



An assessment of U.S. rare earth availability for supporting U.S. wind energy growth targets



D.D. Imholte*, R.T. Nguyen, A. Vedantam, M. Brown, A. Iyer, B.J. Smith, J.W. Collins, C.G. Anderson, B. O'Kelley

ABSTRACT

Global initiatives are focused on deploying clean energy technologies, such as wind energy, to reduce greenhouse gas emissions. U.S. onshore and offshore wind targets have been particularly aggressive. Some wind energy technologies, such as direct-drive wind turbines, rely on a volatile and Chinese-concentrated rare earth element (REE) supply chain. Global efforts have been made to develop new sources of REEs, with limited success. This lack of rare earth availability has been suggested to inhibit direct-drive adoption, despite its energy efficiency benefits. However, it is unclear if new U.S. REE supply could adequately support onshore and offshore direct-drive wind energy growth, and help meet U.S. wind energy targets. This analysis estimates U.S. and Chinese REE availability that could support U.S. direct-drive and other REE demand. Results indicated that U.S. wind installation targets with solely direct-drive designs could only require 4–12% of maximum light rare earth production from Mountain Pass, Bear Lodge and phosphate rock mines. When considering market dynamics and hypothetical U.S. production, U.S. light REE production capacity was not able to provide sufficient light rare earths to achieve wind energy targets. U.S. wind energy targets could be achieved by prioritizing 3–17% of U.S. light REE production for direct-drive wind energy.

1. Introduction

Recent global efforts to limit global temperature rise this century below 2° Celsius have intensified the pursuit of clean energy technologies (Center for Climate and Energy Solutions, 2015). In 2015, United States wind energy accounted for 4.7% of total electricity generated (U.S. Energy Information Administration, 2016c). The U.S. Department of Energy (DOE) has set targets for wind energy growth, aiming for 20% of generated electricity from wind by 2030 (U.S. Department of Energy, 2015c). Currently, direct-drive wind capacity makes up a small portion of the 2017 U.S. wind portfolio. However, direct-drive wind turbine designs are increasingly being considered for offshore and larger onshore installations (Schlossberg, 2016; Smith et al., 2015). Their higher energy efficiency relative to gearbox technology suggests that increased direct-drive adoption could help achieve U.S. wind energy targets (Hau, 2005; Polinder et al., 2006).

As the demand for direct-drive wind turbines grows, so does the demand for rare earth elements (REEs). REE availability for domestic wind energy is risky due to a Chinese-concentrated supply chain (Cordier, 2010, 2011, 2012; Gambogi, 2013, 2014, 2015, 2016, 2017; Humphries, 2010). Since 2013, DOE has been pursuing efforts to develop new sources and improve domestic REE production capacity (U.S. Department of Energy, 2015a). While some non-Chinese REE

production is currently operational, the U.S. has little presence in any stage of the REE supply chain. Furthermore, it is unclear if potential U.S. production capacity could completely supply all the REEs needed to meet increased direct-drive demand and help support U.S. wind energy targets.

REEs are key ingredients in the high performance permanent magnetic alloy, neodymium-iron-boron (NdFeB). NdFeB is used extensively in many products, including mobile electronics, electric vehicle traction motors, and direct-drive permanent magnet generators (DDPMGs). DDPMGs are emerging as a top design choice for U.S. offshore wind applications due to their large power capacity and lower part count (Polinder et al., 2006; Smith et al., 2015; U.S. Department of Energy, 2015c). DDPMG designs contain 160–650 kg NdFeB per MW of wind power capacity, which translates to approximately 51–208 kg of REEs/MW (Constantinides, 2016b; Habib et al., 2014; Hill, 2010; Lacal-Arántegui, 2015; Pavel et al., 2017). DOE targets have recently stated that 22 GW of U.S. offshore wind power capacity by 2030 would be needed to achieve U.S. wind energy targets, which could require up to 4600 mt of REEs for this single domestic application.

In the summer of 2011, a combination of decreased Chinese export quotas and consumer panic buying caused some REE prices to increase by over 1000% (Laurent, 2014). Global focus then shifted on developing REE sources outside of China, including the Mount Weld mine in

* Corresponding author.

Australia and the Mountain Pass and Bear Lodge deposits in the U.S. As of 2017, the Mount Weld mine has sustained production (Lynas Corporation LTD, 2016) while Mountain Pass has suspended production and Bear Lodge has suspended development partly due to relatively low REE prices attributed to unlicensed Chinese production (Miller, 2017; Zink, 2016). Mountain Pass and Bear Lodge are also primarily comprised of light rare earth elements (LREEs), which are of lower value than their heavy (HREEs) counterparts.¹ HREEs are largely produced and processed in China. (Habib and Wenzel, 2014) estimate that China will continue to dominate HREE production in the short and medium term, pending additional supply from recycling.

This article seeks to inform clean energy discussion by bridging the gap between U.S. wind energy policy and domestic REE supply chain development strategies. The primary goal of this analysis is to evaluate whether U.S. and Chinese supply could conceivably provide all the REEs necessary to satisfy demand from U.S. wind energy and other global NdFeB applications (e.g., electric vehicles, electronics). We consider a U.S. NdFeB supply chain that consumes LREE supply from Chinese and U.S. sources. We first estimate the amount of wind energy that can be sustained with only Chinese LREE production to reflect 2017 conditions. We then simulate hypothetical U.S. REE production in a Chinese-dominated REE market, by considering different combinations of operating U.S. REE deposits.

2. Background of wind energy technology and REE production

2.1. Wind turbine technology

Today's wind turbines generally fall under three design categories according to their drive-trains: (i) gearbox, (ii) DDPMGs, and (iii) hybrid (Cao et al., 2012). Gearbox designs use almost no REEs and make up the vast majority of onshore U.S. wind turbines (U.S. Department of Energy, 2015c). DDPMG and hybrid designs use significant amounts of rare earth permanent magnets and both are considered variations of permanent magnet wind turbine generators.

Permanent magnet generators use NdFeB magnets, which contain the key LREE Neodymium (Nd). In order to reduce production costs and improve the performance, some Nd is substituted by its neighboring element Praseodymium (Pr) (Lucas et al., 2015). Small amounts of the HREEs dysprosium (Dy) and terbium (Tb), are also added to improve performance at higher operating temperatures. The total rare earth content of a NdFeB magnet is typically about 32% by weight, with Nd and Pr typically accounting for about 30% and HREEs accounting for about 2% weight (Habib et al., 2014; Speirs et al., 2013), depending upon the grade. Higher HREE content implies a higher maximum operating temperature and a lower LREE content.

Both gearbox and DDPMG designs are considered as suitable systems for land-based applications by wind turbine manufacturers (Smith and Eggert, 2016). DDPMGs designs are more costly to manufacture and also more energy efficient relative to gearbox design, on a per kW basis, and therefore have a higher willingness-to-pay (Hau, 2013; Polinder et al., 2006). REEs have also been labeled as critical materials due to their supply risk, and it has been suggested this could create supply constraints for manufacturers of REE-dependent technologies, such as DDPMGs (Iyer and Vedantam, 2016; U.S. Department of Energy, 2011).

DDPMGs have been slow to enter the U.S. onshore market, but domestic demand could increase due to the increased design reliability and DDPMG superiority in offshore applications where wind energy resources are greater (U.S. Department of Energy, 2015c). The first offshore wind farm in the U.S. (the Block Island Wind Farm) began

supplying power to the state of Rhode Island in December 2016 using five Haliade 150–6 MW offshore wind turbines, which use DDPMGs (Egan, 2016; Schlossberg, 2016).

2.2. The global and U.S. REE supply chains

In 2016, China accounted for over 80% global REE production (Gambogi, 2013, 2014, 2015, 2016, 2017; Hedrick, 2008, 2009; Humphries, 2010). Chinese REE resources are generally distributed with HREEs in its southern provinces and LREE in its northern provinces. China's northern deposits have accounted for the majority of licensed mining production over the past ten years (Chinese Ministry of Land and Resources, 2015). Unlicensed Chinese mining is complex, but is mostly concentrated in the southern provinces for targeting global and domestic Chinese demand (Packey and Kingsnorth, 2016). Chinese exports that target non-Chinese demand are typically a combination of unlicensed production, and licensed production after first prioritizing for Chinese domestic demand (Rathi, 2010). China has produced virtually all of the global HREEs in recent years, and it is anticipated that China will continue to dominate HREE production for the foreseeable future (Habib and Wenzel, 2014; He and Lei, 2013; Rathi, 2010).

U.S. production from 2013 to 2015 was entirely from Mountain Pass and ranged between 3–5% of global REE mining production (Cordier, 2010, 2011, 2012; Gambogi, 2013, 2014, 2015, 2016, 2017). The Mountain Pass and Bear Lodge deposits are two of the most developed REE resources in the U.S. based on previous economic assessments (Long et al., 2010). There are additional U.S. resources that have received considerable attention as potential reserves (Long et al., 2010; Tetra Tech, 2013), but these deposits are in much earlier stages of development and therefore are not the focus of this analysis. While neither mine is currently operational, the Mountain Pass deposit operated until October 2015 and had an on-site separations facility that produced the separated LREE oxides lanthanum (La), cerium (Ce), and didymium (a mixture of Nd and Pr) (SRK Consulting, 2010). As of 2017, the U.S. has little rare earth production at any part of the REE supply chain, including refining (Grasso, 2013; Investing News Network, 2016; Richardson, 2012).

Non-Chinese global REE production accounted for 17% of 2016 REE production, with the majority being from Australia's Mount Weld deposit (Gambogi, 2017). Greater than 80% of Mount Weld's 2016 REO production volume was consumed by Chinese and Japanese companies which produced NdFeB and other REE products (Lynas Corporation LTD, 2017). While Mount Weld production is operational, this analysis specifically focuses on the potential U.S. LREE production that could support a U.S. "mine-to-magnet" supply chain. We then consider the impact such a supply chain could have on U.S. LREE demand, including from direct-drive wind energy.

2.3. Combatting rare earth criticality with alternative supply

There are multiple international agencies and consortiums that apply different research strategies for combatting material criticality (Bartekova and Kemp, 2016). Critical materials are defined here as commodities that are important for clean energy, lack substitutes and have a supply risk (U.S. Department of Energy, 2011). One specific strategy that is currently being investigated is developing phosphate rock as an alternative U.S. REE supply source. Phosphate rock has been reported to have significant production volumes and REE content (International Atomic Energy Agency, 2013; Jasinski, 2014, 2016, 2017; Zhang, 2014). While phosphate rock is not currently commercially processed for its REEs, it has been estimated that annual U.S. phosphate rock production contains over 27,000 mt of REE per year in process waste streams, such as phosphogypsum (Zhang, 2014). Zhang (2014) also estimates that phosphogypsum accounts for up to 10% of all the rare earth elements discarded across all phosphate rock process waste streams. (Kulczycka et al., 2016) identified REE recovery from

¹ We consider LREEs to include atomic numbers 57–62 (i.e., lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd) and samarium (Sm)), while HREEs include atomic numbers 64–71 and yttrium (Y).

Download English Version:

<https://daneshyari.com/en/article/7397830>

Download Persian Version:

<https://daneshyari.com/article/7397830>

[Daneshyari.com](https://daneshyari.com)