NETL Life Cycle Inventory Data
Process Documentation File

Process Name: Rare Earth Oxide Electrolysis

Reference Flow: 1 kg of rare earth metal

Brief Description: Electrolysis of a rare earth oxide using a fluoride-based process.

Section I: Meta Data

Geographical Coverage: United States **Region:** Click here to enter text.

Year Data Best Represents: 2013-2016

Process Type: Manufacturing Process (MP)

Process Scope: Gate-to-Gate Process (GG)

Allocation Applied: No

Completeness: All Relevant Flows Captured

Flows Aggregated in Data Set:

☑ Process ☑ Energy Use ☐ Energy P&D ☐ Material P&D

Relevant Output Flows Included in Data Set:

Releases to Air:	☑ Greenhouse Gases	☐ Criteria Air	☑ Other
Releases to Water:	☐ Inorganic	☐ Organic Emissions	☐ Other
Water Usage:	☐ Water Consumption	☐ Water Demand (throughput)	
Releases to Soil:	☐ Inorganic Releases	☐ Organic Releases	☐ Other

Adjustable Process Parameters:

electricity	*[kWh/kg] kWh electricity per kg of rare earth*
Ce	*[binary] Parameter to select cerium metal as the output*
La	*[binary] Parameter to select lanthanum metal as the output*
Pr	*[binary] Parameter to select praseodymium metal as the output*

Nd	*[binary] Parameter to select neodymium metal as the output*
Sm	*[binary] Parameter to select samarium metal as the output*
Eu	*[binary] Parameter to select europium metal as the output*
Gd	*[binary] Parameter to select gadolinium metal as the output*
Tb	*[binary] Parameter to select terbium metal as the output*
Dy	*[binary] Parameter to select dysprosium metal as the output*
Ho	*[binary] Parameter to select holmium metal as the output*
Er	*[binary] Parameter to select erbium metal as the output*
Tm	*[binary] Parameter to select thulium metal as the output*
Yb	*[binary] Parameter to select ytterbium metal as the output*
Lu	*[binary] Parameter to select lutetium metal as the output*
Y	*[binary] Parameter to select yttrium metal as the output*
yield	*[kg/kg] kg of rare earth metal output per kg of elemental rare earth input*

Tracked Input Flows:

Electricity	*[Technosphere] Electricity*
Rare Earth Oxide	*[Technosphere] Rare earth oxide*
Lithium Fluoride	*[Technosphere] Lithium fluoride*
Lime	*[Technosphere] Lime*
Graphite Anodes	*[Technosphere] Graphite anodes*

Tracked Output Flows:

Rare Earth Metal	*Emission to Air*
Carbon dioxide [Inorganic emissions to air]	*Emission to Air*
Hydrogen Fluoride [Inorganic emissions to air]	*Emission to Air*
Rare Earth Dust [Particles to air]	*Emission to Air*
CaF2 [Waste for disposal]	*Solid Waste*
CaSO4 [Waste for disposal]	*Solid Waste*
Rare Earth Oxide [Waste for disposal]	*Solid Waste*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage1_O_reo_electrolysis_2014.01.xlsx*, which provides additional details regarding relevant calculations, data quality, and references.

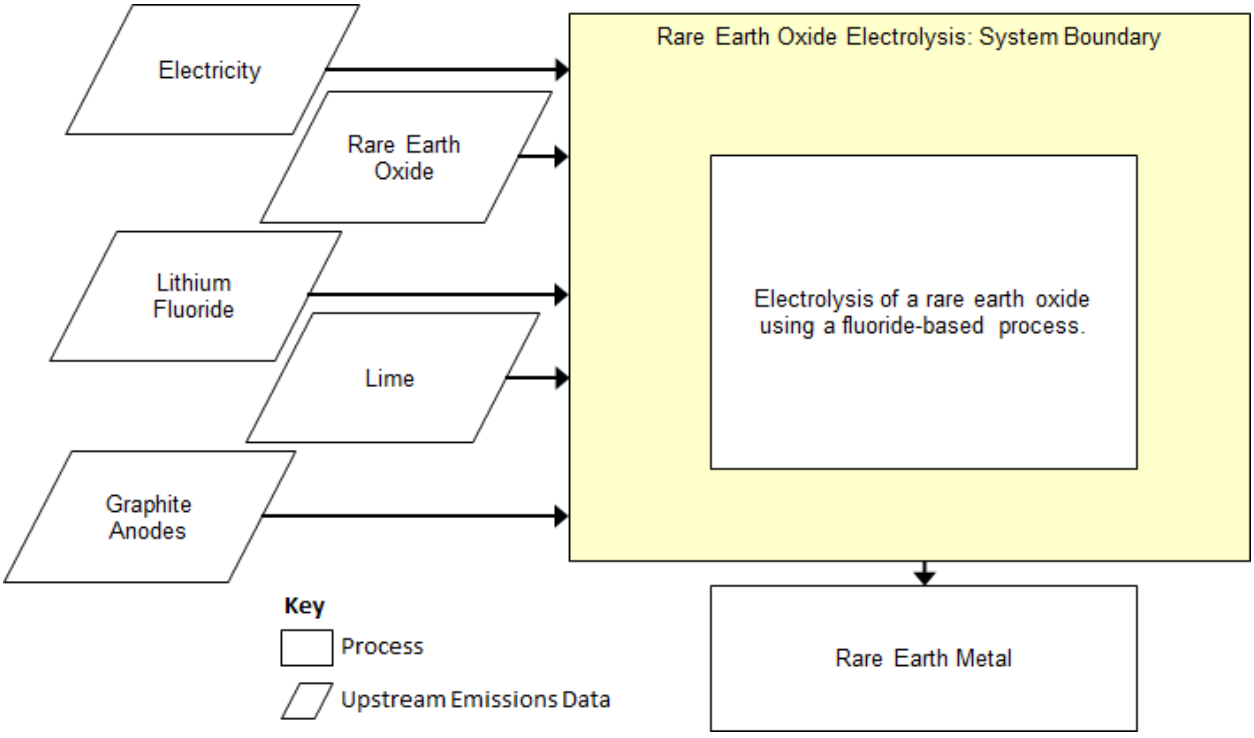
Goal and Scope

This unit process provides a summary of relevant input and output flows associated with electrolytic reduction of a rare earth oxide to rare earth metal. The process takes place in an electrolytic chamber with disposable graphite anodes. The process also accounts for air emissions and solid waste incurred during the electrolysis process. The reference flow of this unit process is: 1 kg of rare earth metal.

Boundary and Description

Figure 1 provides an overview of the boundary of this unit process.

Figure 1: Unit Process Scope and Boundary



This unit process covers rare earth metals produced commercially by the electrolytic reduction of the oxide from a fluoride electrolyte. This process is modeled after the Chinese method which utilizes cells to reduce the oxide and use consumable graphite anodes and inert Molybdenum (Mo) or Tungsten (W) cathode (Lynas Services Pty Ltd., 2013). The metal forming on the cathode drops to an internal Mo receiving dish which is periodically removed from the cell for casting into ingot (Lynas Services Pty Ltd., 2013). The material inputs and air release and waste outputs estimated in the unit process are based on an Environmental Effects Report for a Lyans Services 100 ton per year Didymium Plant (Lynas Services Pty Ltd., 2013). While the Lynas process only shows conversion of didymium (a mix of praseodymium and neodymium), it is assumed that conversion of any other rare earth oxide to metal will result in similar energy and material usage. In addition to the general electrolytic method described above, Lynas has added additional design aspects to improve efficiency and meet safety and environmental regulations, in particular a wet scrubber system to reduce rare earth oxide dust and hydrogen fluoride emissions (Lynas Services Pty Ltd., 2013).

The default value for process yield was calculated using the Lynas process and is based on the amount of rare earth oxide feed and metal yield for their process and the mix of praseodymium and neodymium from the Mountain Pass site, approximately 27% and 73% respectively (Lynas Services Pty Ltd., 2013; Gupta and Krishnamurthy, 2005).

Electricity consumption values were generated using Lynas' plant estimates as a lower bound, with industry values cited in literature as an upper bound (Lynas Services Pty Ltd., 2013;Piero and Mendez, 2013). **Table 1** details the input and output flows for the process.

Table 1: Unit Process Input and Output Flows

Flow Name	Ce	La	Pr	Nd	Sm	Eu	Units (Per Reference Flow)
Inputs							
Electricity	1.06E+01						kWh/kg
Rare Earth Oxide	1.30E-00	1.25E+00	1.28E+00	1.24E+00	1.23E+00	1.23E+00	kg/kg
Lithium Fluoride	1.00E-02						kg/kg
Lime	4.50E-02						kg/kg
Graphite Anodes	3.00E-01						kg/kg
Outputs							
Rare Earth Metal	1.00E-00						kg/kg
Carbon dioxide [Inorganic emissions to air]	1.10E-00						kg/kg
Hydrogen Fluoride [Inorganic emissions to air]	7.00E-03						kg/kg
Rare Earth Dust [Particles to air]	5.00E-03						kg/kg
CaF2 [Waste for disposal]	4.50E-02						kg/kg
CaSO4 [Waste for disposal]	6.00E-03						kg/kg
Rare Earth Oxide [Waste for disposal]	4.50E-02						kg/kg

Flow Name	Gd	Tb	Dy	Ho	Er	Tm	Units (Per Reference Flow)
Inputs							
Electricity	8.00E-00						kWh/kg
Rare Earth Oxide	1.22E+00	1.25E+00	1.22E+00	1.22E+00	1.21E+00	1.21E+00	kg/kg
Lithium Fluoride	1.00E-02						kg/kg
Lime	4.50E-02						kg/kg
Graphite Anodes	3.00E-01						kg/kg
Outputs							
Rare Earth Metal	1.00E-00						kg/kg
Carbon dioxide [Inorganic emissions to air]	1.10E-00						kg/kg
Hydrogen Fluoride [Inorganic emissions to air]	7.00E-03						kg/kg
Rare Earth Dust [Particles to air]	5.00E-03						kg/kg
CaF2 [Waste for disposal]	4.50E-02						kg/kg
CaSO4 [Waste for disposal]	6.00E-03						kg/kg
Rare Earth Oxide [Waste for disposal]	4.50E-02						kg/kg

Flow Name	Yb	Lu	Y	Units (Per Reference Flow)
Inputs				
Electricity	8.00E-00			kWh/kg
Rare Earth Oxide	1.21E+00	1.21E+00	1.35E+00	kg/kg
Lithium Fluoride	1.00E-02			kg/kg
Lime	4.50E-02			kg/kg
Graphite Anodes	3.00E-01			kg/kg
Outputs				
Rare Earth Metal	1.00E-00			kg/kg
Carbon dioxide [Inorganic emissions to air]	1.10E-00			kg/kg
Hydrogen Fluoride [Inorganic emissions to air]	7.00E-03			kg/kg
Rare Earth Dust [Particles to air]	5.00E-03			kg/kg
CaF2 [Waste for disposal]	4.50E-02			kg/kg
CaSO4 [Waste for disposal]	6.00E-03			kg/kg
Rare Earth Oxide [Waste for disposal]	4.50E-02			kg/kg

* **Bold face** clarifies that the value shown *does not* include upstream environmental flows.

Embedded Unit Processes

None.

References

Lynas Services Pty Ltd., 2013	Lynas Services Pty Ltd, 2013. *Environmental Effects Report for Didymium Pilot Plant* http://epa.tas.gov.au/regulation/lynas-corporation,-pilot-plant,-bell-bay#eer (Accessed 29 May 2014)
Piero and Mendez, 2013	Piero, Laura and Menendez, Gara *Material and Energy Requirement for Rare Earth Production*. Journal of The Minerals, Metals & Materials Society Vol 65 No 10 pp 1327 - 1340 10 October, 2013
Gupta and Krishnamurthy, 2005	Gupta, C.K. and Krishnamurthy, N. (2005). Extractive Metallurgy of Rare Earths. Boca Raton, FL: CRC Press.

Section III: Document Control Information

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