS 119, established in November 2015, is to contribute to military aspects of energy security within the NATO Alliance and Partner nations, by examining several key technical areas of interest, sharing information and approaches to enhancing energy efficiency, and promoting best practices among NATO members with respect to enhancing energy efficiency in those areas. This activity supports NATO's energy security agenda by focusing primarily on enhancing energy efficiency through applied technical solutions. It relies mainly on qualitative research; including subject matter expert interviews and/or surveys within the MOD's of the member states to determine relevant already sponsored, initiated, or conducted projects throughout the Alliance.

The above list represents the most important examples of activities recently, or currently carried out by NATO in the field of energy efficiency. As presented, there are different ways and many tools available to improve energy efficiency in the military. Several of these projects have been implemented by individual nations, which has led to a lack of coordinated effort within the NATO sphere. Additionally, energy efficiency tools, whether material (e.g. technologies) or non-material (e.g. energy management techniques) in nature, need to be standardized in order to obtain and maintain interoperability among NATO allies.

More information on what is going on within the NATO energy efficiency domain can be found in my interview "The Paradox of NATO's Inefficiency in the Field of Energy Efficiency for the Armed Forces" by Vitalia Petrone, 2019.

For any clarifications or further information regarding this article you are kindly asked to contact CDR Andrea Manfredini (ITA-Navy): andrea.manfredini@enseccoe.org.

Smart Energy Headquarters at the Capable Logistician 2019 exercise, Drawsko Pomorskie, Poland [Photo: W. Rusow]

Interview with Commander Andrea Manfredini on his article: "The Paradox of NATO's Inefficiency in the Field of Energy Efficiency for the Armed Forces"

by Mr Andrea Manfredini

This interview was conducted in June 2019 by Vitalija Petronė[1], collecting the views of CDR Andrea Manfredini, Head of the Doctrine and Concept Development Division at the NATO Energy Security Centre of Excellence (NATO ENSEC COE) in Vilnius.

***Petronė:* Commander Manfredini, should the title of this interview "The Paradox of NATO's Inefficiency in the Field of Energy Efficiency for the Armed Forces" considered as a provocation with respect to the current situation of the energy efficiency topic within NATO?**

Manfredini: Actually, the oxymoron in the title is used on purpose to attract and cause the curiosity of the reader. On the other hand, it should be stated that the paradox within NATO's inefficiency does exist: it was said NATO's Summit held in Chicago in 2012 that the Heads of State and Government agreed to integrate the energy efficiency of the armed forces as an area of intervention within the vast domain of energy security, in order to increase the overall resilience of the Allies. Then the same message was shifted regularly and included the same content in all the final communiques of the successive Summits, the last of which was in 2018 in Brussels. Almost seven years have passed since the first input of the energy efficiency topic within the NATO Summits. However not much has been implemented. There is even a lack of more effective and widespread sharing of the energy efficiency subject within the Allied Nations.

With this interview, I aim to share my views regarding the current situation of NATO's actions in the field of energy efficiency with the utmost transparency and intellectual honesty. It is my duty to inform you, that even the 29 October 2018 Report on Progress Achieved in the Implementation of NATO's Role in Energy Security prepared for the summits on energy security contains a dedicated paragraph on energy efficiency in which the topic is covered, albeit generally including some examples of ongoing initiatives.

The fact that the NATO ENSEC COE is not a part of the NATO Command Structure, although it is accredited by NATO Allied Command Transformation (ACT), allows us to independently express an overall view on the topic of energy security that is not affected or influenced by any kind of conditioning, inevitable in the case of those who are called to account for what they do.

[1] Subject Matter Expert of Doctrine and Concept Development Division, the NATO ENSEC COE

If, for a moment, undertaking a dutiful gesture of self-criticism, NATO tried to look ahead instead of looking back at what it has done or is struggling to do, and tried to define clear objectives on energy security and shared strategies on how to reach them, immediately it would realize that the road ahead is still long and full of curves.

Continuing with the initial provocation, I would like to say that I perceive what NATO has done so far to the extent of 10% of what it should have done, proceeding with this rate of progress it will take about 70 years more before achieving the concrete goals, which in the meantime will inevitably change!

***Petronė:* Don't you think that this slow progress is due to the lack of interest from NATO nations towards the energy efficiency topic, rather than NATO as an entity?**

Manfredini: On the contrary, with the experience I have gained within these two years working at the NATO ENSEC COE, attending working groups, workshops, meetings and committees, I have to say that I have seen an incontrovertible growth of interest on energy efficiency at the level of single nations. It must be said that, since NATO is an Alliance of currently 29 nations, among them there are different sensitivities and priorities, as well as different ways of approaching this subject: in some states energy efficiency goes hand in hand with environmental protection. In others, efficiency means, above all, reducing the logistics footprint. Still others look at energy efficiency as a medium-long term tool to reduce costs, albeit against a substantial initial investment. Then there is the largest group of nations, which is waiting to see what kind of directions the Alliance will take, so they will adapt themselves to the Alliance later.

***Petronė:* In your opinion, how do you explain the reason of the disconnection between NATO and what the nations do, or are prepared to do?**

Manfredini: NATO is not entirely passive to these pressures; indeed, over time there have been some examples of initiatives within NATO coming bottom-up, which have tried to push on this topic. These are the most relevant examples:

- The Smart Energy Team project from 2013 until 2015, composed of eight experts with the aim of exchanging best practices on national and multinational efforts among NATO Nations and Allies. Their conclusions were summarized in a comprehensive report on need for energy in military activities, focusing on a comparison of the effectiveness of national approaches to reduce energy consumption;

- The Smart Energy Training and Assessment Camp (2016 – ongoing), uses nationally owned micro-grid technologies to test interoperability, measures components by using standard protocols and harmonized data, develops universal energy monitoring and camp simulation tools, and evaluates new STANAGs on integrated micro-grid technologies;

- The System Analysis and Studies SAS – Research Task Group (RTG) 119, (2015 – 2019) contributes to military aspects of energy security within the NATO alliance and partner nations, by examining several key areas of interest, sharing information and approaches for enhancing energy efficiency, and promoting best practices among NATO members with respect to enhancing energy efficiency in those areas. The mission of the SAS RTG panel is to conduct studies and analyses of an operational and technological nature, and to promote the exchange and development of methods and tools for operational analysis as applied to defence problems.

- The Innovative Energy Solutions for Military Applications is a bi-annual international conference and exhibition (first held in 2011), event held in Vilnius that aims to enable information exchange on best practices and technologies for advancing energy efficiency

Energy Efficiency equipment testing phase during international exercise Capable Logistician 2019, Drawsko Pomorskie, Poland [Photo: W. Rusow]

in the military. It brings together numerous experts from military, industry and academia, and creates a platform to present expertise and discuss lessons learned;

- The deployable modular Hybrid Power Generation System (launched in 2016), is a power generator prototype designed to reduce fuel consumption by increasing power generation efficiency and therefore improving the energy supply and security of the military camps. This is achieved with energy storage technologies, namely with high capacity batteries by storing surplus energy and returning it to the load when needed. The HPGS also can incorporate renewable sources of energy, such as PV and wind generation to further reduce diesel generators' fuel consumption. It has been demonstrated that hybrid power systems can reduce fuel consumption by 20% – 30% along with an increase of time required between the regular diesel generators maintenance period[2];

- The Energy Management in a Military Expeditionary Environment uses a case study methodology to identify changes in how energy is managed before and after implementing new guidance based on an enhanced ISO 50001 approach, including ISO 50001 principles (organizational management), technological applications (e. g. metering and monitoring) and behavioural change.

Further information on these projects and activities can be found in my article titled "NATO's Experience in the Field of Energy Efficiency for the Armed Forces".

[2] For more information about the HPGS, download the NATO ENSEC COE report regarding the experimentation phase: https://ensec-coe.org/data/public/uploads/2019/03/phase-1-report-hpgs-performance-analysis.pdf

***Petronė:* What risks can you foresee if a weak cooperation level between NATO allies continues?**

Manfredini: For strictly military aspects, NATO is based on the key concept of interoperability. This is what allows troops from 29 different countries to work in a coordinated and effective manner. Ultimately, interoperability is achieved through the emanation of shared concepts, policies, and finally standards that nations voluntarily decide to abide by.

In the absence of standards, there is a risk of having extreme situations in which the equipment supplied to the different armed forces cannot be interconnected: I am not speaking only of the currently known problem that can be practically solved for example 50Hz or 60Hz or the square plug that does not fit into the round socket. In today's interconnected world, the concept of interoperability has also evolved, it focuses on data exchange protocols which are an essential element, for example, for the realization of micro-grids.

Again, standardization is, more than ever, indispensable in the organization of appropriate chains of command that must deal with energy management.

***Petronė:* In a general way, what role does the world of industry and the manufacturing sector play?**

Manfredini: Because of the absence of standards, the industrial world is navigating on sight. Only the big companies that have capital to invest in research and development are trying to follow their own strategies that focus on certain technologies, which at the end they hope to use to engage the Alliance in the future. Therefore, small and medium-sized enterprises in this sector cannot risk huge amounts of capital without a reasonable certainty of an economic return on investment in the near future. In a nutshell, the industry suffers from the same immobility that is characterising NATO.

It goes without saying that in the absence of standards, there is a risk of leaving this field open to industry to sell the products it wants, which would result in NATO investing in commercial choices rather than fulfilling of specific requirements raised by armed forces.

***Petronė:* It seems that there are many initiatives and different actors involved. But is there a manager within NATO who deals with energy efficiency?**

Manfredini: With such a high number of experts[3], the real problem is the lack of a "control room" that is able to summarize the various initiatives and is able to link and prioritize them between the various levels (political, strategic, operational and tactical) related to energy efficiency. At present, organizational confusion risks complicating things, with a political level body that focuses attention on purely tactical elements and, vice versa, the tactical level that is perceived as interference in the political and economic plan. It is obvious that in the case of such confused scenario, the most direct reaction undertaken by the Nations is blocking of, or at least unsupporting, any kind of initiative.

***Petronė:* Since the problem is well known, what actions has the NATO ENSEC COE taken to support the Alliance in the Energy Efficiency field?**

Manfredini: A few years ago, the NATO ENSEC COE, supported by the Lithuanian representative at NATO Joint Standardization

[3] Hereby is the list (not exhaustive) of the entities that in a certain way deal with energy efficiency on behalf of NATO: NATO Headquarters International Staff (ESCD, ESTF); NATO Headquarters – International Military Staff – (Plans and Policy Division), Allied Command Transformation, Allied Command Operations, Supreme Headquarters Allied Power Europe – Energy Efficiency Environmental Protection Working Group, Environmental Protection Working Group, Science & Technology Organization, Petroleum Committee, Military Engineering Working Group, NATO Energy Security Centre of Excellence, Military Engineering Centre of Excellence.

Board (JSB), brought to the discussion table the proposal to create a special working group, to be placed in the hands of the NATO JSB, which dealt with the subject of energy security as a whole. This proposal was opposed by some of the representatives and, in order to give a possible future to this initiative, the chairman of the assembly asked the SHAPE representative to prepare and present in the following meetings a roadmap on energy security.

After two years in which the energy "wind" seemed to have lost much of its strength, this proposal was finally developed through an initiative that is now bringing together representatives of the main branches of NATO around the same table to deal with the military aspects of energy security.

After several meetings of these representatives, a workflow was born in which all the steps of the Military Aspects on Energy Security Roadmap were defined. The steps which are expressed in 14 points, have been planned to be developed in detail, including steps related to concepts, policies, definitions, projects, management bodies, etc.

At the moment, the situation is that the results of the Military Aspects on Energy Security Roadmap, which were recently presented to the NATO Political Committee, will be submitted for the attention of the NATO Military Committee and a response is anticipated by the end of summer 2019. We hope that the proposal, which contains taskings for the two Strategic Commands (NATO ACT and NATO ACO) will be positively accepted, in order to finally able to proceed with the definition and implementation of this roadmap. The implementation of this roadmap would be the first true integral and structured approach to energy efficiency of the Armed Forces of the Alliance. The most likely timeframe for performing any task seems to be set within five years.

As you can see, we are only at the beginning, but the newly appointed Political Committee as leader of the activities connected to the Roadmap for Consolidating NATO's Role in Energy Security, gives us hope for consistent future developments.

***Petroné:* Can you elaborate more about this initiative at the political level on the Roadmap for Consolidating NATO's Role in Energy Security?**

Manfredini: Despite the fact that the word "roadmap" is aligned with the initiative led by ACT and ACO, this project takes place at the highest level of the decision-making bodies of the Alliance. At the moment the Political Committee is engaged in a series of full-spectrum cognitive conferences on energy security. For example, the NATO ENSEC COE was interested, among other topics, in presenting the situation in the education and training area, for which in 2015 it was appointed as Department Head for Energy Security. For now it is not yet clear whether any initiatives will be undertaken, or what they will be, after these meetings.

What is certain is, that without specific tasks or recommendations issued by the Political Committee, the risk of yet another failed attempt is high. In this regard, I hope that on the part of the speakers who were alternating in these meetings there will be a sense of self-criticism in order to present to the Political Committee the current situation on Energy Security, highlighting successes and limitations as well. It is the only way to unblock a plastered situation that otherwise risks encasing initiatives sustained by a few and probably not fully appropriate to ensure an effective contribution to the Alliance.

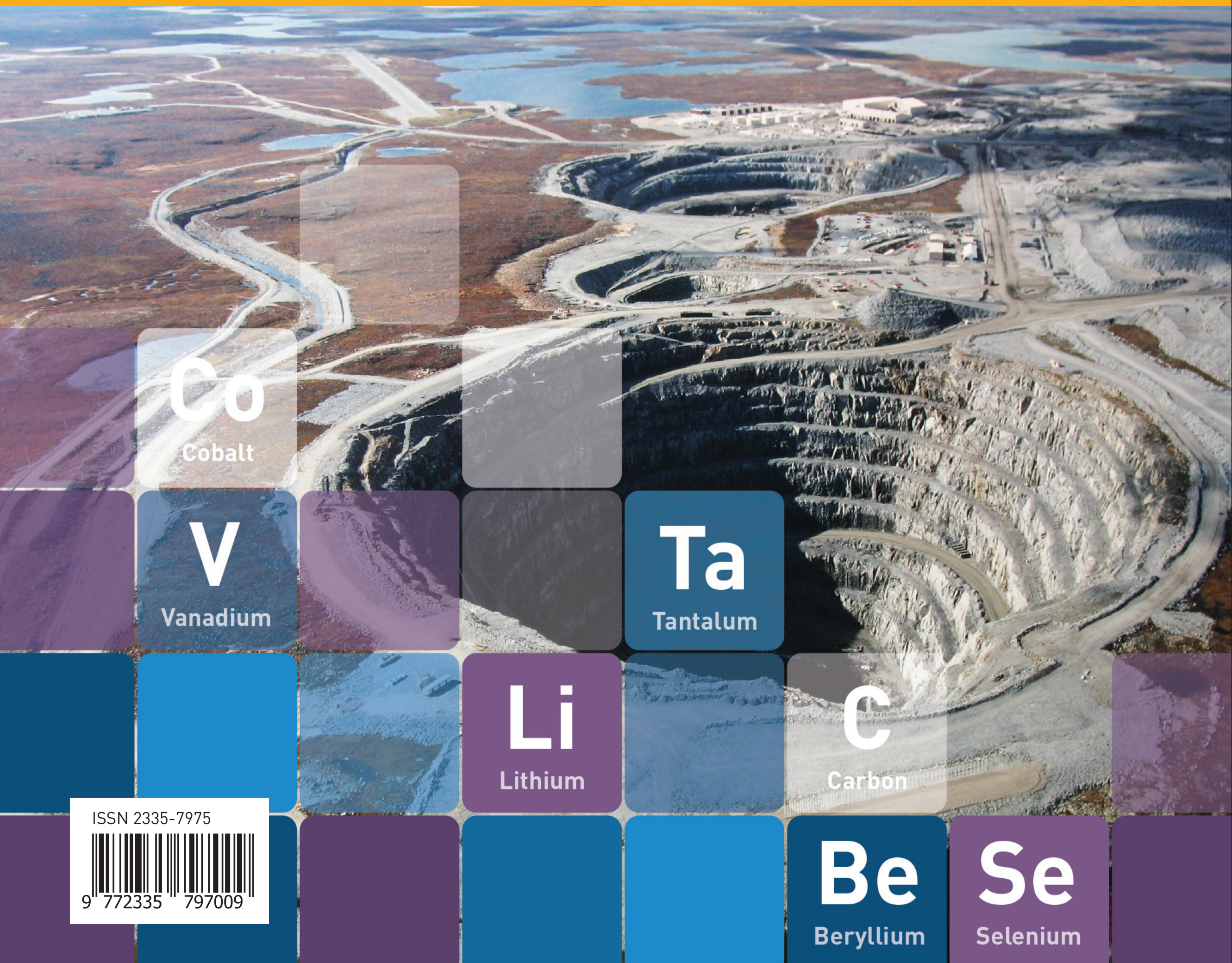
***Petroné:* Commander Manfredini, thank you very much for the interview.**

For any clarifications or further information regarding this article you are kindly ask to contact CDR Andrea Manfredini (ITA-Navy) by Email: andrea.manfredini@enseccoe.org.

Notes

NATO Energy Security Centre of Excellence

Šilo g. 5A, LT-10322 Vilnius,
Lithuania
Phone: +370 5 203 26 86
Fax: +370 706 71010
Email: info@enseccoe.org
www.enseccoe.org



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