Rare Earth Scarcity Impact on NATO Weapon Power and Energy Systems

The NATO Research Technology Organization's (RTO) Research Technology Board (RTB) commissioned a specialist team (ST-002) under the charter of the Applied Vehicle Technology (AVT) Panel to research the production and utilization of rare earth elements and to assess the potential impact a scarcity of these materials may have on the deployment of NATO's next generation weapon electromotive power systems. ST-002 includes members from the United Kingdom, Canada, The Netherlands, Germany, France, and the United States. This team conducted a scan of the rare earth-related political, commercial, and technical environments and assessed the potential impact a reduced supply of these materials would have on NATO capabilities. ST-002 also suggested a few courses of action and presented their work to the RTB, the AVT Panel, the Mechanical Systems and Materials Technical Committee, and the Propulsion and Power Systems Technical Committee.

Rare earth materials have become a vital component to many applications and in many industries. The continued electrification and miniaturization of everyday and high performance products are enabled by rare earth materials. Like it or not our modern society around the world has become dependent on rare earths and this dependency will most certainly continue to grow stronger. Both the automobile industry and the clean energy industry will drive our dependency on these elemental materials. Wind energy has many positive attributes and is being expanded across the United States, Europe, and China with expectations of reducing dependency on foreign energy sources and reducing the environmental impact of power production. A state of the art wind turbine design requires approximately 100 kg of rare earth magnets for every MW of generated power. All-electric and hybrid electric cars also feed our dependency on rare earths. As an example, a typical hybrid electric vehicle requires approximately 15 kg of rare earth materials, principally in the energy storage components and the drive motors. Auto manufacturers around the world are expected to increase production of these vehicles, thereby strengthening our current dependency and competing with defense system applications.

Figure 1: Some of ST-002 members at Molycorp's rare earth mine in Mountain Pass, California, USA.

Currently, 97% of the world's rare earth elements are provided by China. For rare earths, NATO countries and the rest of the world depend on China! Based on recent trends regarding Chinese rare earth exports and based on evolving priorities within China, ST-002 predicts China will cease to export rare earth materials and actually become a net importer of these materials within the next few years. The United States Geological Society estimates that China contains only 60% of the rare earths distributed around the planet. Hence, the rest of the world does have some options including rare earth oxide mines in the United States, Australia, Canada, and perhaps a few other recently discovered sources. But even with alternate sources of the elements, the supply chain required to convert these materials into NATO capabilities is virtually non-existent outside of China and remains as a principal issue for future NATO weapon systems.

The modern world's dependence on a few oil producing nations is well documented and understood by many national leaders and the typical petroleum-fueled automobile owner. Crude oil recovery is the only step in the supply chain entirely controlled by the foreign nation. All other steps after recovery: petroleum refining, fluid catalytic cracking, gasoline production, distribution to filling stations and consumer access, are controlled within the automobile consumer's country. The hybrid-electric vehicle supply chain, in contrast, depends almost entirely on one nation: China. From mining to magnets to vehicle subsystem, China dominates the hybrid-electric vehicle supply chain and modern military weapon systems have similar dependencies.

By controlling this supply chain, China can create more jobs for its growing work force. By providing various incentives and reducing rare earth exports, the Chinese government has encouraged foreign companies to relocate to China; thereby, providing more jobs and a higher standard of living for its growing population. In addition to job growth and an improving economy, Chinese leaders have recognized for decades the political leverage enabled by their rare earth natural resource. In 2010 rare earth exports were thought to have played a significant role in negotiations between China and Japan regarding a territorial dispute.

Rare earth materials may be used in various ways and in various configurations but there are no substitutes for these elements. Rare earths are used in nearly every modern weapon system on land, in the air, in the sea, and in space. Rare earths are necessary to make the world's strongest permanent magnets, the $Nd_2Fe_{14}B$ magnet. Rare earths also enable high temperature permanent magnets, such as Sm_2Co_{17}. Rare earths are used in batteries and fuel cells for high energy density applications and where silent watch capability is needed. Intelligence, surveillance, reconnaissance and communication systems also depend on rare earth materials to make them small, light-weight, and powerful. Rare earth materials are an essential constituent of high performance battery and fuel cell systems and are also a critical element needed for catalytic cracking of fuels. Turbine engines used for propulsion and also for power generation use rare earths in thermal barrier coatings enabling higher operating temperatures. These higher temperatures translate into longer life and higher efficiency and therefore less fuel burned. Without rare earth permanent magnets, motor, generators, and actuation systems would increase in size and weight by about 3X. This increased size would preclude some applications and possibly

diminish war fighting capabilities. The prices of many rare earths have increased significantly over recent months and years highlighting market stability risks in addition to the overall scarcity concerns.

Potential courses of action for NATO could include strategic stockpiling, recycling, and political action. A more comprehensive understanding of the current quantities and specific weapon system applications of rare earths would help to reduce supply risk and also contribute to assessing the potential benefit of recycling. Other courses of action include accelerating existing mine projects, expanding rare earth exploration, and incentivizing the commercial world to rebuild within NATO countries more segments of the various supply chains. ST-002 recommends as a long term course of action that NATO countries collaborate and focus research efforts in order to develop rare earth-lean or even rare earth-free alternatives to current materials and components. As a result of the work of ST-002, NATO RTO has established an exploratory team to refine this assessment, continue to disseminate this message, and to investigate further some of these potential courses of action.