

RARE EARTH MARKET OUTLOOK: SUPPLY, DEMAND, AND PRICING FROM 2016 THROUGH 2025

Adamas Intelligence: Critical Metals and Minerals Research

Following a lengthy, and at times painful, period of adjustment since the boom and bust of the rare earth market in 2011, the future will be marked by strong global demand growth for a number of rare earth elements, including neodymium, praseodymium, dysprosium, and lanthanum, and consequently, will see prices of most rare earth products return to levels that sustain the profitability and growth of today's dominant producers, and incentivize continued investment in exploration and resource development globally.

In this report, we analyze the rare earth market from 2005 through 2015, estimating production, consumption, prices, and the value of regional and global markets in each year. We provide a breakdown of REO consumption per end-use for over 200 individual end-uses and applications, and reveal insightful trends about the trajectory of the rare earth market.

With valuable hindsight in tow, we forecast supply, demand, prices, and the value of regional and global markets for each year from 2016 through 2025. We provide a detailed breakdown of forecasted REO demand per unit and per end-use for more than 200 individual end-uses and applications, and analyze three distinct future scenarios to forecast REO prices under different supply and demand conditions.

Essential reading for:

- Informed investors and financiers
- Technology, material, and chemical developers
- Exploration and mineral development companies
- Government agencies and advisory boards
- NGOs and global think-tanks
- Research organizations
- Advisory firms

Lead Analyst:

Ryan Castilloux
Founding Director / Industry Analyst

rcastilloux@adamasintel.com
+1 347-708-0054

www.adamasintel.com

Disclaimer and User License Agreement

This report and its contents are copyright and confidential. This report is not for public distribution and shall not be reproduced or redistributed in part or whole without prior permission from Adamas Intelligence. This report is for private internal use of the person or company that licenses it and may not be shared, co-licensed, or distributed among consortiums or multi-company organizations. Apart from any use as permitted by law, all rights pertaining to this publication are reserved by Adamas Intelligence and associated copyrights are strictly and legally enforced. This report is watermarked with the licensee's name, company, and e-mail address to help Adamas Intelligence protect and enforce its copyrights.

This report is provided for information purposes only. It is not a complete survey of every material fact respecting any company, project, resource, reserve, mine, market, end-use, application, or nation. This report has been prepared in good faith on the basis of information available up to 30 days prior to the date of publication without independent verification, unless specified otherwise.

The information provided in this report is from primary research, secondary research, and other sources, which we believe to be reliable. Efforts have been made to try and ensure the accuracy of the data and information contained in this report, however, Adamas Intelligence does not guarantee or warrant the accuracy, reliability, completeness, or currency of the information in this report. Readers are responsible for assessing the relevance and accuracy of the contents of this publication. Adamas Intelligence will not be liable for any loss, damage, cost, or expense incurred or arising by any reason of any person or business using or relying on information, forecasts, estimates, or opinions stated in this publication. Companies, exploration projects, mines, or other facilities may be identified by proprietary or trade names herein to help readers identify particular companies, projects, mines, or facilities but this is not, and is not intended to be, an endorsement or recommendation of the project, mine, facility, or company referred to, unless explicitly stated.

This report contains "forward-looking statements" – that is, statements related to future events. In this report, forward-looking statements address our expectations of future rare earth production, supply, demand, consumption, and pricing within parameters defined by stated scenarios, and often contain words such as "forecast", "project", "expect," "anticipate," "intend," "plan," "believe," "seek," "see," or "will." Forward-looking statements by their nature address matters that are, to different degrees, uncertain. A number of future uncertainties exist that could cause actual results to be materially different than those expressed in our forward-looking statements. Readers are responsible for assessing the relevance and accuracy of these forward-looking statements. Adamas Intelligence will not be liable for any loss, damage, cost, or expense incurred or arising by any reason of any person or business using or relying on forward-looking statements in this report.

This report also includes analyses and opinions expressed by the author and Adamas Intelligence. The analyses, opinions, and forward-looking statements expressed are current as of the date of this report's publication and may be subject to change without notice. Readers should not solely rely on the information contained in this report and must make investment and/or business decisions based on their own objectives, risk profiles, and financial positions. At the time of this report's publication, neither the author nor any other employees of Adamas Intelligence owned shares or stock options in any of the publicly-traded companies mentioned herein.

Terminology & Abbreviations

Abbreviation	Terminology	Definition
REE	Rare Earth Element	The lanthanide series of chemical elements, plus yttrium
REO(s)	Rare Earth Oxide(s)	Chemical oxides of lanthanides and/or yttrium
TREO	Total Rare Earth Oxide	The collective group of all rare earth oxides combined
LREO(s)	Light Rare Earth Oxide(s)	La ₂ O ₃ , CeO ₂ , Pr ₆ O ₁₁ , Nd ₂ O ₃ , Sm ₂ O ₃ , Eu ₂ O ₃ , Gd ₂ O ₃
HREO(s)	Heavy Rare Earth Oxide(s)	Tb ₄ O ₇ , Dy ₂ O ₃ , Ho ₂ O ₃ , Er ₂ O ₃ , Lu ₂ O ₃ , Yb ₂ O ₃ , Tm ₂ O ₃ , Y ₂ O ₃
neo-CREO(s)	New Critical Rare Earth Oxide(s)	La ₂ O ₃ , Nd ₂ O ₃ , Pr ₆ O ₁₁ , Dy ₂ O ₃ , Tb ₄ O ₇ (see page 24 for more information)
mag-REO(s)	Magnet Rare Earth Oxide(s)	Nd ₂ O ₃ , Pr ₆ O ₁₁ , Dy ₂ O ₃ , Tb ₄ O ₇ (see page 24 for more information)
add-REO(s)	Additive Rare Earth Oxide(s)	Gd ₂ O ₃ , Tb ₄ O ₇ , Dy ₂ O ₃ , Ho ₂ O ₃ (see page 24 for more information)
Mineral Resource	Mineral Resource	Concentration of mineralized material of economic interest for which there is a reasonable prospect that it could eventually be viably extracted
Mineral Reserve	Mineral Reserve (a.k.a. Ore Reserve)	Economically mineable part of mineral resource as demonstrated by a PFS or FS
Grade	Grade	Concentration (weight percent) of a material of economic interest in its host
NI 43-101	National Instrument for the Standards of Disclosure for Mineral Projects in Canada	Rules and guidelines for reporting information related to mineral properties owned by, or explored by, companies which report these results on stock exchanges within Canada; derived from Canada Securities Authorities
JORC Code	The Australasian Joint Ore Reserves Committee Code	Code for reporting the status of a mineral resource owned by companies that trade on the ASX; derived from an independent mineral industry body
SAMREC Code	South African Mineral Committee Code	Minimum standards, recommendations, and guidelines for the public reporting of exploration results, mineral resources, and mineral reserves
Relative Distribution	Relative Distribution	Relative concentration of an individual REO versus the concentration of all REOs combined; expressed as a percentage of TREO
MLR	China's Ministry of Land and Resources	Government authority responsible for issuing semi-annual REO production quotas in China
MOF	China's Ministry of Finance	Government authority overseeing tax and tariff-related matters of China's REO industry
MOFCOM	China's Ministry of Commerce	Government authority overseeing tax and tariff-related matters of China's REO industry, as well as issuance of rare earth export licenses
GAC	China's General Administration of Customs	Government authority responsible for collection of taxes, customs duties, excise duties and other indirect taxes
MIIT	China's Ministry of Industry and Information Technology	Government authority overseeing industry and information technology sectors, and responsible for promoting the national knowledge economy
FOB	Free on Board	Indicates that the seller pays for transportation of the goods to the port from which it will be shipped, plus pays any loading costs
PEA	Preliminary Economic Assessment	Technical study that evaluates a project's economic potential following a Mineral Resource estimate
PFS	Preliminary Feasibility Study	Due diligence study to determine the viability of proceeding with development of a project
DFS	Definitive Feasibility Study	Final technical study to determine whether or not to proceed with development of a project
BFS	Bankable Feasibility Study	Includes a DFS complete with offtake agreements from prospective customers

Main Table of Contents

Disclaimer and User License Agreement.....	2
Terminology & Abbreviations.....	3
Main Table of Contents.....	4
Executive Summary	6
Chapter 1: Background.....	8
Chapter 2: Mineral Occurrences, Resources, and Reserves Globally	14
Chapter 3: Exploration and Project Development.....	21
Chapter 4: World Rare Earth Mine Production from 1960 through 2015	40
Chapter 5: World Mine Production per Company	65
Chapter 6: Separation of Rare Earths by Country and Company	79
Chapter 7: Illegal and Undocumented Mining and Processing	88
Chapter 8: Recycling and Recovery of Rare Earths from Tailings.....	97
Chapter 9: Global TREO Consumption by Oxide Since 2005	103
Chapter 10: Global TREO Consumption by End-Use Since 2005	107
Chapter 11: Global TREO Consumption by Region Since 2005	135
Chapter 12: International Trade, Policy, and Prices Since 2005.....	145
Chapter 13: Value of the Global TREO Consumption Since 2005	162
Chapter 14: Forecasted Demand by REO from 2016 through 2025.....	176
Chapter 15: Forecasted REO Demand for Battery Alloys	198
Chapter 16: Forecasted REO Demand for Catalysts	215
Chapter 17: Forecasted REO Demand for Ceramics, Pigments, and Glazes	227
Chapter 18: Forecasted REO Demand for Glass Polishing Powders and Additives.....	246
Chapter 19: Forecasted REO Demand for Metallurgy and Alloys.....	256
Chapter 20: Forecasted REO Demand for Permanent Magnets.....	269
Chapter 21: Forecasted REO Demand for Phosphors.....	359
Chapter 22: Forecasted REO Demand for Other End-Uses.....	384
Chapter 23: Forecasted REO Demand by Region.....	402

Chapter 24: Forecasted Global REO Production by Region (Scenario 1)	413
Chapter 25: Forecasted Global REO Production by Region (Scenario 2).....	427
Chapter 26: Forecasted Global REO Production by Region (Scenario 3).....	441
Chapter 27: Forecasted Production-Demand Balance (Scenario 1)	455
Chapter 28: Forecasted Production-Demand Balance (Scenario 2)	473
Chapter 29: Forecasted Production-Demand Balance (Scenario 3)	491
Chapter 30: Forecasted REO Prices (Scenario 1).....	509
Chapter 31: Forecasted REO Prices (Scenario 2)	528
Chapter 32: Forecasted REO Prices (Scenario 3).....	547
Chapter 33: Forecasted Value of Global REO Demand (Scenario 1).....	566
Chapter 34: Forecasted Value of Global REO Demand (Scenario 2).....	580
Chapter 35: Forecasted Value of Global REO Demand (Scenario 3)	594
Chapter 36: Rare Earth Market Outlook.....	608
Appendices: 2005 through 2025.....	616
References	816

Executive Summary

Since the rare earth price spike of mid-2011, the market has endured a wealth of demand destruction. Over the past five years a significant amount of TREO demand, upwards of 30,000 tonnes per annum, has been lost on account of end-users' growing concerns over supply security, and a comparably significant amount of TREO demand, upwards of 20,000 tonnes per annum, has been lost as a result of the ongoing organic phase out of several mature technologies, such as fluorescent lamps, NiMH batteries, and HDDs, for example.

Looking back over the past five years, one can almost be forgiven for thinking that the global rare earth industry is on a terminal course. But, one can open this report to almost any page and see that this is simply not the case. Following a lengthy, and at times painful, period of adjustment since the boom and bust of the rare earth market in 2011, the future will be marked by strong global demand growth for a number of rare earth elements, such as neodymium, praseodymium, dysprosium, and lanthanum, and consequently, will see prices of most rare earth products return to levels that sustain the profitability and growth of today's dominant producers, and incentivize continued investment in exploration and resource development globally.

The outlook for rare earth demand from 2020 through 2025, and beyond, is exceptionally promising. This period reveals that for many of today's most highly publicized rare earth end-uses, such as electric vehicles, wind turbines, and many others, the rate of annual demand growth is poised to accelerate between 2020 and 2025, steering global rare earth demand to unfathomable new heights in the years thereafter.

In this report, we analyze the rare earth market from 2005 through 2015, estimating production, consumption, prices, and the value of regional and global markets in each year. We provide a breakdown of REO consumption per end-use for over 200 individual end-uses and applications, and reveal insightful trends about the trajectory of the rare earth market.

With valuable hindsight in tow, we forecast supply, demand, prices, and the value of regional and global markets for each year from 2016 through 2025. We provide a detailed breakdown of forecasted REO demand per unit and per end-use for more than 200 individual end-uses and applications, and analyze three distinct future scenarios to forecast REO prices under different supply and demand conditions.

This report builds on twelve months of primary research, including personal communication with hundreds of topical experts and rare earth industry stakeholders, and contains a wealth of current data and information covering all facets of the global rare earth industry.

Among the high-level findings of the report:

Government-led initiatives will fuel over half of all new demand growth through 2025

Global rare earth demand has become inextricably and inadvertently linked to government policies, regulations, mandates, and initiatives concerning electric mobility, clean power generation, energy efficiency, greenhouse gas emissions, urbanization, and industry modernization. Looking ahead, we forecast that over 50% of all new global rare earth demand growth over the coming ten years will be directly or indirectly driven by government-led actions.

China will become a net importer of certain rare earths by 2025

As China's insatiable demand for rare earth elements continues to grow over the coming ten years, China's domestic production will struggle to keep up in all scenarios examined herein, leading the nation to become a net importer of certain rare earths at the expense of the rest of the world's supply security. In fact, by 2025 China's domestic demand for neodymium oxide for permanent magnets alone is poised to exceed total global production of neodymium oxide by 9,000 tonnes in our base case scenario, highlighting the imminent need for additional sources of supply.

The market calls for development of a new mine every year by 2025

From 2016 through 2020 demand for neodymium, praseodymium, dysprosium, and lanthanum will grow relatively strongly, but, from 2020 through 2025 the rate of global demand growth for these rare earths will accelerate year-over-year, resulting in major annual demand increases by 2025 that can only be satisfied by the continuous and accelerated development of new mines.

In-lieu of conventional sources of capital, China will become a major investor in development of foreign rare earth resources

As the supply and demand sides of the global rare earth market continue to evolve on dichotomous paths, and China comes to terms with the fact that domestic demand will soon outgrow domestic production, we believe China's investments in development of foreign rare earth resources will rapidly accelerate should conventional sources of capital continue to ignore the rare earth industry. Evidence of this likely outcome is already emerging.