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Monazite Ore Processing for Rare Earth Oxides and Thorium Extraction — Part I

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Glossary

Aq	Aqueous
BFW	Boiler feedwater
bhp	Brake horsepower
BLI	Battery limits investment
°C	Degrees Celsius
capex	Capital expenditure
cfm	Cubic feet per minute
¢/kWh	Cents per kilowatt-hour
¢/lb	Cents per pound
CLD	Central Lanthanide Deposit
cm	Centimeters
¢/Mgal	Cents per thousand gallons
Conc.	Concentrated
$/h	Dollars per hour
$/Mgal	Dollars per thousand gallons
$/Mlb	Dollars per thousand pounds
$/t	Dollars per metric ton
EPC	Engineering, procurement and construction
ETP	Effluent treatment plant
°F	Degrees Fahrenheit
FCC	Fluid catalytic cracker
FOB	Free/freight on board
ft	Feet
G&A	General and administrative
gal	Gallons
gal/lb	Gallons per pound
gpm	Gallons per minute
HEV	Hybrid electric vehicle
hp	Horsepower
HREE	Heavy rare-earth element
HVAC	Heating, ventilation and air conditioning
IUPAC	International Union of Pure and Applied Chemistry
kg	Kilograms
kg/h	Kilograms per hour
kPa	Kilopascals
kW	Kilowatt
kWh	Kilowatt-hour
lb	Pounds
lb/h	Pounds per hour
lb/lb	Pounds per pound
LPS	Low-pressure steam
LREE	Light rare-earth element
µ	Microns
m	Meters
Mlb/h	Thousand pounds per hour
MMBtu/h	Million British thermal units per hour
MMlb/y	Million pounds per year
MREE	Medium rare-earth element
Mt/Mt	Thousand metric tons per thousand metric tons
N	Normality
opex	Operating expenditure
Org	Organic
OSBL	Outside battery limits
PEP	Process Economics Program
PFD	Process flow diagram

Ppt	Precipitate
psia	Pounds per square inch absolute
psig	Pounds per square inch gauge
RE	Rare earth
$RECl_3$	Rare-earth chloride(s)
REE	Rare-earth element
REM	Rare-earth mineral
REO	Rare-earth oxide
$RE(OH)_3$	Rare-earth hydroxide
ROI	Return on investment
ROM	Run-of-mine
sq ft	Square feet
SS	Stainless steel
TBP	Tributyl phosphate
t/d	Metric tons per day
t/h	Metric tons per hour
t/t	Metric tons per metric ton
t/y	Metric tons per year
TFC	Total fixed capital
TREO	Total rare-earth oxide
USGC	US Gulf Coast
wt%	Weight percent
y	Years

Abstract

Advancements in green technologies, expansion of electronics and automotive industries, and thorium-based nuclear reactors are the primary driving factors promoting the significance of rare-earth minerals (REMs) and thorium (Th). The market for light rare-earth elements (LREEs), particularly neodymium (Nd) and praseodymium (Pr), is expected to expand significantly as attention turns to renewable energy sources. NdPr oxide is the primary raw material for permanent magnets (neodymium-iron-boron [NdFeB] magnets) in wind turbines and electric vehicles. Nearly 70%-80% of the total value of the rare-earth oxide (REO) sector is derived from the market for permanent magnets. Recently, thorium-based nuclear reactors have gained interest over conventional uranium nuclear reactors because of several key advantages, such as the abundance of thorium, higher fuel efficiency, reduction in nuclear waste, passive safety mechanisms, and low-cost enrichment process.

Monazite is a phosphate mineral, comprising mainly rare-earth elements (REEs) and thorium. Monazite occurs as an accessory mineral in acidic igneous rocks, metamorphic rocks, and certain vein deposits. The Asia-Pacific region dominates the global monazite market because of its significant monazite reserves and strong industrial growth, as well as its extensive mining and processing capabilities. Mainland China's dominance in the REE market drives the demand for monazite. However, rearranging the manufacturing chain globally would be crucial for the extraction of REEs and thorium from the monazite ore.

The production of REEs (in the form of chlorides) from monazite ore, belonging to the Mount Weld Central Lanthanide Deposit (CLD), Australia, is covered in Part I of this review. Part II will discuss the production of REOs (especially NdPr oxide as the main product, and lanthanum oxide and thorium oxide as coproducts) utilizing rare-earth chlorides ($RECl_3$) as an intermediate compound. To produce $RECl_3$ from monazite, the ore is crushed, ground, physically beneficiated, chemically beneficiated, and then crystallized. Part I of this analysis includes an economic evaluation for a mineral processing plant located at a US Gulf Coast location that can produce 43.98 million pounds per year [MMlb/y] (19,946.52 metric tons per year [t/y]) of $RECl_3$ from the CLD Australia monazite ore, comprising 6.44% of REO within it by weight. The technology presented here would be of great interest to industrial sectors and grassroots plants willing to use monazite ore metallurgical and extractive processing for REMs and thorium.

The process flow diagrams, material balance, major equipment list with specifications, cost information for battery limits, variable costs, capital expenditure (capex) and operating expenditure (opex), and total production costs are evaluated in this analysis. The technological and economic assessment of the process is the Process Economics Program (PEP)'s independent interpretation of a potential commercial process. Each of these is based on the information presented in the open literature, such as patents and technical articles, and may not reflect in whole or in part the actual plant configuration. We do, however, believe that these sources are sufficient to represent the process and process economics within the range of accuracy necessary for the economic evaluations of the conceptual process designs.

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