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Bastnäsite Ore Processing for Rare-earth Oxide Production — Part II

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Glossary

μ	Microns
BFW	Boiler feedwater
bhp	Brake horsepower
BLI	Battery limits investment
capex	Capital expenditure
CCS	Carbon capture and sequestration
¢/lb	Cents per pound
¢/kWh	Cents per kilowatt-hour
D	Distribution coefficient
DBBP	Dibutyl phenyl phosphate
DEHPA	Di(2-ethylhexyl) phosphoric acid
dia	Diameter
DIW	Deionized water
$/h	Dollars per hour
$/kg	Dollars per kilogram
$/Mgal	Dollars per thousand gallons
$/Mlb	Dollars per thousand pounds
EPC	Engineering procurement and construction
EHEHPA	2-Ethylhexyl phosphonic acid mono-2-ethylhexyl ester
ETP	Effluent treatment plant
EV	Electric vehicle
°F	Degree Fahrenheit
FCC	Fluid catalytic cracking
FOB	Freight/free on board
ft dia	Feet diameter
G&A	General and administrative
gal	Gallons
g/L	Grams per liter
gpm	Gallons per minute
HEHEHP	Phosphonic acid
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
kW	Kilowatts
kWh	Kilowatt-hour
kWh/lb	Kilowatt-hour per pound
lb	Pounds
lb/h	Pounds per hour
lb/lb	Pounds per pound
LIX 54	1-Phenyl-3-isoheptyl-1,3-propanedione
LPS	Low-pressure steam
LREE	Light rare-earth element
m	Meters
m^2	Square meter
m^3	Cubic meter
Mlb/h	Thousand pounds per hour
Mlb/lb	Thousand pounds per pound
MMBtu/h	Million British thermal units per hour
MMlb/y	Million pounds per year
MMt/y	Million metric tons per year
Mol. wt.	Molecular weight
MREE	Medium rare-earth element
Nd:YAG	Neodymium-doped yttrium aluminum garnet

[n]M	Molarity
OA	Oxalic acid
OSBL	Outside battery limits
opex	Operating expenditure
P229	Bis(2-ethylhexyl) phosphoric acid
P507	2,4,4-Trimethylpentyl phosphonic acid
PC88A	2-Ethylhexyl 2-ethylhexyphosphonic acid
PEP	Process Economics Program
PFD	Process flow diagram
psia	Pounds per square inch absolute
psig	Pounds per square inch gauge
R&D	Research and development
RE	Rare earth
$RECl_3$	Rare-earth chloride
REE	Rare-earth element
REF_3	Rare-earth fluoride
REM	Rare-earth mineral
REO	Rare-earth oxide
$RE(OH)_3$	Rare-earth hydroxide
ROI	Return on investment
ROM	Run-of-mine
SOFC	Solid oxide fuel cell
sq ft	Square feet
SS	Stainless steel
TBP	Tributyl phosphate
t/d	Metric tons per day
TFC	Total fixed capital
TOPO	Trioctylphosphine oxide
t/t	Metric tons per metric ton
t/y	Metric tons per year
USGC	US Gulf Coast
wt%	Weight percent
y	Year

Abstract

The main driving force behind the magnitude of rare-earth minerals (REMs) is green technologies. As the focus shifts toward renewable energy sources, the market for light rare-earth elements (LREEs), especially neodymium (Nd) and praseodymium (Pr), is anticipated to grow significantly since NdPr oxide is the primary raw material used to make permanent magnets (neodymium-iron-boron [NdFeB] magnets) for wind turbines and electric vehicles (EVs). The market for permanent magnets accounts for between 70% and 80% of the rare-earth oxide (REO) sector's total value.

The production of NdPr oxide from rare-earth chloride ($RECl_3$) is covered in this review, while Part I discussed the production of $RECl_3$ from run-of-mine (ROM) of the California-based Mountain Pass bastnäsite ore because mineral processing of bastnäsite ore to produce NdPr oxide is a complex multistep process. The production of NdPr oxide involves the solvent extraction step (in the order of samarium [Sm] > Nd > Pr > cerium [Ce] > lanthanum [La]) using 40% saponified 2-ethylhexyl 2-ethylhexyphosphonic acid (PC88A) in kerosene, followed by the precipitation of Sm, Nd, and Pr (in the form of oxalates) using oxalic acid, and then roasting to produce individual oxides and NdPr oxide. While precipitating with sodium bicarbonate ($NaHCO_3$) gives respective carbonates of cerium and lanthanum, further roasting produces individual oxides. This Part II of the analysis includes an economic evaluation for a mineral processing plant located at a US Gulf Coast location that can produce 1,358.76 metric tons per year (t/y) of NdPr oxide from $RECl_3$, which contains 16.4% of neodymium chloride ($NdCl_3$) and 3.35% of praseodymium chloride ($PrCl_3$) along with other $RECl_3$ (Ce, La, and Sm) by weight. The technology presented here would be of great interest to industrial sectors and grassroots plants willing to produce NdPr oxide for the renewable energy sector.

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 or technical articles, and may not reflect in whole or in part the actual plant configuration. We do 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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