

An Assessment of the Rare Earth Element Content of Conventional and Electric Vehicles

Elisa Alonso

Massachusetts Institute of Technology

Timothy Wallington, Andrew Sherman and Mark Everson

Ford Motor Co

Frank Field, Richard Roth and Randolph Kirchain

Massachusetts Institute of Technology

ABSTRACT

Rare earths are a group of elements whose availability has been of concern due to monopolistic supply conditions and environmentally unsustainable mining practices. To evaluate the risks of rare earths availability to automakers, a first step is to determine raw material content and value in vehicles. This task is challenging because rare earth elements are used in small quantities, in a large number of components, and by suppliers far upstream in the supply chain.

For this work, data on rare earth content reported by vehicle parts suppliers was assessed to estimate the rare earth usage of a typical conventional gasoline engine midsize sedan and a full hybrid sedan. Parts were selected from a large set of reported parts to build a hypothetical typical mid-size sedan. Estimates of rare earth content for vehicles with alternative powertrain and battery technologies were made based on the available parts' data.

We estimate that approximately 0.44 kg of rare earths are used in a typical conventional sedan, with approximately 80% of the rare earth content in magnets. As such, neodymium is the most extensively used rare earth, followed by cerium, which is used mainly in catalytic converters. The mass of rare earths in a full hybrid electric vehicle with a nickel metal hydride battery is approximately 4.5 kg. A full hybrid electric vehicle with a lithium-ion battery contains approximately 1 kg of rare earth elements. Future plug-in hybrid electric and battery electric vehicles are expected to be equipped with lithium-ion batteries and have rare earth contents that still need to be evaluated.

CITATION: Alonso, E., Wallington, T., Sherman, A., Everson, M. et al., "An Assessment of the Rare Earth Element Content of Conventional and Electric Vehicles," *SAE Int. J. Mater. Manf.* 5(2):2012, doi:10.4271/2012-01-1061.

INTRODUCTION

Understanding the materials content of the automotive fleet allows manufacturers to evaluate their exposure to materials price and volatility and to identify strategies to mitigate the associated risks. It is also used to evaluate the life cycle environmental impact of the fleet, including its recyclability (Cheah, Heywood et al. 2009; Cheah 2010; Wang, Burnham et al. 2010; Kim, McMillan et al. 2011). Studies of vehicle material content often focus on structural materials, such as aluminum and steel (Keoleian 1997; Geyer 2007; Cheah 2010). A few studies have included estimates of vehicle content that identify materials whose mass makes up more than 1% of the vehicle weight (Davis, Diegel et al. 2010; Wang, Burnham et al. 2010). A quantification of materials that are used in small quantities is challenging, but

does exist for a number of expensive materials, specifically the platinum group metals that are used in the catalytic converter (Johnson Matthey and ed. Tom Kendall 2002; Whitfield 2009; Wang, Burnham et al. 2010).

Rare earths are a particularly interesting group of materials in that their availability depends currently almost entirely on a single country: China (Long, Gosen et al. 2010). These materials are used in small quantities in a wide variety of applications, many of which are important to the efficient functioning of the vehicle (Gupta and Krishnamurthy 2005; Kingsnorth 2007; Hocquard 2010). To address concerns related to energy security and climate change there is significant interest in the development of hybrid electric vehicles, plug-in hybrid electric vehicles, and battery electric vehicles. Electric vehicles can contain substantial amounts of

rare earth elements in batteries and in the electric motor (Molycorp Inc. 2011). With the increasing importance of electric vehicles, the demand for rare earth elements is expected to increase significantly. To place estimates of the future demand for rare earth elements on a firmer foundation we report here the first detailed assessment of the rare earth element content of conventional and electric vehicles.

METHODOLOGY

The following is the methodology used for estimating, and an assessment of, the rare earth content for representative midsize sedans with different technologies: a conventional gasoline engine car, a full hybrid vehicle with a nickel metal hydride battery and a full hybrid vehicle with a lithium battery. Full hybrids are defined as vehicles which can run exclusively on battery power, exclusively on gas power, or on a combination of both. Typically, full hybrids deliver 40-50% better fuel economy than comparably sized non-hybrid vehicles (Ford Motor Company 2011). Examples of full hybrids include the Toyota Prius, Ford Hybrid Escape, and Ford Hybrid Fusion. Full hybrids are distinct from mild hybrids and micro hybrids which cannot operate entirely on battery power and have a smaller fuel economy benefit than full hybrids. For convenience we refer to full hybrids as hybrids throughout the rest of this paper.

Vehicle parts suppliers were requested to report material content by mass of vehicle parts. Suppliers were not obliged to report rare earth content. However, over 700 parts were reported to contain at least one of the 17 rare earths. Parts were then categorized by subsystem and then application. Typical subsystems include fuel & exhaust and information & controls and typical applications include the catalytic converter, the speaker system and automatic door locks. Categorization of parts enabled a more efficient sorting of the 700 reported parts.

For each application, a representative part was selected. The basis for selection was that the part was used in a mid-size sedan and contained an average rare earth quantity relative to the other reported mid-size sedan parts. These parts were determined to represent a typical hypothetical mid-size sedan. In addition, rare earth content reported by suppliers for a motor and battery pack were included for the hypothetical hybrid vehicle with a nickel metal battery. Typical lithium ion batteries do not contain rare earth elements, hence we assumed that the battery packs for lithium ion battery vehicles do not contain rare earth elements.

The list of reported parts collected by application were examined by vehicle engineers to determine if the rare earth content reported was technically sound or if misreporting or data input error may have occurred. Where errors were identified, they were corrected.

Literature review was also performed to identify typical vehicle parts that contain rare earths and this list was compared to the list produced from the vehicle parts database (Gupta and Krishnamurthy 2005; Kingsnorth 2007; Roskill Information Services 2007; Molycorp Inc. 2011). In some cases, there were parts that were listed in the literature that were not found in the database. For these identified parts that were not reported in the database, engineers and suppliers were directly contacted to either obtain an accurate reporting for the rare earth content of those parts or to confirm that the parts did not contain any rare earths.

Finally, to determine the total rare earth content of each vehicle type, the number of parts per vehicle were determined (for example, 4 doors) and the rare earth content of each part, multiplied by its quantity per vehicle were summed up.

RESULTS

Of the hundreds of parts that had been reported by suppliers to contain rare earths, 76 were selected to represent a 2012 model year sedan with a typical set of options included in the vehicle, ex. speakers and navigation system. In total, it was found that our representative conventional vehicle contained approximately 0.44 kg of rare earths of which 0.4 kg were considered integral to the vehicle function (includes safety components and basic radio/speaker system) and 0.04 kg were classified as vehicle features (ex. navigation system, DVD player and electrically-controlled seats).

For the hybrid vehicle, two main battery technologies were considered. The lithium battery has no rare earth content, but the nickel metal hydride battery was found to contain over 3.5 kg of rare earths. In addition to the battery, the hybrid motor/generator system contains rare earths. A representative hybrid vehicle was found to contain approximately 0.6 kg of rare earths in the motor/generator system. The motor/generator contains a large Ne-Fe-B permanent magnet, which accounts for its high rare earth content.

In total then, the mass of rare earths in a hybrid electric vehicle with a nickel metal hydride battery is approximately 4.5 kg. The hybrid electric vehicle with a lithium-ion battery contains approximately 1 kg of rare earth elements.

Figure 1 and Figure 2 present the distribution of rare earths by mass in the hypothetical conventional vehicle and hybrid/lithium battery vehicle. The rare earth mass fractions in the NiMH battery could not be obtained and is therefore not described in further detail. The motor/generator system is considered part of the transmission and, as seen from Figure 2, the hybrid has approximately 61% of its rare earth content in that vehicle system.