RARE EARTH
TECHNOLOGY ALLIANCE

The Economic Benefits of the North American Rare Earths Industry

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Contents

Executive Summary

The rare earth industry is essential to the North American economy. The industry directly contributes to the North American economy with $795 million in shipments, employing nearly 1,050 workers with a payroll of $116 million. But the contributions of the rare earth industry go well beyond its direct economic footprint.

The rare earth industry fosters economic activity indirectly through supply-chain purchases and through the payrolls paid by the industry itself and its suppliers. This in turn leads to induced economic output as well. As a result, each job in the rare earth industry generates an additional 5.0 jobs elsewhere in the North American economy, for a total of over 6,300 jobs. These jobs provide over $420 million in wages and salaries. Indirect and induced effects result in $1.1 billion in economic output. Thus, including its direct impact, the industry generates a total of $1.9 billion in economic output in North America.

Moreover, the economic contributions of rare earth chemistry extend downstream as well. Rare earth products are an essential input in magnets and magnetic powders, catalysts, metallurgical additives, polishing powers, phosphors, glass additives, ceramics and other engineered rare earth materials as well as batteries, motors and generators, lasers, drives, sensors, and other components and systems used in a variety of industries producing intermediate goods. In turn these products are used health care, clean energy, automotive, lighting, communications, audio equipment, defense technologies, other electronics, advanced optics, oil refining, and a variety of other economic activity. The rare earth industry is supportive of $329.6 billion in economic output in “downstream” end-market products and technologies that employ 618,800 workers (with a combined payroll of $37.6 billion) in the United States and Canada.

Introduction

This report examines the economic contributions of rare earths to the North American economy. In this report, rare earth is used as a generic term for a set of seventeen chemical elements in the periodic table, specifically the fifteen lanthanides plus scandium and yttrium. The latter are considered rare earth elements since they tend to occur in the same ore deposits as the lanthanides and exhibit similar chemical properties.

The report examines the "economic footprint" of the rare earth industry in terms of its direct, indirect and induced effects as measured by output, payrolls, jobs and taxes paid. The analysis also quantifies downstream economic activity (as measured by output, payrolls, and jobs) supported by the use of rare earth products.

What are Rare Earths?

Rare earths are a series of chemical elements found in the Earth's crust that are vital to many modern technologies, including consumer electronics, computers and networks, communications, clean energy, advanced transportation, health care, environmental mitigation, national defense, and many others. Despite their name, rare earth elements (with the exception of the radioactive promethium) are relatively plentiful in the Earth's crust.

Because of their unique magnetic, luminescent, and electrochemical properties, these elements help make many technologies perform with reduced weight, reduced emissions, and energy consumption; or give them greater efficiency, performance, miniaturization, speed, durability, and thermal stability.

Rare earth-enabled products and technologies help fuel global economic growth, maintain high standards of living, and even save lives. There are 17 elements that are considered to be rare earth elements—15 elements in the lanthanide series and two additional elements that share similar chemical properties. They are listed below in order of atomic number (Z):

Scandium or Sc (21) - Scandium, a silvery-white metal, is a non-lanthanide rare earth. It is used in many popular consumer products, such as televisions and fluorescent or energy-saving lamps. In industry, the primary use of scandium is to strengthen metal compounds. The only concentrated sources of scandium currently known are in rare minerals such as thortveitite, euxenite, and gadolinite from Scandinavia and Madagascar.

Yttrium or Y (39) - Yttrium is a non-lanthanide rare earth element used in many vital applications, such as superconductors, powerful pulsed lasers, spark plugs, cancer treatment drugs, rheumatoid arthritis medicines, and surgical supplies. A silvery metal, it is also used in many popular consumer products, such as energy-efficient bulbs, color televisions and camera lenses. It is also used as coating to protect aerospace high-temperature surfaces.

Lanthanum or La (57) - This silver-white metal is one of the most reactive rare earth elements. It is used to make special optical glasses, including infrared absorbing glass, camera and telescope lenses, night vision goggles, and can also be used to make steel more malleable. Other applications for lanthanum include wastewater treatment and petroleum refining as well as rechargeable nickel-hydride batteries used in hybrid vehicles.

Cerium or Ce (58) - Named for the Roman goddess of agriculture -- Ceres -- cerium is a silvery-white metal that easily oxidizes in the air. It is the most abundant of the rare earth elements and has many uses. For instance, cerium oxide is used as a catalyst in catalytic converters in automotive exhaust systems to reduce emissions, and is highly desirable for precision glass polishing and for fluorescent bulbs. It is also used in oil refining catalysts and in polishing computer chips and transistors. Cerium can also be used in iron, magnesium and aluminum alloys, magnets, certain types of electrodes, and carbon-arc lighting.

Praseodymium or Pr (59) - This soft, silvery metal was first used to create a yellow-orange stain for ceramics. Although still used to color certain types of glasses and gemstones, praseodymium is primarily used in rare earth magnets used in anything from hand tools to wind turbines. It can also be found in applications as diverse as creating high-strength metals found in aircraft engines and in flint for lighters and starting fires.

Neodymium or Nd (60) - Another soft, silvery metal, neodymium is used with praseodymium to create some of the strongest permanent magnets available. Such magnets are found in most modern vehicles and aircraft, hand tools, wind turbines and earrings, as well as popular consumer electronics such as headphones, microphones and computer discs. Neodymium is also used to make high-powered, infrared lasers for industrial and defense applications.

Promethium or Pm (61) - Although the search for the element with atomic number 61 began in 1902, it was not until 1947 that scientists conclusively produced and characterized promethium, which is named for a character in Greek mythology. It is the only naturally radioactive rare earth element, and virtually all promethium in the earth's crust has long ago decayed into other elements. Today, it is largely artificially created, and used in compact fluorescent bulbs, watches, pacemakers, and in scientific research.

Samarium or Sm (62) - This silvery metal can be used in several vital ways. First, it is part of very powerful magnets used in many transportation, defense, and commercial technologies. Second, in conjunction with other compounds for intravenous radiation treatment it can kill cancer cells and is used to treat lung, prostate, breast and some forms of bone cancer. Because it is a stable neutron absorber, samarium is used to control rods of nuclear reactors, contributing to their safe use.

Europium or Eu (63) - Named for the continent of Europe, europium is a hard metal used to create visible light in compact fluorescent bulbs and in flat panel television and computer color displays. Europium phosphors help bring bright red to color displays and helped to drive the popularity of early generations of color television sets. Fittingly, it is used to make the special phosphors marks on Euro notes that prevent counterfeiting.

Gadolinium or Gd (64) - Gadolinium has particular properties that make it especially suited for important functions, such as shielding in nuclear reactors and neutron radiography. It can target tumors in neuron therapy and can enhance magnetic resonance imaging (MRI), assisting in both the treatment and diagnosis of cancer. X-rays and bone density tests can also use gadolinium, making this rare earth element a major contributor to modern health care solutions.

Terbium or Tb (65) - This silvery rare earth metal is so soft it can be cut with a knife. Terbium is often used in compact fluorescent lighting, color television displays, X-ray identifying screens, and as an additive to permanent rare earth magnets to allow them to function better under higher temperatures. It can be found in fuel cells designed to operate at elevated temperatures, in some electronic devices and in naval sonar systems. Discovered in 1843, terbium in its alloy form has the highest magnetostriction of any such substance, meaning it changes its shape due to magnetization more than any other alloy. This property makes terbium a vital component of Terfenol-D, which has many important uses in defense and commercial technologies.

Dysprosium or Dy (66) - Another soft, silver metal, dysprosium has one of the highest magnetic strengths of the elements, matched only by holmium. Dysprosium is often added to permanent rare earth magnets to help them operate more efficiently at higher temperatures. Turbines, lasers, cathode lamps, and commercial lighting can use dysprosium, which may also be used to create hard computer disks and other electronics that require certain magnetic properties. Dysprosium may also be used in nuclear reactors and modern, energy-efficient vehicles.

Holmium or Ho (67) - Holmium was discovered in 1878 and named for the city of Stockholm. Along with dysprosium, holmium has incredible magnetic properties. In fact, some of the strongest artificially created magnetic fields are the result of magnetic flux concentrators made with holmium alloys. In addition to providing coloring to cubic zirconia and glass, holmium can be used in nuclear control rods, microwave equipment, and high-discharge lamps.

Erbium or Er (68) - Another rare earth with nuclear applications, erbium can be found in neutron-absorbing control rods. It is a key wavelength amplifier component of high-performance fiber optic communications systems, and can also be used to give glass and other materials a pink color, which has both aesthetic and industrial purposes. Erbium can also help create lasers, including some used for medical and dental purposes.

Thulium or Tm (69) - A silvery-gray metal, thulium is one of the least abundant rare earths. Its isotopes are widely used as the radiation device in portable X-rays, making thulium a highly useful material. Thulium is also a component of high-intensity discharge lights and metal halide lamps as well as highly efficient lasers with various uses in defense, medicine and meteorology.

Ytterbium or Yb (70) - This element, named for a village in Sweden associated with its discovery, has several important uses in lighting and in health care, including in certain cancer treatments. Ytterbium can also enhance stainless steel and be used to monitor the effects of earthquakes and explosions on the ground.

Lutetium or Lu (71) - The last of the rare earth elements (in order of their atomic number) has several interesting uses. For instance, lutetium isotopes can help reveal the age of ancient items, like meteorites. It is used in high-intensity discharge lamps and also has applications related to petroleum refining and positron emission tomography. Experimentally, lutetium isotopes have been used to target certain types of tumors.

All of the rare earth elements have extremely similar chemical properties as a class, and are generally all considered as members of Group IIIA in the periodic chart. Although only the lanthanides—cerium through lutetium—have 4f electrons, the elements are grouped together by the International Union of Pure and Applied Chemistry (IUPAC) and by chemists in general.

Rare earths are iron gray to silvery lustrous metals and as a rule are soft, malleable and ductile. They are ordinarily reactive, particularly at elevated temperatures or when finely separated. The range of melting points is from 798° C (cerium) to 1,663° C (lutetium). Rare earths' favorable attributes are used in a broad variety of applications, including magnets, rechargeable batteries, catalysts, metal alloys, fluorescent lighting elements and lasers, optics and many others.

Collectively, the rare earth elements contribute to vital technologies we rely on today for safety, health and comfort. All of the rare earth elements contribute to the advancement of modern technologies and to promising discoveries yet to come.

The Rare Earth Industry

Rare earths were discovered in 1787 by Karl Axel Arrhenius, an officer in the Swedish army, when he gathered the black mineral ytterbite (later renamed gadolinite) from a feldspar and quartz mine adjacent to the hamlet of Ytterby, Sweden. Because of similarity in the elements and the fact that they occur in nature as a group, or subgroup, without separation by natural forces, rare earth elements are not easily isolated. The first element to be separated was an impure yttrium oxide that was isolated from ytterbite by a Finnish chemist, Johan Gadolin, in 1794.

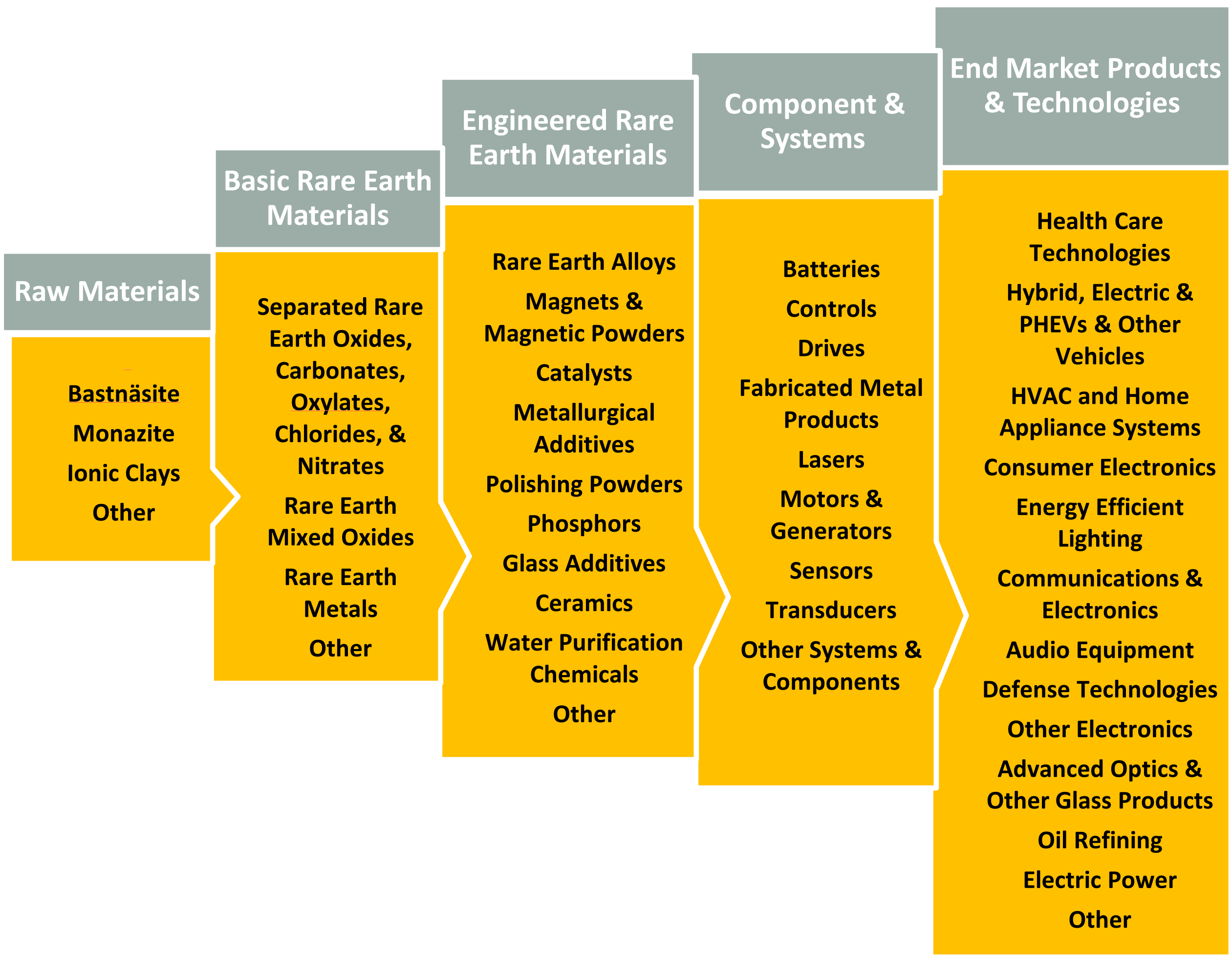
The first commercial applications for rare earths arose during the 1880s with the introduction of the Welsbach incandescent lamp, which initially required the oxides of zirconium, lanthanum, and yttrium. By 1900, rare earths found other applications in lighting. Over the past 110 years or so, the use of rare earths has grown from a few hundred metric tons to over 80,000 tons consumed annually. This is miniscule when compared to iron ore, bauxite and other minerals, but rare earths represent a strategic segment of industrial minerals, metals, and inorganic chemicals.

Despite the small volume of rare earths used, ***literally hundreds of billions of products are made possible by rare earths,*** which are a critical and essential element in many advanced technologies. Rare earth products include automotive catalytic converters, petroleum refining catalysts, glass manufacture and polishing, ceramics, permanent magnets, metallurgical additives and alloys, and rare earth phosphors for lighting, television, computer monitors, radar and x-ray intensifying film, among a myriad of applications.

As defined in the economic nomenclature of the United States (the NAICS coding system), the rare earth industry is not one distinct industry. Rather, rare earths are included as part of several different industries. The primary industry (nearly 70% of the total) is NAICS 325180 (Other Basic Inorganic Chemical Manufacturing), which is comprised of establishments primarily engaged in manufacturing basic inorganic chemicals (except industrial gases and synthetic dyes and pigments). About 30% of the total in which rare earth manufacturing occurs is NAICS 212299 (All Other Metal Ore Mining), which is comprised of establishments primarily engaged in developing the mine site, mining, and/or beneficiating (i.e., preparing) metal ores (except iron and manganiferous ores valued for their iron content, gold ore, silver ore, copper, nickel, lead, zinc, and uranium-radium-vanadium ore). Included are bastnäsite and monazite mining and beneficiating.

Minerals that are commercially important sources of rare earths primarily include bastnäsite and monazite although xenotime and loparite present other sources. The rare earth elements are often found together. Most of the current supply of yttrium originates in the ionic (or iron absorption) clays. In Europe, significant quantities of rare earth oxides are found in tailings accumulated from uranium ore, shale and loparite mining.

Figure 1 - Rare Earth Value Chain



Rare earth salts, metals and compounds are used in a diversity of applications including catalysts, magnets, metallurgy, batteries, glass and ceramics, chemicals, and other intermediate goods as well as health care, electric and other light vehicles, appliances, consumer electronics, lighting, communications, electronics, defense technologies, oil refining, electric power and other final goods and services.

The value chain of the rare earth industry includes basically five stages of transformation:

1) rare earth mining (ores);
2) basic rare earth materials (e.g., extraction/separation/processing for concentrates and chemicals);
3) engineered rare earth products (metals, ceramics, glasses, chemicals, etc.);
4) components and systems (motors, generators, etc.) and
5) end-use products and technologies.

Value-added occurs at each one of these stages. For purposes of simplifying this analysis stages 1 and 2 are combined and stages 3 and 4 are combined.

Rare earth elements provide solutions for many challenges of modern business and home life. Figure 1 illustrates the rare earth supply chain from mineral raw materials, to manufacture of rare earth salts and compounds, to the manufacture of intermediate engineered products (magnets, additives, etc.) and to final goods and services purchased by consumers or for investment.

How big is the North American rare earth industry? In terms of shipments, the industry had reached nearly a billion in 2011 and 2012. Table 1 provides data on shipments (or revenues) for the rare earth industry in North America.

Table 1
Trends in North American Rare Earth Materials Shipments

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Shipments (million $)	$107	$114	$116	$118	$145	$204	$127	$225	$957	$923	$795

Sources: Bureau of the Census, Bureau of Labor Statistics, Statistics Canada, and American Chemistry Council
Note: This includes both mining and manufacturing of basic rare earth materials.

Based on data from the Census Bureau, US Geological Survey, and Statistics Canada, North American shipments of rare earth materials were $795 million in 2013. Shipments present the net selling values, f.o.b. or free on board plant to the customer (after any discounts or allowances and exclusive of freight and taxes), of all products shipped from a mining or manufacturing establishment. Inventories typically average 1.3 times monthly shipments and for the industry as a whole averaged over $90 million during 2013. Finished goods inventories account for about 40% of the inventories on hand, and are followed by materials and supplies inventories (at 35%) with work-in-progress accounting for the remaining 25%.

The rare earth industry is a materials-intensive industry. Purchased raw materials represent 50% of the value of shipments. Fuel and power (including purchased electricity) is another important cost element, accounting for 9% while payroll accounts for 15% of the value of shipments. IT, communications, repair and maintenance, professional and technical, and other purchased services account for 3% of the value of shipments, with depreciation accounting for 4% and other expenses accounting for 4%.

Due to the capital-intensive nature of rare earth mining and processing, the direct employment footprint of the North American industry is modest.

Production workers account for 60% of the workforce. These include plant operators, repair and related occupations, as well as various trade and craft, and supervisors. Continuing improvement in the automation of production processes has been a leading contributor to large improvements in productivity during the past 10 years.

Because of the highly technical nature of the industry's operations and products, technical services provided to customers are important factors. The rare earth industry employs chemical engineers, other engineers, chemists, other scientists, IT professionals, technicians, other technical support personnel, finance professionals, marketing and sales staff, and management.

With 1,050 employees in 2013, the North American rare earth industry has approximately a $116 million payroll, which includes employee benefits. Payroll is equivalent to 15% of the value of shipments. As with employment, the overall impact of the industry's payroll is much larger.

The complex nature of rare earth chemistry requires certain skills, and trained and educated workers. In other areas, the need for chemists, chemical engineers, and other technically trained personnel continues to mount. In addition to salaries and wages reflecting occupational knowledge intensity, the industry also provides benefits to its employees. These include legally mandated expenditures, and may include voluntary programs such as profit-sharing and other compensation, vacation and other leave, health and life insurance, stock purchase plans, pensions, 401-K contributions, and others. In addition to salaries and wages, these typically can add a third or more to the cost of compensation.

Upstream Rare Earth Supplier Economic Impact

The economic contributions of the North American rare earth industry are numerous, though often overlooked in traditional analyses that consider only the direct jobs and output of the industry. Not only are jobs created directly by the industry, additional jobs are supported by the North American rare earth industry and by subsequent expenditure-induced activity. The rare earth industry pays its employees' wages and salaries and purchased supplies and services (including transportation, contract workers, warehousing, maintenance, accounting, etc.). These supplier businesses, in turn, made purchases and paid their employees, thus the North American rare earth industry generates several rounds of economic spending and re-spending.

In addition to the direct effects of the North American rare earth industry, the indirect and induced effects on other sectors of the economy can also be quantified. The economic impact of an industry is generally manifested through four channels:

- Direct impacts - such as the employment, output and fiscal contributions generated by the sector itself
- Indirect impacts - employment and output supported by the sector via purchases from its supply chain

- Induced impacts - employment and output supported by the spending of those employed directly or indirectly by the sector
- Spillover (or catalytic) impacts - the extent to which the activities of the relevant sector contribute to improved productivity and performance in other sectors of the economy

This report presents the economic contributions related to the first three channels. Spillover (or catalytic) effects do occur from rare earth chemistry, but these positive externalities are difficult to accurately quantify and were not examined in the analysis.

To estimate the economic impacts from the North American rare earth industry, the IMPLAN[1] model was used. The IMPLAN model is an input-output model based on a social accounting matrix that incorporates all flows within an economy. The IMPLAN model includes detailed flow information for 440 industries. As a result, it is possible to estimate the economic impact of a change in final demand for an industry at a relatively fine level of granularity. For a single change in final demand (i.e., change in industry spending), IMPLAN can generate estimates of the direct, indirect and induced economic impacts. Direct impacts refer to the response of the economy to the change in the final demand of a given industry to those directly involved in the activity. Indirect impacts (or supplier impacts) refer to the response of the economy to the change in the final demand of the industries that are dependent on the direct spending industries for their input. Induced impacts refer to the response of the economy to changes in household expenditure as a result of labor income generated by the direct and indirect effects.

An input-output model such as IMPLAN is a quantitative economic technique that quantifies the interdependencies between different industries (or sectors) of a national economy. Although complex, the input-output model is fundamentally linear in nature and as a result, facilitates rapid computation as well as flexibility in computing the effects of changes in demand. In addition to studying the structure of national economies, input-output analysis has been used to study regional economies within a nation, and as a tool for national and regional economic planning. A primary use of input-output analysis is for measuring the economic impacts of events, public investments or programs such as base closures, infrastructure development, or the economic footprint of a university or government program. The IMPLAN model is used by the Army Corp of Engineers, Department of Defense, Environmental Protection Agency, and over 20 other agencies, numerous government agencies in over 40 states, over 250 colleges and universities, local government, non-profits, consulting companies, and other private sector companies.

[1] Implan Group LLC . See www.implan.com for details.

Table 2

Upstream Economic Impact of the Rare Earth Industry

Impact Type	Employment	Payroll ($ Million)	Output ($ Million)	Taxes ($ Million)
Direct	1,049	$116	$795	$53
Indirect (Supply Chain)	2,550	$175	$717	$71
Payroll-Induced	2,738	$131	$418	$52
Total	**6,337**	**$422**	**$1,930**	**$176**

The direct output and employment generated by the North American rare earth industry is significant. The $795 million industry directly generated 1,050 jobs and $116 million in payroll. The industry pays about $53 million in taxes. But the full economic impact of the industry goes well beyond the direct jobs and output. Businesses in the rare earth industry purchase raw materials, services, and other products throughout the supply chain. Thus, an additional 2,500 indirect jobs are supported by North American rare earth operations. Finally, the wages earned by workers in the rare earth industry and throughout the supply chain are spent on household purchases and taxes generating an additional 2,740 payroll-induced jobs. All told, the $795 million in rare earth output generates a total of $1.93 billion in output in the economy and 6,335 jobs with a payroll of $422 million. As a result, each job in the rare earth industry generates an additional 5.0 jobs elsewhere in the North American economy, and $1.14 billion in additional upstream output in supplier and payroll-induced sectors.

Downstream Rare Earth Industry End-Use Markets Economic Impact

The rare earth mining (ores) and rare earth basic materials (e.g., extraction/separation/processing of concentrates and chemicals) combined represents a $795 million business in North America. With the opening of the Mountain Pass mining, rare earth mining has expanded and now generates $250 million in revenues. Rare earth concentrates and chemicals account for the remaining $545 million in revenues.

Demand for rare earths results from the large number of applications that rely on rare earths—especially the growing use in high technology applications. In addition, demand is driven by more general uses, the expanding global population, and economic growth.

A large number of industries purchase products and services from the rare earth industry and, therefore, are directly supported by the rare earth chemistry. In addition to the previous analysis using input-output analysis to trace relationships among supplier (or upstream) industries, we also examine customer (or downstream) industries that produce products that use rare earth elements as their raw material or for processing.

Rare earths are used in a myriad of diverse intermediate and final demand applications as well as dynamic markets. During the years, these various markets have developed in a very uneven manner. Rare earth elements (and compounds) have many diverse uses. Thousands of producers and manufacturers, and millions of workers, rely on products and services enabled by rare earth chemistry every day to provide solutions to new manufacturing needs and to sustain excellence in functional performance. In fact, without rare earths many of the products we rely on would not perform as well.

Primary intermediate end-use customers are manifold. These are the manufacturers of engineered rare earth materials. Most notable are magnets and magnetic powders, catalysts, metallurgical additives, batteries, polishing powders, phosphors, glass additives, and ceramics. These direct customer industries supply products that are used in a wide variety of industries even further downstream; as well as batteries, magnets, various components and systems, and other products (and services) closer to the consumer, including health care, vehicles, lighting, communications, electronics, oil refining, electric power and others.

Some of the downstream applications of rare earths in North America are presented in Table 3. The economic activity associated with these downstream customer industries has been extensive. In 2013, rare earth chemistry was supportive of $329.6 billion in the economic output of other downstream industries and sectors. These sectors employ 618,800 people with a $37.6 billion payroll. Although challenging to measure, the support that rare earths provide to the broader North American economy is widespread.

Table 3
North American Economic Activity Supported by Rare Earth Chemistry

Industry	Revenues ($ Millions)	Employment (thousands)	Payroll ($ Millions)
Rare Earth Compounds	**$795**	**1.1**	**$116**
Intermediate Products	**$43,910**	**114.1**	**$6,850**
Magnets & Magnetic Powders	$532	0.9	$48
Catalysts	$3,907	4.7	$389
Metallurgical Additives	$19,363	49.8	$2,714
Polishing Powders	$459	0.4	$25
Phosphors	$408	0.6	$50
Glass Additives	$423	0.5	$38
Ceramics	$831	4.9	$204
Batteries	$3,801	8.8	$484
Other Components & Systems	$14,187	43.4	$2,897
End-Market Products & Technologies	**$285,645**	**504.7**	**$30,741**
Health Care	$11,402	115.7	$5,744
Hybrid, Electric, PHEVs & Other Vehicles	$70,748	76.4	$4,332
Lighting	$3,617	13.0	$637
Communications Systems	$7,847	20.7	$1,860
Audio Equipment	$3,147	7.9	$470
Defense Technologies	$13,579	35.9	$3,088
Other Electronics	$29,608	54.7	$3,544
Advanced Optics & Other Glass Products	$5,095	18.1	$907
Oil Refining	$93,071	7.9	$914
Wind Power	$11,397	9.3	$961
Other	$36,225	145.2	$8,285
Total - Downstream Customer Sectors	**$329,645**	**618.8**	**$37,591**

Sources: Bureau of Economic Analysis, Bureau of Labor Statistics, Census Bureau, Statistics Canada, American Chemistry Council analysis
Notes: Intermediate Products includes engineered rare earth materials and components and systems. All revenue and payroll data are in U.S. dollars.

The United States dominates the North American market. Table 4 presents some of the downstream applications of rare earths in the United States. The economic activity associated with these downstream customer industries has been extensive. In 2013, rare earth chemistry was supportive of $298.6 billion in the economic output of other downstream industries and sectors. These sectors employ 536,200 people whose payroll is $33.4 billion.

Table 4
U.S. Economic Activity Supported by Rare Earth Chemistry

Industry	Revenues ($ Millions)	Employment (thousands)	Payroll ($ Millions)
Intermediate Products	**$39,196**	**101.8**	**$6,110**
Magnets & Magnetic Powders	$517	0.8	$46
Catalysts	$3,562	4.2	$349
Metallurgical Additives	$18,157	46.3	$2,513
Polishing Powders	$425	0.3	$20
Phosphors	$349	0.6	$44
Glass Additives	$378	0.5	$33
Ceramics	$818	4.8	$200
Batteries	$3,746	8.6	$474
Other Components & Systems	$11,247	35.7	$2,432
End-Market Products & Technologies	**$259,365**	**433.5**	**$27,258**
Health Care	$10,795	99.3	$5,347
Hybrid, Electric, PHEVs & Other Vehicles	$65,864	67.7	$3,818
Lighting	$3,340	11.8	$586
Communications Systems	$7,584	19.5	$1,798
Audio Equipment	$2,810	6.5	$390
Defense Technologies	$12,413	30.6	$2,758
Other Electronics	$27,413	49.3	$3,227
Advanced Optics & Other Glass Products	$4,560	16.3	$813
Oil Refining	$85,652	7.1	$823
Wind Power	$10,389	8.2	$839
Other	$28,546	117.1	$6,858
Total – Downstream Customer Sectors	**$298,561**	**535.2**	**$33,368**

Sources: Bureau of Economic Analysis, Bureau of Labor Statistics, Census Bureau, American Chemistry Council analysis
Note: Intermediate Products includes engineered rare earth materials and components and systems.

Table 5 presents some of the downstream applications of rare earths in Canada. The economic activity associated with these downstream customer industries has been extensive. In 2013, rare earth chemistry was supportive of $31.1 billion in the economic output of other downstream industries and sectors. These sectors employ nearly 84,000 people whose payroll is $4.2 billion.

Table 5
Canadian Economic Activity Supported by Rare Earth Chemistry

Industry	Revenues ($ Millions)	Employment (thousands)	Payroll ($ Millions)
Intermediate Products	**$4,714**	**12.3**	**$740**
Magnets & Magnetic Powders	$15	0.1	$3
Catalysts	$346	0.5	$40
Metallurgical Additives	$1,206	3.4	$201
Polishing Powders	$34	0.1	$6
Phosphors	$59	0.1	$6
Glass Additives	$45	0.1	$5
Ceramics	$13	0.1	$4
Batteries	$55	0.2	$11
Other Components & Systems	$2,940	12.3	$466
End-Market Products & Technologies	**$26,371**	**71.3**	**$3,483**
Health Care	$608	16.4	$397
Hybrid, Electric, PHEVs & Other Vehicles	$4,884	8.6	$514
Lighting	$278	1.2	$51
Communications Systems	$263	1.2	$62
Audio Equipment	$337	1.4	$80
Defense Technologies	$1,166	5.3	$330
Other Electronics	$2,454	6.4	$365
Advanced Optics & Other Glass Products	$535	1.8	$93
Oil Refining	$7,420	0.8	$91
Wind Power	$1,008	1.1	$122
Other	$7,679	28.1	$1,427
Total – Downstream Customer Sectors	**$31,084**	**83.6**	**$4,223**

Sources: Statistics Canada, American Chemistry Council analysis
Notes: Intermediate Products includes engineered rare earth materials and components and systems. All revenue and payroll data are in U.S. dollars.

The rare earth industry exists because of the unique physical and chemical properties exhibited by rare earth-containing materials. These properties allow the synthesis or fabrication of materials and products that would not otherwise be possible. These unique properties are the single most important force that defines the rare earth industry. Because of their unique magnetic, luminescent, and electrochemical properties, these elements help make many technologies perform with reduced weight, emissions, and energy consumption, and give them greater efficiency, performance, miniaturization, speed, durability, and thermal stability. Rare earth-enabled products and technologies help to fuel global economic growth, maintain high standards of living, and create products that help to save lives.

The following is a review of the major intermediate markets for rare earths (e.g., engineered rare earth materials and components and systems) as well as final end-market products and technologies.

Intermediate Products - Rare earths are used in a myriad of diverse intermediate applications, including magnets and magnetic powders, catalysts, steel alloys and other metallurgical additives, batteries, polishing compounds, phosphors, glass additives, ceramics and other engineered rate earth materials and applications in finished components and systems. In 2013, the $795 million in rare earth chemistry was supportive of $43.9 billion in the economic output of these intermediate products downstream. These industries employed 114,100 people with a payroll of $6.9 billion. Rare earth elements are used extensively in the industries that are described here in this report.

Magnets & Magnetic Powders: Magnets represent a large market for rare earths. Although the majority of magnets in use today are ferrites, rare earth magnetic materials receive wide acceptance in some uses because of performance advantages. Metallic alloys containing cobalt or iron in conjunction with lanthanides have considerable magnetic properties. A variety of alloys are used but the most important are samarium-cobalt and neodymium-iron-boron. These magnets are used in higher-value applications. Even with ferrites, thulium is used.

Rare earth magnets containing the rare earth component samarium or praseodymium have been widely used since their introduction in the early 1970s. The alloys involved often contain more than one single rare earth metal, and mixtures are common. These alloys are generally classified into two groups, RCo5 and R2Co17, although the materials may vary somewhat from those compositions. Favorable properties include the ability to withstand high temperatures and corrosion resistance.

Samarium cobalt offers high energy with excellent coercive (resistance to demag) forces. This makes samarium an excellent choice for small, compact designs where high-temperature environments may be present. It is used in many different applications ranging from small Hall-effect sensors to blocks used in motor applications. Characteristics include high-energy products, good mechanical characteristics, good corrosion resistance (thus requiring no surface treatment), and the ability to withstand higher temperatures.

The neodymium-iron-boron (Fe14Nd2B) magnets or NIB magnets are relatively new permanent magnet materials. Though the market for these Nd-Fe-B magnets currently represents only a small fraction of the market for magnetic materials these materials are replacing other materials. Because of its magnetic properties, neodymium can be used to create some of the most powerful magnets. Nd-Fe-B material offers the most advanced permanent magnet material available today. Nd magnets allow small shapes and sizes with high magnetic fields. These magnets can be found in high-performance motors, actuators, speakers, hard disk drives, sensors, and numerous other areas. Favorable characteristics include high-energy products and good mechanical attributes.

Applications for Sm-Co magnets have been well-integrated into high-energy, high-stability magnet applications. The choice of Sm-Co type magnets in some applications is necessary where high temperature performance is needed. Another area where Sm-Co magnets have applications is where protection against demagnetization in reversed fields is important.

In general, rare earths magnets are used in a wide variety of applications, too many to quantify. They are replacing ferrite magnets in motors and offer reduction in power consumption, emissions, size, weight (important for light-weighting in automobiles) and lifecycle costs. Magnets are ubiquitous and Table 6 lists a number of key applications for rare earth magnets. Rare earth magnets in motors find widespread use in aerospace, defense, light vehicles, clean energy, computing and networking technologies, and appliance applications. An emerging technology using rare earth magnets -- magnetic refrigeration -- could potentially improve the energy efficiency of refrigerators for home and commercial use.

Although these magnets and magnetic powders account for only about 1-3% of the broader industries encompassing magnet manufacturing, rare earths magnets and materials generate $532 million in output and 900 jobs (with a payroll of $48 million) in North America.

Table 6
Rare Earth Magnet Applications

AC Compressors and Fans	Hand Power Tool Motors
Aerospace Motors:	Hard Disk Drives
Controls	Headphones
Rudder Motors	HVAC Circulation Pumps
Tailfin Motors	Hysteresis Clutch
Appliance Motors	Industrial Motors
Automotive Applications:	Loudspeakers
AC Compressor Motors	Low-Voltage Motors
Electric Drives for EVs, PHEVs, and HEVs	Magnetic Refrigeration
Fuel Pump Motors	Magnetic Separation
Fuel Valve Controls	Microphones
Headlight Adjustment Motors	Microrelays
Passive Constraint/Air Bag Controls	Motors for Off-Highway Trucks, Machinery, etc.
Power Steering Sensor Motors	Motors for Mining and Construction Equipment
Seat Motors	MRI
Sensors	Optical Disk Drives
Window Lift Motors	Pipe Inspection
Bicycle Dynamos	Printers
Brakes	Refrigerator Motors
Ceiling Fan Motors	Relays and Switches
CD/DVD Drives	Reprographics
Defense:	Sensors
Hybrid Electric Motors	Servers
Fin Motors	Spindle Drive Motors
Laser Gun Sights	Switched Reluctance Motors
Navigation and Radar System Motors	Super High-Efficiency Motors
Reference System Motors	Torque-Coupled Drives
Direct Drive Motors	Torque-Coupled Drives
Electric Bicycles	Traction Drives
Energy Storage Systems	Transducers
Fax Machines	Vacuum Cleaner Motors
Gauges	Vibration Motors
Generators	Wind Turbine Generators
Guitar Pickups	

Catalysts: Catalysts represent a large market for rare earths. A catalyst is a substance used in very small quantities to increase the rate of a desirable chemical reaction without itself being changed chemically. It is employed to increase overall efficiency, quality and other favorable attributes. A variety of rare earth elements are utilized in catalysis applications. Reflecting key end-use applications, mixed lanthanide, cerium, and fluorides are widely used. Rare earths play a large role in providing bonding and other catalytic properties desired for effective catalysis in automotive and processing applications. Catalysis is pervasive in modern industrial and other economic activity.

The major catalytic application for rare earths is in fluid cracking catalysts (FCC) in the petroleum industry. The use of rare earths in FCC catalysis emerged in the early-1960s when zeolite-cracking catalysts for oil refining were introduced. The rare earth acts to retain catalyst effectiveness. Rare earth catalysts are used to increase the yield of the gasoline fractions by cracking the heavier oil fractions. Rare earths used in FCC catalysts tend to be the lighter ones, especially lanthanum and praseodymium. These rare earth-containing zeolite catalysts (REX) contain up to 5% trivalent rare earths. The major use of lanthanum is in cracking catalysts used to refine crude oil into gasoline, distillates, lighter oil products and other fuels. These also are responsible for eliminating leaded gasoline. The use of these lanthanide fluidized cracking catalysts also promotes very energy efficient petroleum cracking. In addition, cerium is also used as a combustion catalyst for exhaust gases to reduce emissions of pollutants.

Automotive exhaust catalysts represent a large market. Cerium is used in these catalysts, which are the active ingredient in catalytic converters in automobiles and other combustible engines. Indeed, one of the crucial chemical components in catalytic converters is cerium oxide or other cerium compounds. The use of cerium provides the alumina the ability to survive the high temperature without forming the low surface area alpha alumina phase. Also, cerium enhances the oxidative ability of the system by acting as an oxygen reservoir and promotes a water-gas shift reaction. In addition to cerium oxide, lanthanum oxide is also added to platinum-rhodium and platinum-rhodium-palladium catalysis. Praseodymium is also used in automobile and other internal combustion engine pollution control catalysts.

Rare earth oxides have also been used as emission control catalysts (ECC) at stationary sources. That is, to reduce air pollutant emissions. For example, they have been used for reducing sulfur dioxide emissions during regeneration of FCC catalysts. Palladium, zeolite, and other catalysts represent the catalyst platforms most widely used. Lanthanum is used as a catalyst for reducing nitrogen oxides, and cerium-based pollution control catalysts help to significantly reduce the sulfur oxide emissions from oil refineries. Cerium is also used as a recycled oxidant for performing low-temperature, energy efficient waste treatment on many pollutants. Other applications for rare earth ions in catalysis include the use of cerium in combustion catalysts for air pollution control.

Rare earths may also serve as polymerization catalysts. All other catalysis applications, mostly chemical processing, account for the remaining.

These rare earth-based catalysts account for only about 12-14% of the broader catalyst industry. Rare earth-based catalysts contribute $3.9 billion in economic output and 4,700 jobs (with a payroll of about $389 million) in North America.

Metallurgical Additives: Rare earth metals have found wide use in a number of metallurgical applications, including ductile iron and graphite iron, high-strength low-alloy (HSLA) stainless and specialty steels, as an alloying element in aluminum and magnesium, superalloys, and as an additive in hot-dipped galvanizing processes. Demand is largely driven by trends in the construction and automotive markets.

Rare earth metals are used in iron and steel castings to remove traces of sulfur from the materials. Properties of cast irons are greatly affected by the presence of small concentrations of oxygen and sulfur, causing major changes in the morphology of the cast material. The production of nodular iron with spheroidal graphite inclusions makes the materials less easy to fracture and improves yield, tensile strength and elongation, producing cast iron materials with properties similar to malleable iron.

Rare earth materials such as mischmetal, rare earth silicide, and other alloys are used in steel to control crystallite morphology and to improve workability and corrosion performance. Mischmetals are added directly to the “melt” (or as part of a ferrosilicon alloy) where they act as sulfur scavengers. Rare earth additions to steel also lead to dramatically improved ductility. Neodymium is used as a gas scavenger in iron and steel manufacture. Cerium improves the physical properties of high-strength, low-alloy steels due to its affinity to scavenge oxygen and sulfur. Cerium is added primarily to provide sulfide shape control. Rare earths are very stable and with low volatilty.

Rare earths were first used in manufacturing highly alloyed stainless steels, which are more expensive and justify the cost of rare earth additives. Rare earths are still used in manufacturing stainless steels used in very corrosive environments. Ytterbium is used as an alloying agent to improve the strength of stainless steel. Didymium oxide is also used in stainless steel.

Changes in steel manufacturing technology, however, have opened up new markets for rare earths, particularly in desulfurizing. As polymers captured a larger share of the automobile market, steel manufacturers developed high-strength, low-alloy (HSLA) steels as a means to thwart penetration of polymers into automotive body, chassis, and mechanical applications. These HSLA steels can crack when cold-formed on a tight radius and the addition of rare earths improves ductile properties.

Niobium is used in the metallurgy of micro-alloyed and other specialty steels for numerous industries, including automotive, pipelines, shipbuilding, and rail. Gadolinium is used as an alloying agent in the production of specialty steels and lanthanum is used in alloys. Yttrium and other lanthanides are used as stabilizers and mold formers for exotic lightweight jet engine turbines and other parts. Cerium is used in jet engine alloys.

Superalloys are a family of nickel-based or cobalt-based alloys designed for high temperature service in corrosive and abrasive atmospheres. Typically 0.01% to 0.2% La, Y, or Ce is added to improve high temperature performance. The rare earth metals improve performance by acting to better nonmetallic and tramp elements, thus controlling diffusion mechanisms in surface oxidation films. This improved performance is caused by forming oxidation- and corrosion-resistant adherent films that cover the underlying metal. These superalloy materials in turn have been used in the combustors, flame holders and exit nozzles of jet aircraft.

Rare earths have been employed in magnesium and aluminum alloys. Magnesium producers have developed various casting alloys containing rare earth metals. The group of magnesium-rare earth alloys, usually containing other alloying elements, has found major application in military helicopter use, where weight and strength considerations are very important. The addition of 3.5% rare earths to magnesium alloys allows thin-wall castings, an important characteristic in defense applications. It has also found use in automotive applications. Alloys available include a variety of alloys from ZE41 (containing 4% zinc and 1% rare earth metals), WE54 (5.25% yttrium, 3% rare earth metals, and 0.5% zirconium), ZRE1 (3% rare earth metals, 2.5% zinc, and 0.6% zirconium), RZ5 (4.2% zinc, 1.3% rare earth metal, and 0.7% zirconium), and others, designed for high strength at elevated temperature, castability and weldability. Small quantities of praseodymium are added to magnesium to form an alloy that is stronger and more resistant to corrosion. The alloy is used in both automotive and aircraft applications. Neodymium is used to increase the heat resistance of magnesium. The utilization of these materials in aerospace and military applications, particularly helicopter applications, has led to significant use of mischmetal in cast magnesium parts. The cast parts are easily machined and various coatings are applied to provide improved corrosion and abrasion performance.

Aluminum alloys containing yttrium and lanthanum have been developed. The alloys offer significant corrosion resistance and high-temperature performance compared to Duraluminum. Most uses are niche applications. For example, premier lines of baseball and softball bats incorporate high-strength scandium-aluminum alloy. Cerium compounds are used in the electrowinning of aluminum.

Rare earth metals find applications in other metal markets. Applications include mischmetal, other alloys, metals research and other uses. Mischmetal (lanthanide-iron-silicon) is produced by arc furnace reduction of the lanthanide fluorocarbonate to a metal form. Praseodymium is used to manufacture mischmetal. It is commonly employed in applications for a pyrophoric material. Applications include lighter flints, where the alloy typically contains 70% rare earths with the remainder iron. Mischmetal is an important compound used in steel alloys (covered elsewhere), and contains about 18% neodymium. It is also used to make alloys for many uses including steel, batteries, and magnets. It is also used in tracer bullets used as markers in machine-gun ammunition, and in incendiary bombs. Terbium is used in specialty alloys with unique magnetic properties for use in compact discs. Dysprosium's unique magnetic properties also allow it to be used in special alloys that form the heart of magneto-optic recording technology used for handling computer data. Erbium, ytterbium oxide are used in special alloys.

Metallurgical alloys and uses support about 4-5% of the broader iron and steel industry and because of their role in ductile iron, they support roughly 30% of the foundry industry. They support nearly 15% of non-ferrous metals. In total, rare earths are supportive of $19.4 billion in metallurgical applications output and 49,800 jobs (with a payroll of about $2.7 billion) in North America.

Polishing Powders: Glass applications for rare earths include glass polishing, an older, mature segment of the rare earth business. The use of rare earth products in glass is actually quite extensive.

Cerium oxide-based glass polishes have been found greatly superior to other glass polishes because the polishing is much faster and the cleanup following use is a great deal easier. Because of this, use of cerium oxide-based polishes dominates in the polishing of ophthalmic lenses, television and computer monitor plate glass, and high quality mirrors. Indeed, it is by far the most efficient polishing agent for most glass compositions. Cerium oxide is generally slurried in water and is the active ingredient in polishing compounds for glass, television faceplates, mirrors, optical glass, and other products such as silicon microprocessors and disk drives.

Demand for polishing compounds has lately been driven by the increase in production of large-screen televisions but as the production base of televisions and monitors moved to Asia in the last decade, so has the rare earth polishing powder industry. With the popularity of lighter weight polycarbonate lenses for vision correction, there has been a continuing decline in the quantity consumed for polishes used for glass lenses for spectacles. Polishing compounds are also used in the production of dimensional stone (such as granite) as well as for mirrors and flat glass.

These rare earth-based polishing compounds are supportive of $459 million in output and 400 jobs (with a payroll of $25 million) in North America.

Phosphors: Phosphors are optical transducers providing luminescence. Rare earths are extensively used as dopant ions as well as part of many of the host compounds. Their role is as sensitizers. The most important use of europium compounds is associated with phosphors for color TV screens and for computer monitors. Other applications include compact and other energy-efficient fluorescent lighting and other lighting as well as medical imaging. In addition to europium, a wide variety of rare earths are used in phosphor applications, including cerium compounds, lanthanum, didymium oxide, praseodymium, and samarium oxide.

Rare earths are used as activators and hosts in consumer electronics phosphors. Activators determine the emission spectra of the phosphor while the host converts absorbed energy into radiant energy. Rare earth compounds used as phosphor activators include europium, terbium, cerium, thulium, and praseodymium while compounds used as hosts include yttrium, gadolinium or lanthanum. Europium-activated red phosphors are the primary compound used while yttrium-oxide and related compounds are primarily used as hosts.

Rare earth phosphors have been widely used to enhance the performance of medical X-ray imaging products since the early 1970s. The phosphor accepts the X-ray and efficiently converts the photon to the visible range, which is then used to expose the film. Activators include terbium, thulium and europium in various hosts, including a gadolinium oxysulfide. Intensifying screens, using these phosphors, aids in decreasing the exposure time needed for producing film. These improvements have allowed lower patient and medical personnel exposure, increased the operating lifetime of X-ray equipment, and decreased the silver loading on X-ray film. Gadolinium, terbium, and yttrium phosphors are used to impart sharper images.

These rare earth-based phosphors are supportive of $408 million in output and 600 jobs (with a payroll of $50 million) in North America.

Glass Additives: Rare earth elements are widely used in glass manufacturing, primarily in five areas: decolorizers, color tint, refractive index enhancers, color filters, and radiation and UV protection.

Cerium oxide is the most commonly used rare earth with lanthanum, neodymium, praseodymium, and erbirum compounds also used.

Raw materials used in glass manufacture (such as sand and limestone) contain iron oxide, which can impart color to the glass product. In the decolorizing of glass, ceric oxide, CeO2, is added to the glass melt to oxidize iron oxides to the ferric (Fe3+) state to remove the bluish color from the ferrous iron present in impurities added to the glass melt. The presence of cerium also decreases the requirement for selenium to decolorize the yellow hue present from the ferric iron. The ceric ion absorbs ultraviolet light, which is beneficial because it reduces the rate of deterioration of products in glass bottles, containers and tableware. Cerium compounds are used as a discoloration retardant in glass. Because cerium oxide stabilizes the physical decolorizers, smaller amounts of the physical decolorizers are required and this results in a brighter glass. In addition, toxic arsenic is no longer needed as a stabilizer. Physical decolorization can also be achieved with the addition of neodymium oxide, erbium oxide and certain didymium compounds. Neodymium oxide is used in potassium silicate glasses, lead glasses and heat-resisting glasses that are high in boric oxide. Erbium oxide is used to make minor adjustments in conjunction with other decolorizers.

Color tinting is achieved in glass by adding various metal oxides that selectively absorb light in the visible range. Glasses colored by rare earths have high powers of light transmission. Neodymium oxide, which is used in artistic and technical glass, engenders a violet color that can be shifted to pink by the addition of selenium. Praseodymium oxide, which imparts a green color, is also used for artistic and technical glasses as well as welder's goggles. Erbium oxide gives a pink color to some photochromic and crystal glasses. A cerium oxide–titanium oxide colorant is also used with manganese to impart a yellowish-pink shade to ophthalmic glass. Europium, holmium, samarium and ytterbium compounds can also be used as colorizers.

Specialty optical glasses are characterized by a high index of refraction and are used for special applications such as camera lenses and for some spectacles. Lanthanum oxide is the primary rare earth product used to increase the refractive index of optical glasses. Small amounts of gadolinium oxide, ytterbium oxide and yttrium oxide are also used for this application. Cerium oxide is used as an additive for photosensitive glass and is also used as a refractive index enhancer additive for photosensitive glass used in fiber-optic connectors, photocopiers, and fax machines.

Color filtration is important for glass used in safety goggles and glass containers. Neodymium oxide is added to glass to suppress the yellow light transmission. Goggles made with this additive are used by lamp workers, welders and glass blowers for protection. Cerium oxide and neodymium oxide are used in glass containers reduce the rate of deterioration of foods, beers and pharmaceuticals. Samarium oxide is used in infrared-absorbing glasses and europium oxide is also used to suppress the ultraviolet radiation transmission.

Finally, radiation and UV protection is possible by the addition of cerium compounds. Ultraviolet or higher-energy radiation, such as X-rays, gamma-rays and cathode rays, can cause glass to darken over time and long-term exposure to sunlight can oxidize metal ions to new states that impart color and darken the glass. Cerium compounds prevent solarization by trapping the liberated electrons before they can form color centers. Cerium ions also prevent browning from higher energy radiation. Cerium-stabilized glass is used in television and other cathode ray tube faceplates and in radiation-shielding windows for the nuclear industry. Radiation shielding windows are made from high-density, cerium-stabilized lead glasses.

These rare earth-based glass additives represent only about 5-8% of the inorganic pigment industry. They are supportive of $423 million in output and 500 jobs (with a payroll of $38 million) in North America.

Ceramics: Rare earth elements are widely used in ceramics manufacturing, primarily in three areas: colorants in glazes, refractories, electronic ceramics, and other applications. Yttrium oxide is used in advanced ceramics as a sintering agent for structural components and coatings made of silicon nitride, sialons (Si-Al-O-N ceramics) or zirconium oxide. Yttrium oxide (yttria) allows formation of crystal planes that are tougher and more stable than those made with other sintering agents. Yttria-stabilized zirconium oxide coatings are used as thermal barriers in jet engines. Cerium oxide is also growing in importance as a sintering agent. Lanthanum oxide is used in technical ceramics.

Praseodymium oxide in a zirconium silicate matrix is used as a yellow stain in enameling. Green colorants are sometimes prepared by blending a praseodymium-zirconium stain with a vanadium-based blue colorant. Neodymium oxide and yttrium oxide can also be used in ceramic pigments. Erbium oxide added to glaze colorants produces a vibrant pink color and has been used as a colorant in porcelain enamel glazes. Cerium compounds are used as opacifying agents in glazes and enamels, where they impart yellow color.

Yttrium oxide is used as an additive in yttrium-stabilized zirconium oxide (YSZ) and is the primary rare earth compound used in refractory ceramics. Included are YSZ oxygen sensors used to measure the oxygen content in automobile exhaust gases, molten glass and molten steel. They are also used to control industrial furnaces and as aqueous pH sensors in primary water systems of nuclear reactors, geothermal power, and other high-temperature or high-pressure solutions. Yttrium oxide is also used as a refractory coating and in crucibles for vacuum and inert gas melting of reactive metals. Another refractory material containing 9:1 yttrium oxide and thorium oxide is used in windows for high-temperature furnaces, lenses for studying molten materials, and high-intensity incandescent and discharge lamps. Calcium oxide, magnesium oxide, ytterbium oxide and scandium oxide are also used as stabilizers for zirconium oxide. Cerium monosulfide, yttrium hexaboride, lanthanum hexaboride and holmium oxide have also been used for refractory applications. Cerium oxide has been used as an additive to the walls of “self-cleaning” ovens where it aids in preventing the buildup of cooking residue.

Rare earth oxides are consumed in electronic ceramics, including electro-optical applications such as microwave garnets and laser dopants. Neodymium oxide, praseodymium oxide, didymium oxide and lanthanum oxide are used in manufacturing temperature-compensating capacitors, resistors and thermistors. Barium titanate thermistors that have been doped with rare earth oxides may be used as heat-actuated switches. Lanthanum oxide is also consumed as additives in lead zirconate–lead titanate ceramics. These lanthanum-modified lead zirconate–lead titanate (PLZT) materials are used in optical shutters and modulators, color filters and image storage devices. Yttrium oxide can be used as a dielectric for capacitors in microelectronics.

Conductive rare earth ceramics such as lanthanum manganite and lanthanum chromite have been used in prototype high-temperature fuel cells that generate electricity directly from the oxidation of methane or methanol. A wide variety of other rare earth applications are also found in this market.

These rare earth-based products used in ceramics are supportive of $831 million in output and 4,900 jobs (with a payroll of $204 million) in North America. They support about 38-40% of the broad ceramics manufacturing industry.

Batteries: The use of lanthanum and mischmetal nickel-metal hydride (NiMH) secondary (recharchable) batteries has grown considerably over the last decade. These NiMH batteries have largely supplanted nickel-cadmium (NiCad) secondary batteries in many applications. Nickel-metal hydride batteries provide higher performance and a more "green" solution for consumer products by eliminating one source of cadmium, a toxic metal.

NiMH technology was first commercialized in 1990 and these batteries are a modification of nickel hydrogen technology that avoids some of the disadvantages and allows the fabrication of small cells with a nickel hydrogen electrode couple. Since cadmium is eliminated, the battery is much lighter than NiCad cells. In addition, performance is strong and includes very high cycle lives, no persistence (the tendency of NiCad batteries to lose recharge ability when repeatedly partially discharged), and a good stability. Nickel-metal hydride batteries have penetrated several high growth markets—laptops, tablets, portable communication products, and portable tools.

Lanthanum provides the classic intermetallic hydride used in NiMH rechargeable batteries. One of the more common uses of these types of batteries is in laptop computers. Lanthanum nickel alloys have the outstanding hydrogen storage properties needed for longer battery life.

These rare earth-based batteries account for about 32-35% of the broader battery industry. As a result, rare earths are supportive of $3.8 billion in output and 8,800 jobs (with a payroll of $484 million) in North America.

Other Components and Systems: A variety of other intermediate goods represent markets for rare earths. Included are garnets, laser crystals, nuclear applications, carbon arc electrodes, drying agents in paints, textiles specialties, and other products. Most of these applications are niche markets. In addition, some of the applications above are further incorporated into finished components and systems.

Rare earths are used as host and dopants in iron and aluminum garnets. Yttrium-iron (YIG) and gadolinium-iron garnet (GIG), for example, are used as ferrite materials in microwave devices (attenuators, filters, phase shifters, switches, etc.), cellular telephones, and related devices. They are also used as resonators in frequency meters, magnetic field measurement devices, tunable transistors, and Gunn oscillators. Yttrium containing garnets are ultimately used in mobile communications devices. Yttrium-aluminum garnets (YAGs) are used in microwave applications, lasers and in synthetic gemstones. Neodymium oxide-doped YAG lasers are used for welding, boring holes, trimming and for surgery. The latter are often doped with holmium or erbium oxide. Other ytterbium compounds are used as dopants for garnets.

A wide variety of rare earths are used in lasers including erbium, gadolinium oxide, lanthanum fluoride, praseodymium, samarium, terbium, thulium and ytterbium compounds. The most commonly used laser in communications applications is the Nd:YAG, which includes a neodymium substituted yttrium aluminum garnet composition in the light tube. Many solid-state lasers use neodymium because it has an optimal selection of absorption and emitting wavelengths. Neodymium lasers are used in material processing, drilling, spot welding and marking, and also in medicine. Other lasers that depend on rare earth components are common. These include holmium-, chromium- and thulium-doped yttrium scandium aluminum garnets. One of the most common lasers for low power applications is the neodymium-glass laser.

Gadolinium, samarium, europium and dysprosium have been used as neutron absorbers in various nuclear applications because of the high capture thermal neutron cross-section. Yttrium has been used for tubing in nuclear installations where molten salts are used for heat transport, because yttrium has a very low neutron capture cross section. Because of their high atom density for hydrogen storage and high-temperature stability, yttrium and certain hydrides have served as neutron moderators. Gadolinium is used in nuclear shielding and in control rods for nuclear reactors and is the single most efficient component used in detection of power plant radiation leaks. Europium is often used as a shield material because it has a high thermal neutron cross section and has also has been used for control rods in certain compact nuclear power reactors (e.g., submarines). Samarium has found use in various nuclear well-logging instruments and is also used as a neutron absorber. Other rare earths are also used in nuclear applications.

Mixed rare earth oxides are used in the manufacture of carbon arc electrodes to increase the intensity and quality of light. These rare earth compounds are derived from monazite, which contains rare earths necessary to produce a brilliant yet balanced white light. Cerium compounds, lanthanum fluoride, lanthanum oxide, europium hexaboride, and praseodymium oxide are used to form carbon-arc electrodes that are in turn used in high-intensity carbon arc lamps used in searchlights, motion picture projectors, and in the graphic arts industry for photoengraving. Praseodymium is widely used as a core material for carbon arcs used by the motion picture industry for studio lighting and projection Didymium oxide is also used in carbon arcs and neodymium oxide is used in carbon arc-light electronics. Ytterbium oxide is used in carbon rods for industrial lighting.

Organometallic compounds using cerium, lanthanum and neodymium are used as paint driers. A rare synthetic rare earth, promethium is used as a luminescent paint for watch dials. Cerium sulfide is used as a pigment to replace cadmium-based compounds used in polymer colorants.

Rare earth compounds are used in textiles. Cerium compounds are used in waterproofing and mildew-proofing applications and as dyes. Praseodymium oxide is used in textile treatments as well. Other rare earth compounds are used in textile applications to increase soil resistance and to protect against creasing, bleaching by the sun, and mildew.

Other industrial applications exist for rare earths. Neodymium sulfate is used as a solvent, esterfying agent, and an intermediate. Dysprosium compounds are used in semiconductors and as oxidizing agents. Cerium compounds are used as oxidants, heat stabilizers, developing agents, and as scavengers for azides as well as in military signals, ignition devices, and rocket propellants. They are used as lubricant additives, polymerization initiators, and as heat stabilizers for PVC resins.

Lanthanum is used in rocket propellants and as a reducing agent. Rare earth products are used as embalming fluids, antiknock additives for gasoline, in rubber processing, and other industrial uses. Cerium compounds are used in spectrography, and promethium-147 is used to measure the thickness of paper. Gadolinium is used in neutron radiography by the airline, aircraft and shipbuilding industries to search for hidden flaws and weaknesses in fuselages and hulls.

Rare earths are used in pharmaceuticals and health care applications. For example, cerium oxalate is used in motion sickness drugs and neodymium isonicotinate is used to treat thrombosis. Lanthanum nitrate is used as an antiseptic and cerium–141 is used in biological and medical research. In living tissue research, highly sensitive luminescence is provided by europium attached as a tag to complex bio-chemicals to assist in real-time tracing of these materials. Other rare earth compounds are used as nausea preventatives, anticoagulants, and other medicines.

Rare earth fertilizers can promote vigor of the plant root system, increase the content of chlorophyll and the rate of photosynthesis, improve material metabolism, raise the plant yields, and strengthen the nutrient uptakes. They are currently applied to cottons and oil-plants.

Rare earths are often used as reagents and in other chemistry applications. Gadolinium oxide and praseodymium oxide are used as laboratory reagent. Cerium compounds are used analytical reagents as well and find other uses in analytical chemistry. Lanthanum chloranilate is used as a reagent for fluoride determination. Holium and ytterbium compounds are used in chemistry research.

Finally, magnets, magnetic powders, various additives and other engineered rare earth materials are used in other products that are not part of final demand for goods and services. These are additional intermediate products such as finished components and systems. Typical products include controls, drives, fabricated metal products, motors and generators, sensors, transducers, and other systems and components. Batteries are similar components but are broken-out separately.

These rare earth-based products are supportive of $14.2 billion in output and 43,400 jobs (with a payroll of $2.9 billion) in North America. They support 10% to 30% of most end-use manufacturing industries they serve. Virtually 100% of motor and generators are dependent upon rare earth chemistry.

End Market Products & Technologies – The direct customer industries described above supply engineered material products and finished components and systems that are used in a wide variety of final products and services closer to the consumer, including health care, vehicles, lighting, communications, electronics, oil refining, electric power and others. Business investment and government purchases of goods and services play a large role in driving final demand downstream. In 2013, the $43.9 billion in intermediate goods (engineered rare earth materials and components and systems) were supportive of $285.7 billion in the economic output of these downstream final goods and services sectors. These sectors employ 505,000 people whose payroll is $30.7 billion. Rare earth elements are used extensively in the final demand sectors described in the following text.

Health Care: Rare earth permanent magnets have facilitated an evolution in health and medical technology. They produce a powerful magnetic field used in medical imaging devices, such as MRIs, that enable doctors to diagnose illnesses that otherwise would be much harder to detect. Rare earth elements are also used in many modern surgical machines, such as those for robot-assisted surgeries. They are used in pioneering technologies, such as cochlear implants. Yttrium is used in solid state lasers and in cancer-treating drugs. Rare earth elements are essential to modern medicine. Rare earth elements are indispensable in many electronic, optical and magnetic applications. Health care applications supported by rare earth chemistry contribute $11.4 billion in North American economic activity and employ nearly 116,000 people with a $5.7 billion payroll.

Transportation and Vehicles: Rare earth magnets have many uses in automobiles, especially in new generation vehicles designed to reduce energy consumption. For instance, they are used in the electric motors of many hybrid cars and electric vehicles and in batteries to help power them. These advanced energy technologies help to reduce CO2 and other emissions. They are found in catalytic converters in cars and can help reduce harmful air pollutants. In addition, ductile iron castings used in automotive applications rely upon rare earth elements. Hybrid, electric and other motor vehicle applications supported by rare earth chemistry generate $70.7 billion in North American economic activity and provide 76,000 jobs with a $4.3 billion associated payroll.

Lighting: Rare earth elements are widely used in compact and other energy-efficient fluorescent lighting and other lighting devices. This is an important market; one fostered lately by energy-efficiency programs and green building initiatives. Rare earth elements are essential to both compact fluorescent lighting (CFLs) and LED lighting. These energy-efficient lights help to reduce CO2 and other emissions. Lighting applications supported by rare earth chemistry generate $3.6 billion in North American economic activity and provide 13,000 jobs with a $637 million associated payroll.

Communications Systems: Rare earth elements are essential to smart phone and other mobile devices, making them faster, smaller, and lighter. They enable us to continually improve our communications and computing capabilities. Communications applications supported by rare earth chemistry represent $7.8 billion in North American economic activity and employ 20,700 people with a $1.9 billion payroll.

Audio Equipment: Rare earth elements enable faster, smaller, and lighter products such as in-ear headphones, microphones, loudspeakers, and related technologies. They support improved entertainment. Audio equipment applications supported by rare earth chemistry represent $3.1 billion in North American economic activity and employ 7,900 people with a $470 million payroll.

Defense Technologies: Rare earth elements are indispensable in many electronic, optical and magnetic applications. Rare earth magnets are incredibly powerful; some can retain their magnetic strength at high-temperatures, making them ideal for defense applications. Rare earth elements are also used for lasers and resolution technologies. These technologies are critical to modern aerospace systems. Motors using rare earth magnets are widely used in aerospace and defense technologies. Defense applications supported by rare earth chemistry represent $13.6 billion in North American economic activity and employ nearly 36,000 people with a $3.1 billion payroll.

Other Electronics: Rare earth elements enable faster, smaller and lighter computer hard drives, printers, and related products. They make color displays more vivid in computer screens and other devices. They are also important for tablet computers and commercial and industrial applications. They enable us to continually improve our computing capabilities. These electronic applications supported by rare earth chemistry represent $29.6 billion in North American economic activity and employ 54,700 people with a $3.5 billion payroll.

Advanced Optics & Other Glass Products: Optical fibers, which consist of bundles of high-index glass hairs, can contain up to 20% lanthanum oxide. Erbium-doped optical fibers have been commercialized as fiber amplifiers for fiber-optic telecommunications systems, allowing light-wave signals to be amplified without converting from light to electrons and back again. Similar fibers have shown the ability to transmit optical signals over much greater distances than previously possible, opening up the possibility for low-cost transoceanic fiber-optic cables with fewer intermediate amplifier stages. Fiber optics have applications in medical and industrial sensors, energy delivery systems and computer interconnects. Fiber optic and related applications supported by rare earth chemistry represent $5.1 billion in North American economic activity and employ more than 18,000 people with a $907 million payroll.

Oil Refining: Rare earth catalysts are vital in making oil refining of crude oil into gasoline more efficient. Fluid cracking catalysis (FCC) accounts for about 11% of oil refining in North America but this is a large end-use industry. As a result, oil refining applications supported by rare earth chemistry represent $93.1 billion in North American economic activity and employ nearly 8,000 people with a $914 million payroll.

Wind Power: Rare earth elements are used in wind turbines, which help to reduce CO2 and other emissions. Rare earths are critical to new clean energy technologies but fossil fuels still dominate energy. Wind power for electricity applications are supported by rare earth chemistry, and represent $11.4 billion in North American economic activity and employ 9,300 people with a $960 million payroll.

Other: Rare earths are vital in many manufacturing processes. They are used in many specialty metal alloys and ductile iron which are in turn used extensive in building and construction. Motors using rare earth magnets are used in appliances, machinery, equipment and other commercial and industrial applications. Rare earths are used in water purification, nuclear applications, R&D applications, and a myriad of other final goods and services. Rare earth elements enable faster, smaller, and lighter products. These other applications supported by rare earth chemistry represent $36.2 billion in North American economic activity and provide 145,000 jobs with an $8.3 billion payroll.

Summary

The contributions of the rare earth industry to the North American economy are significant and extensive. The rare earth industry is small, generating less than $800 million in output directly and employing only 1,050 people (with a payroll of $116 million). However, when the industry's indirect (supply-chain) and payroll-induced (upstream) effects are also taken into account, the rare earth industry generated a total[2] of $1.9 billion in output, 6,300 good jobs, and $422 million in annual salaries and wages.

The essentiality of rare earths to society and our economy is prodigious. The industry supplies basic rare earth materials that are used in a wide variety of engineered materials and components and systems. These downstream customer industries supply products that are used in many other industries and broader sectors of the economy, including health care, clean energy, automotive, and electronics among others. Rare earth elements support $329.6 billion in downstream economic activity, which in turn employs 619,000 people with a payroll of $37.6 billion. ACC's analysis presented here in this report illustrates the extensive role and support that rare earth products have provided and can continue to provide to the broader economy.

[2] The "total" represents the sum of direct, indirect (supply-chain), and payroll-induced (upstream) effects.

Rare Earth Technology Alliance

The Rare Earth Technology Alliance, or RETA, is an international organization representing a wide coalition of organizations that produce, use, and study rare earths. RETA members include producers, processors, and original equipment manufacturers that utilize rare earths in their products and technologies, as well as academic and research leaders who study rare earths and help develop new applications for them.

RETA's members are:

Arnold Magnetic Technologies
Avalon Rare Metals
Colorado School of Mines
Ford Motor Company
General Electric
Global Tungsten & Powders
Iowa State University
Knowles
Molycorp
Montana Tech
Rare Element Resources
ReNew Rare Earth Inc.
Solvay
W.R. Grace

RETA is the only rare earth association whose mission is to provide all stakeholders -- the media, policymakers, regulators, manufacturers and users of rare earth technologies around the world -- with comprehensive, science-based information about rare earths and their associated technologies. Members include leaders from across the globe interested in working together to use their experience and expertise in support of a growing, strong, and viable rare earth sector.

Economics & Statistics Department

The Economics & Statistics Department provides a full range of statistical and economic advice and services for ACC and its members and other partners. The group works to improve overall ACC advocacy impact by providing statistics on American Chemistry as well as preparing information about the economic value and contributions of American Chemistry to our economy and society. They function as an in-house consultant, providing survey, economic analysis and other statistical expertise, as well as monitoring business conditions and changing industry dynamics. The group also offers extensive industry knowledge, a network of leading academic organizations and think tanks, and a dedication to making analysis relevant and comprehensible to a wide audience. The lead author of this report was Dr. Thomas Kevin Swift.

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