Center for Strategic and International Studies
Rare Earth Elements: Geology, Geography, and Geopolitics

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History – The Discovery

- The rare earths were discovered in 1787 by Swedish Army Lieutenant Carl Axel Arrhenius.
- Carl, an amateur mineralogist collected the black mineral ytterbite, later renamed gadolinite, from a small feldspar and quartz mine at Ytterby, Sweden.
- With similar chemical structures the rare earths proved difficult to separate.
- It was not until 1794 that Finnish chemist Johann Gadolin separated the first impure yttrium oxide from the mineral ytterbite.
History – The Discovery

The rare earths perplex us in our researches, baffle us in our speculations, and haunt us in our very dreams. They stretch like an unknown sea before us, mocking, mystifying, and murmuring strange revelations and possibilities.

Sir William Crookes, 1902

In point of respectability your radium family will be a Sunday school compared with the rare earth elements, whose chemical behavior is simply outrageous. It is absolutely demoralizing to have anything to do with them.

Bertram Boltwood, 1905
History – The Commercialization

- The rare earths were commercialized when the incandescent lamp mantle industry was established in 1884 with mantles of zirconium, lanthanum, and yttrium oxides with later improvements requiring only the oxides of thorium and cerium.
- The lamp mantle was discovered by Baron Carl Auer von Welsbach
- The mantles also used small amounts of neodymium and praseodymium as an indelible brand name Welsbach label
History – The Early Mining

- Rare earths were first produced commercially in the 1880s with the mining in Sweden and Norway of the rare-earth thorium phosphate mineral monazite

- Foreign Production
  - Brazil produced monazite as early as 1887
  - India produced monazite starting in 1911

- Domestic Production
  - Monazite production in the United States was first recorded in 1893 in North Carolina - a small tonnage of monazite was reportedly mined in 1887
  - Monazite mining in South Carolina began in 1903
History – The Processing

- Three main methods for separating and refining the rare-earth elements since they were discovered
  - Fractional Crystallization
    - Time consuming
    - Thousands of steps to separate and refine
  - Ion-Exchange (IX)
    - Less expensive in the short term
    - High continuous cost for ion exchange resin beads
  - Liquid-Liquid Extraction or Solvent Extraction (SX)
    - High cost in the short term to build a SX plant
    - Lowest cost in the long term to operate
History – Metal Production

- An impure cerium metal powder was prepared by Carl Gustav Mosander in 1827 from cerium chloride with potassium in a hydrogen atmosphere
- Beringer in 1842, Marginac in 1853, and Wöhler in 1867 used different methods to prepare cerium metal by reducing cerium chloride using sodium
- In 1875, Hillebrand and Norton prepared the first fairly pure cerium, lanthanum, and didymium metals by electrolytic reduction
- In 1903, Auer von Welsbach prepared mischmetal (natural rare-earth mixed alloy) for commercial use in lighter flints
- The last RE metal to be produced was promethium in 1931
History – REE Production Trends by Gordon Haxel, Greta Orris, and James Hedrick, updated by Hedrick
History – U.S. Source of Supply 2008

by James Hedrick and Robert Callaghan
History – Significant Events in REE
(1 of 3)

- 1787 Discovery of rare earths in the mineral ytterbite (gadolinite) collected at Ytterby, Sweden, by Lt. Carl Axel Arrhenius
- 1794 Discovery of impure rare earth oxide, yttrium, by mineralogist Johann Gadolin
- 1827 Discovery of the first metallic rare earth by Carl Gustav Mosander
- 1884 Discovery of commercial application, the lamp mantle, by Carl Auer von Welsbach
History – Significant Events in REE
(2 of 3)

- 1885 (18 Sep) Patenting of the incandescent mantle containing 60% Magnesium oxide, 20% Lanthanum oxide and 20% Yttrium oxide
- 1885 Magnesium replaced in the incandescent lamp mantle with Zirconium oxide
- 1891 Patenting of the incandescent mantle with 99% Thorium oxide and 1% Cerium oxide
- 1903 Patenting of the first pyrophoric alloy for lighter flints
- 1947 Discovery of ion exchange (IX) separation by Frank H. Spedding and others
History – Significant Events in REE

(3 of 3)

- 1953 Development of solvent exchange (SX) separation process by D. Peppard and others
- 1949 Discovery of the Mountain Pass deposit
- 1951 Mountain Pass deposit begins production
- 1964 Color TV’s get red color phosphor - europium
- 1985 China begins large-scale production
- 2002 Molycorp closes mine at Mountain Pass, CA
- 2010 Chinese use rare-earth embargo as “gunboat diplomacy” political leverage
Outlook – Mines and Processors

(Mine production in the near term)

- Molycorp Mining LLC, Mountain Pass, San Bernardino County, California, USA
- Lynas Corporation Ltd., Mount Weld, Western Australia, Australia
- Rare Element Resources, Bear Lodge deposit, Crook County, Wyoming, USA
- Arafura Resources Limited, Nolans Bore, Northern Territories, Australia
- Wings Enterprises, County, Pea Ridge Mine, Washington County, Missouri, USA
- Great Western Minerals Group & Rare Earth Extraction Co. Ltd., Steenkampskraal, Western Cape Province, South Africa
Outlook – REE Deposits for the Future
(Mine producers in the longer term)

- U.S. Rare Earths, Inc.
  - Lemhi Pass, ID and MT, USA
  - Diamond Creek, ID, USA
  - North Fork, ID, USA
  - Sheep Creek, MT, USA
- Ucore Rare Metals Inc., Bokan Mountain, Alaska, USA
- Avalon Rare Metals Inc., Nechalacho, Northwest Territories, Canada
- Aurizon Mines Ltd, Kipawa deposit, Quebec, Canada
- Rare Earth Metals, Inc., Red Wine deposit, Labrador, Canada
- Great Western Minerals, Hoidas Lake, Saskatchewan, Canada
- Quest Uranium Corp., Strange Lake, Quebec, Canada
Outlook – REE in the Short Term

- China will control the rare-earth market supply
- China plans to continue to reduce REE exports
- U.S. supply will continue to come mostly from China
- Molycorp will produce modest amounts of REE concentrates and compounds from its stockpile of bastnäsite concentrates until the mine restarts
- The lack of a U.S. stockpile is expected to cause significant supply disruptions by 2012
- Even if new mines come online, it will take one year to build a SX plant and another year to get product
- China is likely to cut off REE supply at any time, it should be recognized as an unreliable and fragile source
Outlook – REE in the Long Term

- Over the last century the use of rare earths has grown from hundreds of tons in 1900 to tens of thousands of tons in 2000.
- Over the past decade the use of rare earths has grown from around 80,000 tons to 130,000 tons.
- Growth in the long term is expected to continue to be substantial as new applications and discoveries are made.
- Based on the last century’s growth in demand, a straight line forecast is 12.8 million tons by 2100.
- Modest amounts are expected to be recycled as costs increase.
- A few rare-earth applications will be substituted, most will not.
- Demand for rare earths is expected to continue to grow and new applications are expected to be developed.
The End

- Rare Earths – The Future of a Free America