

## APPENDIX 3C. RARE EARTH PHOSPHOR MARKET

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## **APPENDIX 3C. RARE EARTH PHOSPHOR AVAILABILITY AND PRICING**

### **3C.1 INTRODUCTION AND PURPOSE**

Rare earths are commercially defined to include 17 elements that have similar chemical properties. “Phosphors” are a subgroup of these rare earth elements, some of which are critical to high-performance general service fluorescent lamps (GSFL). During the operation of common GSFL, cathodes that seal each end of the lamp emit a flow of electrons that reacts with mercury vapor in the lamp and emits invisible ultraviolet (UV) radiation. To convert this UV radiation into visible light, manufacturers coat the inside of the lamp’s glass with a powder of blended elements, or phosphor. These phosphors fluoresce when struck by UV rays, generating visible light. In high performance GSFL, this phosphor blend usually includes some rare earth materials.

Broadly speaking, the phosphor powders that manufacturers use in GSFL can be divided into two groups: blends of only “halophosphor” and blends incorporating various amounts of “rare earth phosphors.” Halophosphor blends are much less costly than those containing rare earth materials. However, halophosphor blends are also less efficient and produce a lower quality light. For some less efficacious GSFL, manufacturers coat the lamp glass tubes with only halophosphor blends. Comparatively, coating a lamp with a layer of rare earth phosphor blends, in addition to or in place of halophosphors, can increase efficacy, while dramatically improving color quality and lumen maintenance. The precise blend and weight of the phosphor mixes also influence the color correlated temperature (CCT) and the color rendition index (CRI).

During the comment period following the April 2009 NOPR, manufacturers expressed concern that more stringent energy conservation standards for GSFL would necessitate very large increases in their demand for the more costly rare earth triphosphor blends. Manufacturers asserted this would drive up the price of the key rare earths—specifically, terbium, europium, and yttrium—which, in turn, would increase the cost of lamps to consumers. Depending on the lamp type, rare earth triphosphor can be the highest input material cost of a GSFL. Manufacturers were also concerned about whether there were sufficient recoverable sources of the key rare earths remaining in the ground, particularly with regard to Tb, Y, and Eu. Manufacturers further commented that China’s near monopoly on the rare earth market could severely limit access to the world supply. (For a complete description of manufacturer comments and DOE’s response, see the June 2009 Final Rule.) To address these concerns, the Department of Energy (DOE) analyzed the rare earth phosphor market and conducted interviews with several industry players and experts, seeking to understand the potential impact of the standards on the market for rare earth triphosphor. This appendix reflects DOE’s findings.

### 3C.2 RARE EARTH PHOSPHOR COMPOSITION

Generally, in high-performance GSFL, manufacturers combine a blend of three rare earth phosphors: one that emits green light; one that emits red light; and one that emits blue light. These “triband” or “triphosphor” lamps require the use of varying amounts of key rare earth elements (in addition to other elements) in the green, red, and blue phosphors. Specifically, three key rare earth elements are commonly used in the triphosphor blends: yttrium (Y), europium (Eu), and terbium (Tb). These elements work to emit light at the wavelengths (and therefore colors) to which human eyes are most sensitive. Y and Eu are used in the red-light-emitting phosphor; Eu is used in the blue phosphor; and Tb is common to the green phosphor. Table 3B.2.1 displays the general chemical formulas for each color phosphor (there are two common options for blue).

**Table 3B.2.1 General Chemical Formulas for Key Phosphors**

Phosphor Color	Chemical Formula
Red	$Y_2O_3:Eu$
Green	$LaPO_4:Ce,Tb$
Blue #1	$BaMgAl_{10}O_{17}:Eu$
Blue #2	$(Sr,Ca,Ba)_5(PO_4)_3Cl:Eu$

After each color phosphor is manufactured, the phosphors are blended together for use in triphosphor lamps. Table 3C.2.2 displays the share of each phosphor color of a representative unit of triphosphor. While it can vary, a standard triphosphor GSFL is coated with triphosphor composed of approximately 55% red, 35% green, and 10% blue. The amount of rare earth material in each of these phosphor colors can vary by manufacturer and application requirements. The red phosphor is almost entirely composed of yttrium and europium, the vast majority being yttrium. The green phosphor is generally composed of approximately 10% terbium, and the blue phosphor is usually less than 5% europium.<sup>1</sup>

**Table 3C.2.2 Representative Triphosphor Composition**

Phosphor Color	Share of Triphosphor Weight
Red	55%
Green	35%
Blue	10%

### 3C.3 SUPPLY CHAIN AND APPLICATIONS

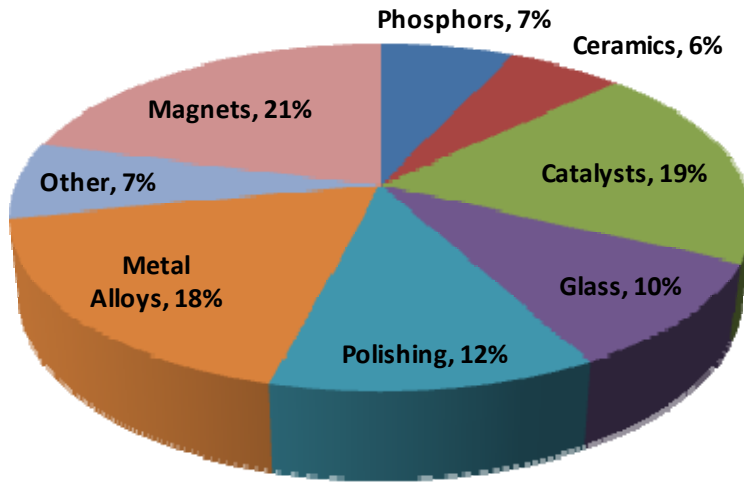
Hundreds of mining firms, mostly in China, extract rare earth-containing material from ground. Rare earths are mined primarily from bastnasite, monazite, and xenotime ores, as well as ion-adsorption clay. Naturally mixed in with many other elements, rare earths must be concentrated through a series of separation processes to distill the rare earth elements from the ore. Most of the mining firms also perform the initial stages of this concentration process. The two principal means of separating rare earths are solvent extraction and ion exchange, either of which can yield purities up to 99.999%.<sup>2</sup> As discussed previously, the most important rare earths for lighting applications are yttrium, europium, and terbium. Very high levels of purity (99.99% or greater) are necessary for these phosphors in lighting applications, which increases the cost to lamp manufacturers. One of the difficulties associated with processing rare earths such as Y, Eu, and Tb is that to achieve the required purity levels, the processor must refine all of the ore's elements down to those levels, which can be very expensive and require these companies to find markets for other materials beyond rare earths, which may not be in demand to the same extent. As a result, demand for these other elements can affect the market for the key rare earths for lighting.

Next, the concentrated rare earth product is usually shipped to a handful of phosphor manufacturers who further process the rare earths to higher levels of purity and/or manufacture the phosphor. For lighting applications, the phosphor manufacturer may sell the individual manufacturer colored phosphors or the mixed triphosphor to lamp manufacturers. In other instances, lamp manufacturers may perform the phosphor blending in-house.

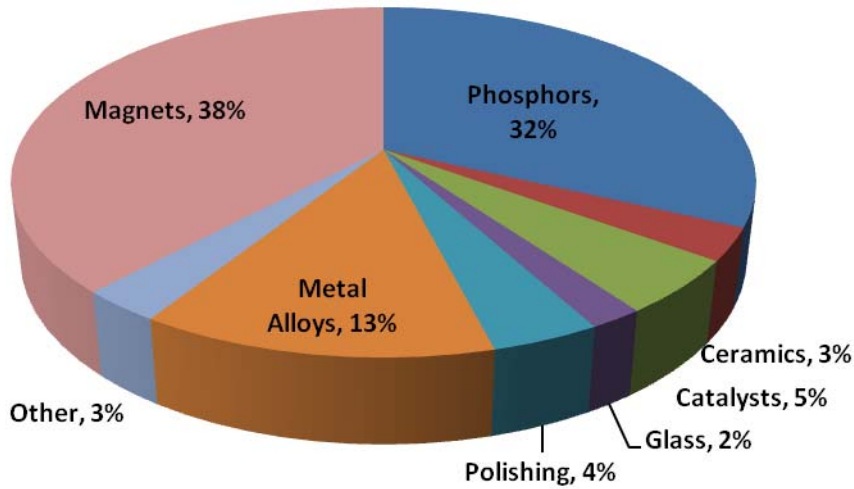
Rare earth materials, including phosphors, have found an increasing range of practical applications in recent decades. Aside from the energy efficient applications, rare earths are used in automotive catalysts, metals and magnets, petroleum catalysts, glass polishing, and ceramics. The industry has experienced significant demand growth in recent years for use in electric and hybrid vehicles.

Figure 3C-1 and Figure 3C-2 show 2008 rare earth oxide consumption by volume and value, respectively.<sup>3</sup> Various sources estimate that phosphors represent 4 percent to 15 percent of the rare earth market by quantity; the most recent estimates typically range between 7 percent and 11 percent.<sup>4</sup> However, phosphors are the largest segment by value as terbium and europium are among the most valuable rare earths. Within this phosphor subgroup, there are three main applications: televisions (plasma, LCD and cathode ray tube), tri-phosphor fluorescent lamps, and x-ray intensifying screens. Currently, there are few, if any, suitable substitutes in most applications, including high efficiency GSFL.

**Figure 3C-1 Rare Earth Application by Volume**



**Figure 3C-2 Rare Earth Application by Value**



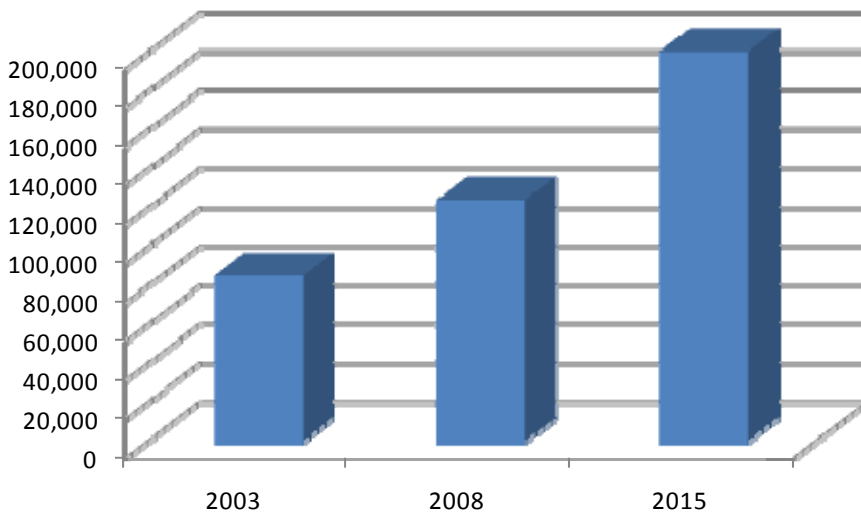
### **3C.4 RARE EARTH MARKET**

#### **3C.4.1 Overview**

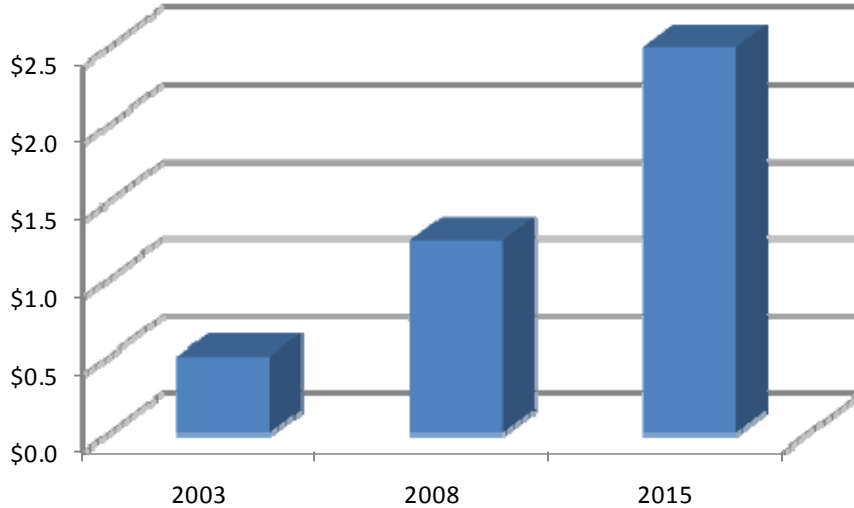
Historically, unstable supply and demand and significant price fluctuations have been the norm in the rare earth market. The 1980s saw rapidly increasing demand, followed by substantial oversupply in the 1990s when China entered the market and quickly established a dominant market position.<sup>5</sup> Prior to China's arrival as the dominant supplier of rare earths, most production came from the United States. By the late 1990s, China's low-cost supply had driven down prices, causing many suppliers to cut or cease operations. China has only consolidated its dominant position since. At the time of publication of the June 2009 final rule, rare earths were not mined in the United States.<sup>6</sup>

Reports estimate the overall value of the rare earth market was roughly \$1.25 billion in 2008 and it is expected to double by 2015, roughly a 10% CAGR. In terms of rare earth oxide volume, growth is estimated to be 7% annually through 2015. Figure 3C-3 and Figure 3C-4 show estimates of the market by volume and value, respectively.<sup>7</sup>

**Figure 3C-3 Rare Earth Market Size by Volume (metric tons)**



**Figure 3C-4 Rare Earth Market Size by Value (\$billions)**



According to a Rhodia presentation, the 2007 phosphor portion of the rare earth market totaled about \$670 million<sup>8</sup>, while an earlier Roskill report put the 2000 total rare earth phosphor market at \$300 million.<sup>9</sup> That implies a 12.2 percent compounded annual growth rate (CAGR) in the rare earth phosphor market from 2000 to 2007.

Of Rhodia's \$670 million estimate for the 2007 phosphor market, lamps accounted for \$355 million (\$30 million of which was halophosphor). The presentation also predicted the phosphor market will grow to \$925 million by 2012, a 6.8 percent CAGR, or 8.1% for only rare earth phosphors. Lamps will account for approximately 60 percent of that growth.<sup>10</sup> Another industry report expects 7% annual growth through 2014.<sup>11</sup>

### **3C.4.2 Supply, Demand, and Pricing**

Large, economically viable deposits of important rare earths (such as terbium and europium) are scarce because they are mixed with other minerals and require a costly purification process to isolate. Despite being more abundant than other industrial metals, rare earths are much less likely to become concentrated in minable deposits. Furthermore, portions of different rare earths vary greatly in deposits. These ratios often do not correspond to the ratios of rare earths required in their applications. Therefore, to recover enough of the rarer, more important elements, mining companies must produce large amounts of more widespread elements. This can be an expensive process that can limit supply and drive prices of Eu, Tb, and Y.<sup>12</sup> In most deposits, for example, 80% to 99% is composed of the most common rare earths (not Eu, Tb, or Y).<sup>13</sup>

The most attractive geological concentrations of Tb and Eu appear to be located in China, which dominates rare earth supply. Chinese mines are thought to have relatively lax

environmental controls. Combined with lower labor costs and aggressive policy, these factors have created a market in which China accounts for more than 90 percent of world's rare earth production.<sup>14</sup>

Beginning early this decade, China began to take steps to curb the exportation of rare earths and thereby attract the industries that utilize rare earths to China, according to DOE interviews and research. The desire to preserve the resource and address environmental concerns has constrained Chinese supply. Recently, the country instituted mining quotas, which have been continually reduced. China has continued to drop its export quotas by roughly 3% per year. In 2008, the country exported 53,150 tons of rare earth, compared with 65,600 tons five years earlier.<sup>15</sup> In the meantime, short-term production outside China has not increased to make up for the latter's lower output and the increasing worldwide demand.

Demand for rare earth phosphors is projected to grow rapidly. Macro trends towards greater energy efficiency and larger display technologies have driven growth in phosphor demand. The growth in CFLs is also contributing to phosphor demand. Lynas Corporation projects demand for rare earth phosphors for use in CFLs to grow from 1,600 tons in 2004 to 3,779 tons by 2010, or 15 percent annually.<sup>16</sup> Rare earth demand from China itself is also sapping supply, growing at 25 percent annually from 2004 to 2007, according to Roskill.<sup>17</sup>

Of particular concern to this rulemaking, however, is the demand and supply of Eu, Tb, and Y. A Rhodia presentation forecasted Eu, Y, and Tb demand to grow 50 percent, 47 percent and 40 percent, respectively, from 2007 to 2012, annualized growth rates of 9.6, percent, 7.0 percent, and 9.1 percent. The table below represents Rhodia's demand and supply projections for each of the key phosphors. It appears there was an oversupply of yttrium; however, that was not true of the highest grade Y, which is necessary for use in phosphor lighting.<sup>18</sup>

**Table 3C.4.1 Supply and Demand Projection for Key Rare Earth Elements**

Element	Year	Supply	Demand
In Metric Tons			
Eu	2007	300	300
	2012	450	450-500
Tb	2007	300	300
	2012	420	420
Y	2007	11,700	7,500
	2012	14,000	10,600

DOE's discussions with industry experts show that current demand and supply of Eu, Tb, and Y, are in currently in balance. (Rhodia, No. 93 at p. 1; AMR, No. 95 at p. 1) Historically, prices for rare earths, particularly the key three phosphors in lamps, have been extremely volatile. Recent price estimates have already proven well off the mark. Tb, Eu, and Y experienced dramatic prices increases prior to the recent economic downturn. Between 2000 and summer 2008 prior to the recent economic downturn, the prices of Y, Tb and Eu increased roughly 45 percent, 420 percent and 53 percent, respectively, since 2000, according to Rhodia.

Much of the price increases occurred from 2006 to 2008.<sup>19</sup> Chinese policy, environmental concerns, increases in tariffs and other taxes, demand growth, and speculation all contributed to the run up in prices. For example, in June 2006 China established a 10 percent tariff on rare earths; the tariff on key rare earth phosphors is now 25 percent.

However, since their highs in the summer of 2008, these rare earth prices have fallen sharply, pressured by the sluggish economy and, to a large extent, lower energy prices, which constitute a large portion of the mining and concentration production costs. Prices fell as much as 30 to 40 percent.

### **3C.4.3 Long Term Outlook**

DOE's research revealed that Chinese policy is the most significant factor in the long term supply and prices of Y, Tb, and Eu. (Kingsnorth, No. 96 at p. 1; AMR, No. 95 at p. 1; Rhodia, No. 93 at p. 1; USGS, No. 94 at p.1) Assuming their current policy remains, Rhodia said the industry could meet Y, Eu, and Tb demand for at least 20 years. (Rhodia, No. 93 at p. 1). After that time shortages of Tb and Eu could be possible without the development of additional resources. Other industry players and experts have offered more optimistic and more pessimistic outlooks.

The U.S. Geological Survey said exploration for rare earths "continued strong in 2008,"<sup>20</sup> although DOE's interviews indicate the worldwide credit crisis severely hampered efforts to develop new sources. (Kingsnorth, No. 96 at p. 1, USGS, No. 94 at p. 1). Several projects listed below are in early phases of development around the world (see section 3C.4.3.1 below for a description of these projects). Additionally, the threat of limited supply has also driven interest in phosphor reclamation (see section 3C.4.3.2).

According to the U.S. Geological Survey, "Undiscovered resources are thought to be very large relative to expected demand."<sup>21</sup> The USGS estimates that globally there are 88 million metric tons of proven economically viable reserves of rare earth oxide content; 61 million tons of which are outside China. The total estimated "reserve base," which includes reserves that have a "reasonable potential for becoming economic within planning horizons," is much larger. The USGS estimates that this reserve base totals 154 million; however, nearly all of the difference comes from China.<sup>22</sup> The USGS concludes that "world reserves are sufficient to meet forecast world consumption well into the next decade. Several very large rare-earth deposits in Australia and China have yet to be fully developed." While such a forecast bodes well for the long term outlook of rare earths, these "undeveloped" resources may not necessarily contain sufficient quantities of the rare earths useful to lighting applications. Further, it is important to note that rare earth reserves may not necessarily contain attractive amounts of the key rare earth elements to lighting use (yttrium, terbium, and europium). However, the USGS does publish estimates on the reserves of yttrium, which is the largest component of rare earth elements in the triphosphor used in lamps. Reserves are estimated at 540,000 metric tons of

yttrium oxide and the reserve base is estimated to be 610,000, with 40% of each located in China.<sup>23</sup>

Issues beyond the physical resources have also restricted supply. Environmental and regulatory factors and costs have contributed to Chinese dominance in the market. Additionally, monazite, the most common mineral deposit with economic concentrations of rare earth elements, often contains thorium as well. Thorium is weakly radioactive, and that has caused concerns about its further processing. In the past decade, such concerns have led to the reduction of monazite mining and processing.<sup>24</sup>

### **3C.4.3.1 Rare Earth Projects**

First, it is important to note that the estimates below reflect published estimates that may be based on varying assumptions used by mining firms to assay the content of their mines. For instance, some firms' production estimates may utilize different cut-off grades or rare earth content, which can significantly change the estimated amounts of recoverable rare earth and the economics of its recovery. Also note that an estimate of rare earths production is not the same as an estimate of the production of rare earth phosphors. For example, just as terbium demand reflects approximately 0.3% of total rare earth demand,<sup>25</sup> it also reflects only a very small portion of even the most terbium-rich mines. This list is meant to be illustrative of the potential for the development of rare earth projects.

Australia has the potential to become a major rare earth supplier. Lynas Corporation's Mt. Weld project in Western Australia was expected to ramp to full capacity by 2011.<sup>26</sup> However, a Chinese firm acquired a majority stake in the company after the financial downturn forced the company to suspend the project.<sup>27,28</sup> Lynas' planned production was 21,000 tons per year of rare earth oxide, about 7 percent to 9 percent of total 2007 global supply based on various estimates.<sup>29,30</sup> Based on the company's estimated rare earth distribution, this implies approximately 14 tons of terbium and 93 tons of europium annually. The total resources available at the mine, measured by rare earth oxide, are 917,000 metric tons (769,000 tons of which is proven and economically viable).<sup>31</sup>

Also in Australia, Afurara Resources' Nolans project has identified 577,000 metric tons of indicated and inferred REO. The company plans to reach 50 percent production capacity by 2011 and full capacity, or 20,000 metric tons, by 2013. That amounts to roughly 10 percent of worldwide supply at that time.<sup>32</sup> Notably, a Chinese firm recently acquired a 25% stake in the company.<sup>33</sup> Alkane Exploration Ltd.'s Dubbo Zirconia Project in Australia may begin producing Yttrium by mid-2010. A feasibility study indicated an annual yield of 1,200 tons of Yttrium and other rare earths is possible.<sup>34</sup>

In Canada, Avalon Ventures Ltd.'s Thor Lake site may be able to produce 3,000 to 5,000 metric tons of REO per year.<sup>35</sup> The deposit appears to be relatively rich in terbium and europium. Great Western Minerals Group has a rare earth deposit in Saskatchewan at Hoidas Lake with REO measured reserves of some 123,000.

In the United States, Molycorp, Inc.'s rare earth mine in Mountain Pass, CA, is an example of rare earth production in response to recent change in prices. Just 10 years after generating more than 40 percent of worldwide rare earths revenue, the mine shut down operations in 2000 "due to record lows" of rare earth prices.<sup>36</sup> The mine only remained open for the concentration, purification, and sale of its previously mined stocks.<sup>37</sup> The mine has some 20 million metric tons of rare earth reserves.<sup>38</sup> Mountain Pass could potentially produce more than 40 tons of Eu annually. (Molycorp, No. 97 at p. 1)

Wings Enterprises, Inc., is planning to redevelop an iron-ore mine, Pea Ridge, in Missouri. Studies of the deposit show relatively high concentrations of rare earths useful to lighting, including terbium. The mine has proven reserves of 600,000 tons of rare earth ore, with relatively high concentrations of terbium and europium. The mine plans to produce rare earths both as a byproduct and as a primary product in two different mineral formations onsite.<sup>39</sup>

### **3C.4.3.2 Triphosphor Reclamation**

Reclamation efforts can also play a significant role in augmenting supply in the long term. Rhodia estimates that by 2015 there will be more than 250 tons of rare earth oxide in recycled lamps.<sup>40</sup> However, the recovery of rare earth from recycled lamps brings with it many technical and economic challenges. First, the infrastructure to collect recycled GSFL must be in place. With this infrastructure, a commercial scale technically viable process for distilling the rare earths from the other lamp materials—glass, alumina, halophosphate, etc.—must be established. This will include chemical treatments, mercury removal, and waste disposal.

Rhodia, a large rare earth phosphor supplier, already has some reclamation ability and is ramping up its capacity, although the commercial scale economics of this enterprise are unclear at this time. The attractiveness of reclamation will depend not only on the cost of the process versus the price of normal rare earth acquisition, but also the amount of rare earth available for recovery in the retiring lamp stock. Currently, the universe of retiring lamps was installed several years ago; they are mostly halophosphor lamps. Therefore, the yield of rare earth oxides from recycling would not likely make commercial scale reclamation economically attractive currently. However, in several years, Rhodia expects the amount of recoverable useful rare earth to grow significantly as high performance GSFL become commonplace.<sup>41</sup> Just as standards will increase the demand for rare earth phosphor in 2012, they will provide larger volumes available for reclamation when they retire.

Finally, because of phosphor degradation, recovered rare earth phosphor will have to be brought back to its original elements and 're-manufactured' to have the quality required to meet TSL 4 and TSL 5.

### 3C.5 ANALYSIS OF IMPACT OF STANDARDS AND RESULTS

Based on its research and interviews with manufacturers, supply chain participants, and industry experts, DOE developed this market assessment and analyzed the impacts of standards at each TSL. DOE's methodology is described below.

In general, DOE estimated the total amount of triphosphor that would be required by manufacturers at each TSL and in the base case. Next, in accordance with manufacturer discussions and comments, and consistent the opinions of the industry experts with whom DOE spoke, DOE focused specifically on the amount of europium, terbium, and yttrium that standards would require. These are the key ingredients that improve the performance of lamps and also drive the cost differential between rare earth and halophosphor lamps. DOE determined how much of these rare earths, manufacturers would require due to standards. Additionally, because these key rare earths have many applications and are transacted in a global market, DOE assessed the standards-induced increase in their demand in the context of global supply and demand. DOE used these results to assess phosphor availability, and, in turn, GSFL product availability.

As for the impact of greater manufacturer phosphor needs on consumers, DOE chose not to attempt to model future rare earth prices due to the volatile nature of the market and impracticality of specific price projections for individual rare earth elements. However, DOE did conduct a sensitivity analysis to address the potential increases in end-user lamp prices attributable to greater phosphor input costs. DOE compared the life-cycle cost (LCC) savings due to purchasing higher efficacy GSFL (as calculated in chapter 8) to LCC savings under scenario with higher phosphor prices. A more detailed description of DOE's methodology and assumption follows.

To analyze the impact of efficacy standards on manufacturer rare earth phosphor requirements relative to the world supply, DOE calculated the increased national demand for rare earth phosphors that would result from higher GSFL efficacy standards. To calculate this increased demand, DOE first estimated the mass of triphosphor used in each lamp type (*e.g.*, 4-foot T8 medium bipin) for three series of rare-earth phosphor lamps— 700, standard 800, and high-performance 800. Specifically, in interviews, manufacturers provided estimates for the mass of rare earth phosphor per high performance 800-series 4-foot T8 medium bipin (MBP) lamp. DOE found similar figures in its research and industry interviews. Manufacturers also reported at the public meeting that improving a high performance 800-series lamp required 3 times the quantity of rare earth triphosphor as a 700-series lamp. By using the relative efficacies of the 700 series, 800 series, and high performance 800 series and industry curves relating phosphor thickness to efficacy, DOE derived estimates for the amount of rare earth phosphor used in the three series of 4-foot T8 MBP lamps. DOE extrapolated the estimated 4-foot MBP rare-earth phosphor requirements to 8-foot single pin (SP) slimline, 8-foot recessed double contact (RDC) high output (HO), 4-foot miniature bipin (MiniBP) standard output (SO), and 4-foot MiniBP HO lamps using relative lamp surface areas.

Next, by multiplying these amounts by its shipments projections of each lamp type in each year, DOE determined the total amount of triphosphor that would be required to meet each TSL in each year. This allowed DOE to compare observe national lamp triphosphor demand in the base case versus the standards case. DOE estimates that at TSL 3, TSL 4, and TSL 5, manufacturer demand for triphosphor in covered products in 2012 would be 171 percent, 183 percent, and approximately 230 percent of base-case usage, respectively. These estimates reflect the average of the lower and upper bound scenarios.

Next, DOE estimated the total quantities of each rare earth element required to meet the shipment demands. As discussed above, DOE determined from its research the approximate share (by weight) of blue, green, and red phosphor in triphosphor. DOE also found the share of each key rare earth element in each phosphor. (See 3C.2 for these amounts.) With these data points, DOE determined that the total standards-induced demand for these elements at each TSL.

DOE compared these results (for 2012) to industry projections of total worldwide demand to evaluate how standards may affect the overall supply-demand balance for Tb and Eu, in 2012. The difference between demand in the standards case and demand in base case in 2012 was not more than 11% of Rhodia's projections of 2012 demand for each element. That is, DOE found that standards alone would not increase world demand by more than 11 percent for any key element.

For further detail on trial standard levels and GSFL shipment forecasts, see chapter 10 and chapter 11 of this TSD, respectively.

### **3C.5.4 Impact on Consumer LCC**

Given the historically volatile prices of rare-earth phosphors and the unpredictable future determinants of supply and demand (notably Chinese policy), DOE has not developed supply and demand curves to estimate future phosphor prices. However, DOE recognizes significant price increases are possible given the expected increase in demand, particularly for Tb and Eu. Therefore, to analyze the impact of higher phosphor prices on the consumer, DOE also conducted a sensitivity analysis to address the potential increases in end-user lamp prices attributable to greater phosphor input costs. That is, DOE compares the life-cycle cost (LCC) savings due to purchasing higher efficacy GSFL (as calculated in chapter 8) to LCC savings under scenario with higher phosphor prices.

As discussed earlier, DOE determined the quantity of each rare-earth phosphor required to manufacture each phosphor series of GSFL. DOE then determined the cost of the rare earth phosphors to the manufacturers for each lamp type, considering the quantity of each phosphor required and the current estimated cost of each phosphor type. Next, by applying manufacturer and retail markups, DOE analyzes how an increase in phosphor prices may affect LCC savings for a consumer of each lamp type.

Four-foot T8 MBP lamps account for the majority of triphosphor costs over the analysis period at high standard levels. For this product class, DOE calculated that the triphosphor costs

are approximately \$0.28 per high performance 800 series T8 lamp at current phosphor prices. Using the combined manufacturer and retail markup employed in the MIA, DOE estimates triphosphor account for approximately \$0.64 of the per-unit cost to the consumer. Because purchasers of all 4-foot MBP baseline lamps for all events in the commercial sector show LCC savings of at least \$4.93 upon purchasing high performance 800-series lamps, phosphor prices could increase at least 7 times (and more in most cases) before commercial consumers would experience negative LCC savings for this product class. In the residential sector, for events that show positive LCC savings at current triphosphor prices, consumers could sustain even larger phosphor price increases before they experience negative LCC savings.

Using the same methodology, DOE determined that for 8-foot SP slimline lamps, phosphors prices could increase by a factor of 5 before any commercial consumers that receive positive LCC savings at current triphosphor prices would experience negative LCC savings. For the 60W T12 baseline, consumers already face negative LCC savings in the lamp failure event and standards-induced retrofit events. For the 58W T8 baseline, consumers already face negative LCC savings in the new construction and ballast failure events.

For 8-foot RDC HO lamps, triphosphor prices could increase by more than 20 times before commercial or industrial consumers experience negative LCC savings in all events for the 110W T12 baseline lamp. The lamp failure event for the 95W baseline lamp is the only event in all sectors in all product classes that could experience positive LCC savings at current triphosphor prices and negative LCC savings with a moderate jump in triphosphor prices. A doubling of triphosphor prices could negate LCC savings in this event.

For 4-foot T5 MiniBP SO lamps, phosphor prices could increase more than 300 percent before any commercial or residential consumer experienced negative LCC savings for any event. For 4-foot T5 MiniBP HO lamps, where LCC savings are positive at current phosphor prices for all events, only a 50-fold increase in triphosphor prices could jeopardize positive LCC savings. The lamp failure and the standards-induced retrofit events already experience negative LCC savings.

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<sup>6</sup> Hedrick, James B. *Mineral Commodity Summaries*. United States Geological Survey. January 2009.

<sup>7</sup> See for example, <http://www.roskill.com/reports/rare> (Last accessed June 11, 2009.) and *Ibid* 3.

<sup>8</sup> Cuif, Jean-Pierre. *Rhodia Silcea - Electronics BU, Is there enough rare earth for the "green switch" and flat TVs?* Phosphor Global Summit 2008, March 2008.

<sup>9</sup> [http://findarticles.com/p/articles/mi\\_qa5348/is\\_200201/ai\\_n21307831](http://findarticles.com/p/articles/mi_qa5348/is_200201/ai_n21307831). (Last accessed June 11, 2009).

<sup>10</sup> *Ibid* 8.

<sup>11</sup> *Ibid* 3

<sup>12</sup> Hedrick, James U.S. Geological Survey. *2006 Minerals Yearbook*. May 2008.

<sup>13</sup> *Ibid* 5

<sup>14</sup> *Ibid* 5.

<sup>15</sup> *Ibid* 3

<sup>16</sup> [http://www.lynascorp.com/application.asp?category\\_id=1&page\\_id=10&app\\_id=2](http://www.lynascorp.com/application.asp?category_id=1&page_id=10&app_id=2) (Last accessed June 11, 2009)

<sup>17</sup> *Ibid* 7.

<sup>18</sup> *Ibid* 8.

<sup>19</sup> *Ibid* 8.

<sup>20</sup> *Ibid* 6.

<sup>21</sup> *Ibid* 6.

<sup>22</sup> [Ibid](#) 6

<sup>23</sup> [Ibid](#) 6

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<sup>25</sup> *Ibid* 3and 8

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<sup>28</sup> [http://www.lynascorp.com/content/upload/files/Announcements/2009/Investor\\_Relations\\_Call\\_5th\\_May\\_-\\_Supporting\\_Presentation.pdf](http://www.lynascorp.com/content/upload/files/Announcements/2009/Investor_Relations_Call_5th_May_-_Supporting_Presentation.pdf) (Last accessed June 11, 2009).

<sup>29</sup> *Ibid* 26.

<sup>30</sup> *Ibid* 8.

<sup>31</sup> *Ibid* 26.

<sup>32</sup> Alistair J Stephens, "Singapore Asia Mining Conference", Afurara Resources Ltd., 2008.

<sup>33</sup> <http://clients.weblink.com.au/clients/Arafura/article.asp?asx=ARU&view=6440570> (Last accessed June 11, 2009).

<sup>34</sup> Ian Chalmers, "The Dubbo Zirconia Project", Alkane Exploration Ltd., May 2008.

<sup>35</sup> [http://www.avalonventures.com/projects/rare/thor\\_lake/](http://www.avalonventures.com/projects/rare/thor_lake/). (Last accessed June 11,200)9;  
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<sup>36</sup> [http://www.molycorp.com/operational\\_excellence/rehistory.asp](http://www.molycorp.com/operational_excellence/rehistory.asp)

<sup>37</sup> *Ibid* 12.

<sup>38</sup> *Ibid* 5

<sup>39</sup> [http://www.wingsironore.com/data/wings\\_enterprises\\_reo\\_quick\\_summary.pdf](http://www.wingsironore.com/data/wings_enterprises_reo_quick_summary.pdf) (Last accessed on June 11, 2009)

<sup>40</sup> *Ibid* 1

<sup>41</sup> *Ibid* 1