Reagent supply challenges

to realizing US critical minerals production goals

by Chris Nyikos, Joshua Cowdrey, Rob Mellon, Ian McNicholes, Susan Steblay and Daniel Palo

Image from Shutterstock

Electronics and electric vehicles (EVs) are driving increased battery demand. To meet this demand, the production of batteries is growing apace, requiring increased input of the critical minerals necessary for their function. While much has been written about the scarcity of mines to produce the critical minerals, the supply crunch of reagents for the added processing involved to extract and refine these critical minerals is a potential hurdle that currently lies just below the surface. Reagent supply for critical minerals is on track to emerge both as a slate of challenges and as a window to new opportunities.

Demand for EV batteries in the United States grew 40 percent year on year to surpass 750 GWh in 2023.

According to the International Energy Agency's (IEA) Global EV Outlook 2024, the growth of the EV market is the greatest influencer on the increasing demand for critical minerals in the United States. The United States and Europe are now, for the first time, experiencing a faster growth in the EV market than China. The demand for EV batteries in the United States surpassed 750 GWh in 2023, an increase of 40 percent from 2022 demand. Benchmark Source, a research and analytics group, has projected global battery production will reach 1.4 TWh this year and expects the market to surpass 4 TWh by 2030.

The increased production of batteries requires more extraction and refining of the key metals necessary for their function, such as cobalt (Co), nickel (Ni), manganese (Mn) and lithium (Li). Meanwhile, the United States is seeking to "onshore" the production of key metals for the electric economy as a matter of national security. This has led to much analysis and many articles illustrating the sheer number of new mines that must be developed to meet domestic demand.

However, along with this production comes a demand for those reagents that make this production possible, such as acids, bases, lixiviants, flotation and flocculation reagents. This raises the question of reagent supply to meet what we in the mining industry hope is a rapidly expanding production capacity within the United States. In this article, we explore the increased demand for reagents necessary to support this production capacity and the potential supply-and-demand dynamics it may cause.

Chris Nyikos, SME member, is a senior mining engineer at Barr Engineering Co., Salt Lake City, UT; **Joshua Cowdrey** is a process engineer at Barr Engineering Co., Minneapolis, MN; **Rob Mellon**, SME member, is a senior process engineer at Barr Engineering Co., Denver, CO; **Ian McNicholes** is a chemical/environmental engineer at Barr Engineering Co., Duluth, MN; **Susan Steblay** is a senior processing engineer at Barr Engineering Co., Salt Lake City, UT; and **Daniel Palo**, SME member, is a vice president and senior process engineer at Barr Engineering Co., Salt Lake City, UT, email DPalo@barr.com.

Legislation

The U.S. government has made clear its desire to onshore and diversify critical minerals supply chains through key legislation, such as the Infrastructure Investment and Jobs Act, the Inflation Reduction Act, and various trade policies. The Biden administration's Inflation Reduction Act of 2022 provides financial incentives through tax credits ($12 billion for EV incentives), which can reduce capital expenses of U.S. cathode production by up to 30 percent, according to Benchmark Source. The United States has significant deposits of many critical minerals for batteries, but it accounts for only 2 percent of mined lithium and less than 1 percent of global production of mined cobalt and nickel. Manganese ore containing 20 percent or more manganese has not been produced domestically since 1970, and most of the domestic manganese supply is derived from imports.

These statistics underscore what most in the industry already know — the United States is facing a supply crunch for the minerals necessary to supply the 800 GWh of battery-cell manufacturing capacity anticipated to be in place by the end of 2030. The United States is blessed with mineral resources containing these metals; however, according to S&P Global, it takes an average of 29 years for a mine to go from discovery to production in the United States.

The Energy Permitting Reform Act of 2024 attempts to accelerate the permitting process for the domestic mining of critical minerals to close the supply gap. In addition, in 2024, the United States is increasing tariffs on China's lithium-ion (Li-ion) batteries and battery parts to 25 percent, up from 7.5 percent.

Recycling

Investment in U.S. battery recycling infrastructure is growing. The U.S. Department of Energy's consumer electronics Battery Recycling, Reprocessing, and Battery Collection Funding Opportunity provides $125 million for advanced battery recycling research and development. China currently controls 79 percent of the recycling feedstock, making it difficult for domestic recyclers to source materials; however, this is expected to change with the increase in EV penetration into the U.S. car market. For instance, Benchmark Source analysis predicts an increase in domestic Li-ion battery recycling from 140 kt (155,000 st) in 2023 to 209 kt (230,000 st) in 2024.

The metals and REEs

Cobalt. Benchmark Source forecasts the global demand for cobalt to reach 182 kt (200,000 st) in 2024 with EVs accounting for 78 percent of the 13 percent year-on-year growth. The pace of growth in battery demand is expected to surpass the mining capacity of cobalt, regardless of the current oversupply. The EV industry accounts for approximately 40 percent of global cobalt demand and this is expected to nearly double to 352 kt (388,000 st) by 2030.

Nickel. The demand for nickel is also driven by EV batteries and is expected to increase from 2 Mt (2.2 million st) to a range of 3.2 Mt to 3.6 Mt (3.5 to 4 million st) by 2030, according to McKinsey

& Co. The nickel supply is further complicated by the requirement of Class 1 nickel for battery manufacturing. Class 1 nickel has at least 99.8 percent purity, while Class 2 refers to materials such as nickel pig iron, mixed hydroxide precipitate, and nickel sulfate. While the alloy steel industry uses a mixture of Class 1 and Class 2 nickel, a battery's performance is intrinsically dependent on the purity of nickel. An estimated 46 percent of the global nickel production meets Class 1 requirements, but the sulfide deposits preferred for the production of Class 1 nickel are scarce.

Manganese. Almost half of today's Li-ion batteries contain manganese, and this share is expected to grow to above 60 percent by 2030. Global demand forecasts indicate that more high-purity manganese mines and processing plants are required than for any other battery metal. African nations dominate the production of manganese ore, followed by Australia. U.S. sources tend to be low grade relative to these sources, so if a commitment is made to produce manganese in the United States, it is likely the reagent usage per ton produced will be much higher comparatively.

Table 1

Projected metal demand growth — primary supply. (IEA, Announced Pledges Scenario)

Metal	Production (kt)			CAGR (percent)
	2023 actual	2030 forecast	Variance	
NdPr	67	98	31	5.6
Co	166	299	133	8.8
Mn	27	39	12	5.4
Ni	3,061	4,615	1,554	6.0
Li	160	502	342	17.7

Rare earth elements (REEs). In addition to battery metals, demand for the critical rare earth elements (REEs) neodymium (Nd) and praseodymium (Pr) to form the alloy NdPr, required for the high-strength permanent magnets found in EV motors and wind turbines, is expected to grow by about 44 percent from 2023 to 2030. Currently, there is only one NdPr mining and processing site in North America. Although

Table 2

Major reagents used in the processing of metals.

Reagent	Metals processed
Sulfuric acid	Co, Li, Mn, Ni
Hydrochloric acid	Li, NdPr
Caustic soda	Li, NdPr
Flotation reagents (Calgon, HEDP, KAX20, MIBC, PAX)	Co, Li, Mn, NdPr, Ni
Soda ash	NdPr
Sodium chloride	Li, NdPr
Sodium metabisulfite	Li

REEs are often discussed as a group, we have chosen to focus on NdPr as an illustration of a key REE pair, having vital importance in the market and a high degree of reagent usage in its production.

Co, Li, Mn, Ni and NdPr. The projected compound annual growth rate (CAGR) from 2023 to 2030 for demand for Co, Li, Mn, Ni and NdPr ranges from 5.4 percent for manganese to 17.7 percent for lithium (Table 1). This article focuses on these key metals to illustrate the reagent demand situation, but as the United States seeks to ramp up the production of other important metals like copper, other base metals, and rare earth metals, the same reagent demand issues are likely to be seen for them as well.

Reagent supply, prices and logistics

Part of the story of all this projected and hoped-for growth in the U.S. battery and critical metals market is the increased demand that it causes for key reagents. Reagents are used in multiple ways for mineral extraction and recovery, and the primary methods of mineral recovery are reagent intensive. In general, three broad applications are involved: (1) separation and collection of the metals during froth flotation, (2) acid leaching to separate the metals from the gangue minerals, and (3) precipitation of the metals from solution. The major reagents used in these processes are listed in Table 2.

With all the recent projects related to these metals, many developers have proprietary processes. The information presented and usage numbers in Table 1 are based on available, published information related to these metals and their processing, and are thus incomplete. Note also that the reagent usage described in this article does not account for the additional demand related to producing the final products — whether they be Li-ion batteries, permanent magnets or electric motors.

The costs for several of the higher-usage reagents when sourced in the United States are shown in Fig. 1. Prices for many of these key processing reagents have been relatively volatile in the last few years.

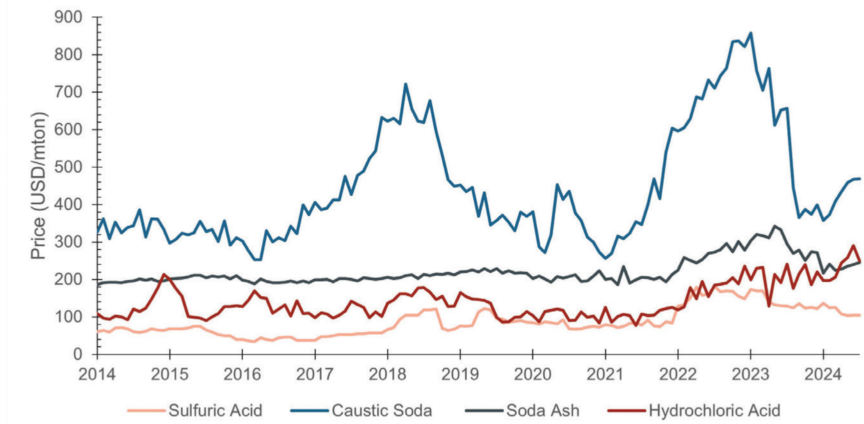
In our own work of conducting prefeasibility and feasibility studies for battery metals and critical materials projects, we are finding that some regional suppliers are unsure of their ability to source or deliver enough of some reagents for a given project, simply due to the demand intensity. This is a general indicator of potential supply-and-demand mismatches and will affect the production of metals beyond those described, such as copper and other rare earths.

Recovery of metals

With more demand for batteries and other products that rely on these critical minerals, the global mining industry may not keep up with the rate of change,

Figure 1

Cost of reagents in the United States.



making metal recycling crucial to supplement the growing demand. As existing batteries and electronics age and become obsolete, there is also a need to process them at the end of their usable lives. Recycling of these metals can supplement the global supply and lower the demand on mined resources. Proposed battery recycling projects estimate that a battery recycling facility can process from 75 to 18,000 t/a (83 to 20,000 stpy) of battery material, depending on the design.

Most battery recycling uses hydrometallurgical processes to separate individual components of the spent Li-ion battery cathodes. End-of-life batteries are received at a recycling facility, then discharged and dismantled or shredded. The cathode and anode are separated from the copper and aluminum foils, as well as the steel or aluminum casing, and the cathode material is captured as black mass. The black mass is dissolved using acid leaching to create a mother liquor containing dissolved battery metals. The battery elements Co, Li, Mn and Ni are precipitated out of the liquor selectively through neutralization and/or crystallization. These elements precipitate as sulfates and other salts, which can be used as precursor materials to produce new Li-ion batteries.

Hydrometallurgical processes are less energy intensive than shredding and smelting in mechanical recycling processes. Traditional smelting processes (high-temperature furnaces with long residence times) are being phased out, and many new companies are pursuing metal recycling through hydrometallurgical processes. These methods require reagents, both acids and bases, to leach and precipitate the minerals.

The projected increase in hydrometallurgical reagent usage for the recovery of Co, Li, Mn, Ni and Nd/Pr ranges from about 40 percent to more than 200 percent (Table 3). The projected increase of these reagents for hydrometallurgical consumption associated with primary production of Co, Li, Mn, Ni and Nd/Pr is illustrated in Fig. 2. Increased consumption projections for higher-usage reagents (more than 50 kg per tonne treated) are illustrated in Fig. 3.

Current major suppliers, projected production, and limitations for reagent production

The projected increased demand for high-usage reagents ranges from 2 percent of current U.S. production for hydrochloric acid (HCl) to 0.5 percent of U.S. production for caustic soda and sulfuric acid, respectively. While these percentages may seem low and possibly within the "noise" of what is produced, they are significant because the major reagents shown are used across multiple industries with generally growing demand volumes, so widespread competition may lead to shortfalls in supply.

Figure 4 shows the projected increases in consumption of most high-usage reagents compared to U.S. production of these reagents. Multiple companies currently supply these reagents in North America. Growth in U.S. production of

Figure 2

Projected increase of total reagent consumption for Co, Li, Mn, Ni and Nd/Pr.

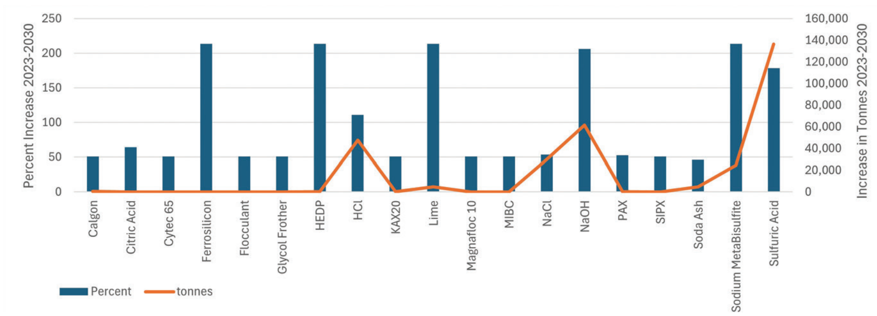
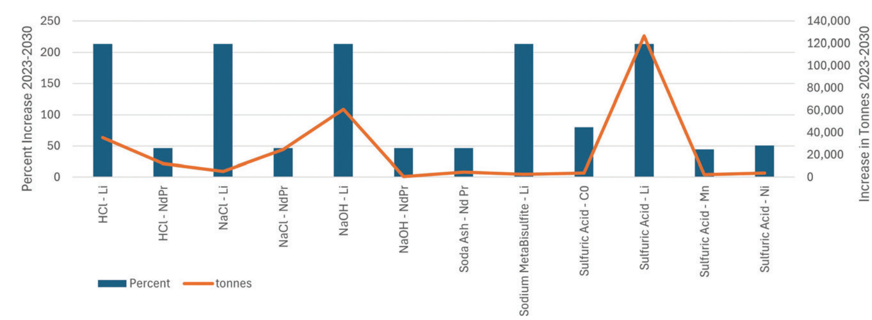


Figure 3

Projected increase of higher-usage reagent consumption.



some of these reagents is potentially limited due to various factors:

- Sulfuric acid production growth is projected to be impacted negatively by a reduction in byproduct sulfur available from fossil-fuel production. It can also be impacted by significant downturns in sulfide ore processing (gold, copper), where significant quantities of sulfuric acid are produced.
- If caustic soda production capacity remains at current levels with no new plants built, the forecasted consumption may exceed capacity, resulting in supply shortages.
- Only one company in North America produces sodium metabisulfite, a potentially key lithium processing reagent.

Operations relying on reagents should conduct a risk assessment of reagent supply needs for existing or planned projects that probes the following:

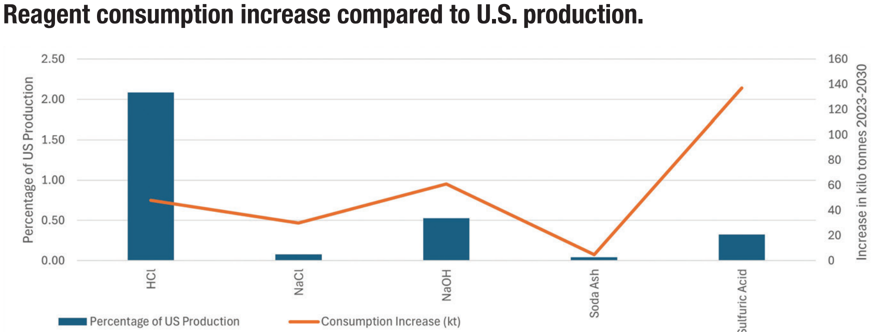
- Will you be able to source the reagents needed through strategic supply agreements? Are the reagents available from multiple suppliers?
- Could you encounter regional supply issues and have to pay more for freight to obtain the reagents required for your process?
- Have you considered the add ed demand for the same reagents by your competitors or by other growing or emerging industries? Are you engaging your potential reagent suppliers early enough in the project?
- Will you need to budget the capital expenditure (CAPEX) for a reagent plant (for example, acid, chlor-alkali) and the associated operational expenditure (OPEX) related to additional staffing, land, and utilities?
- If you produce your own reagents, do you have enough water for your overall operations?
- Have you explored alternative reagents, if possible? Can you afford some additional research during process development that could pay large dividends in the long run?
- What else can be done to minimize risk from reagent supply shortfalls?

Opportunities

The challenge of supplying enough critical minerals to support increased demand for batteries presents an opportunity to process more of these minerals in the United States through increased mining and mineral processing, as well as recycling. However, the increased demand pressures on the U.S. supply of key reagents for the processing of ore and battery waste should not be overlooked. Careful planning will be necessary when considering the

Figure 4

Reagent consumption increase compared to U.S. production.



availability of the reagents required for an existing facility or proposed facilities.

Based on supply trends and projections, sourcing these reagents may be increasingly difficult in the future if production rates struggle to match projected demand growth. The demand for many of these reagents is tied to other industries beyond what is described here, and those markets could stretch the existing production resources. A holistic approach to the development of these emerging projects is thus warranted.

There may be opportunities to manufacture the chemicals needed for the process in the same facility where processing takes place; however, the CAPEX and OPEX associated with this option could present a significant challenge to project economics, and securing adequate supplies of some precursor materials may present similar difficulties. This also presents an opportunity for those developing modular process technologies to assist new miners in developing "small chemical plants" to support their operations.

Additionally, opportunities for research and development of new processes that are less chemical- and energy-intensive in both initial mineral processing and recycling would make these processes more resilient to outside influences and ensure that critical minerals will be better positioned to meet the increasing demand. New mine and process developers who can minimize their reagent usage or successfully substitute with more readily available alternatives could find they have the advantage in the market in terms of key project factors, such as CAPEX; OPEX; environmental, social and governance (ESG) scoring factors; and minimization of market-based risk. These are simple steps that can be taken as a project is developing to make sure key options have been explored and opportunities are realized. This is one of the fundamentals of both ESG evaluation and project risk mitigation. ■

Table 3

Projected reagent usage based on metal demand forecast.

Reagent	Metal	Rate (kg/kt)	Projected reagent usage (t)			Percent increase, 2023 to 2030
			2023	2030	Variance	
Calgon	Ni	300	918	1,385	466	51
Citric acid	Li	1,000	160	502	342	214
Cytec 65	Ni	3	9	14	5	51
Ferrosilicon	Li	169	27	85	58	214
HEDP	Li	370	75	113	38	214
HCl	Li, Nd/Pr	494,000	42,770	90,428	47,658	114
KAX20	Ni	100	306	462	155	51
Lime	Li	14,000	2,240	7,028	4,788	214
Magnafloc 10	Ni	10	31	46	16	51
MIBC	Ni	61	187	282	95	51
NaCl	Li, Nd/Pr	815,000	56,000	85,930	29,930	53
NaOH	Li, Nd/Pr	197,800	29,788	91,216	61,428	206
PAX	Co, Ni	394	598	912	314	53
SIPX	Ni	14	43	65	22	51
Soda ash	Nd/Pr	150,000	10,050	14,700	4,650	46
Sodium metabisulfite	Li	72,000	1,152	3,614	2,462	214
Sulfuric acid	Co, Li, Mn, Ni	588,455	76,494	212,883	136,388	178

References

IEA, Critical Minerals, https://www.iea.org/topics/critical-minerals.

IEA, Global EV Oulook 2024, Trends in electric vehicle batteries, https://www.iea.org/reports/global-ev-outlook-2024

IEA, Announced Pledges Scenario (APS), https://www.iea.org/reports/global-energy-and-climate-model/announced-pledges-scenario-aps.

Benchmark Source, The four eras of the lithium ion battery: Simon Moores opens Giga USA 2024, benchmarkminerals.com.

Benchmark Source, EVs drive cobalt demand uplift despite persistent supply overhang, benchmarkminerals.com.

Mining.com, Ranked: The world's top cobalt producing countries, https://www.mining.com/web/ranked-the-worlds-top-cobalt-producing-countries/.

McKinsey & Co., How clean can the nickel industry become? https://www.mckinsey.com/industries/metals-and-mining/our-insights/how-clean-can-the-nickel-industry-become.

Fastmarkets, INSG forecasts 2023 nickel surplus amid increase in Class 2 supplies, https://www.fastmarkets.com/insights/insg-forecasts-2023-nickel-surplus/.

Mining Digital, McKinsey: EV batteries driving demand for clean nickel, https://miningdigital.com/technology/mckinsey-ev-batteries-driving-demand-clean-nickel.

U.S. Geological Survey, Mineral Commodity Summaries, 2023, https://www.usgs.gov/publications/mineral-commodity-summaries-2023.

University College London, UCL News, Analysis: Sulfuric acid – the resource crisis that could stifle green tech & threaten food security, https://www.ucl.ac.uk/news/2022/aug/analysis-sulfuric-acid-resource-crisis-could-stifle-green-tech-threaten-food-security.