U.S. Department of Energy
Advanced Research Projects Agency-Energy (ARPA-E)

Request for Information
DE-FOA-0003374
on Recovery of High Energy-Value Materials from Wastewater

Introduction:

The purpose of this Request for Information (RFI) is to solicit input for a potential ARPA-E program focused on the development of technologies to recover high energy-value materials from wastewater to reduce energy demands and greenhouse gas (GHG) emissions associated with conventional sourcing and waste stream treatment. Wastewater in this RFI is broadly defined, and includes municipal, livestock, industrial, and mining sources. High energy-value materials under consideration are nutrients (i.e., ammonia and phosphorus) and critical minerals, where the latter are a group of 50 elements in the periodic table including lithium and rare earth elements (REEs).[1]

Ammonia losses from wastewater represent more than 50% of ammonia demand in the United States,[2,3,4] requiring approximately 0.4 quads of energy per year to supply (quads/yr)[5] and resulting in annual emissions of more than 60 million metric tons (MMT) of carbon dioxide equivalents (CO_2 eq).[6] Ammonia in this document refers to both ammonia (NH_3) and ammonium (NH_4^+) unless otherwise specified.

Metal losses in select industrial and mining wastewaters can be large as well. For example, produced water contains sufficient lithium to provide all U.S. needs (e.g., approximately 3,000 metric tons in 2022), while select mining wastewater can contain milligram per liter (mg/L) quantities of select REEs (e.g., cerium and neodymium).[7,8,9,10]

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[1] "Infographic: Critical Minerals," Energy.gov. Office of Fossil Energy and Carbon Management, 2024, https://www.energy.gov/fecm/articles/infographic-critical-minerals.

[2] "Sources and Solutions: Wastewater," EPA.gov. U.S. Environmental Protection Agency, 2023, https://www.epa.gov/nutrientpollution/sources-and-solutions-wastewater.

[3] Metcalf & Eddy. *Wastewater Engineering: Treatment and Resource Recovery.* New York: McGraw-Hill, 2014.

[4] "Estimated Animal Agriculture Nitrogen and Phosphorus from Manure," EPA.gov. U.S. Environmental Protection Agency, 2023, https://www.epa.gov/nutrientpollution/estimated-animal-agriculture-nitrogen-and-phosphorus-manure.

[5] "Ammonia Technology Roadmap," iea.org. International Energy Agency, 2021, https://www.iea.org/reports/ammonia-technology-roadmap.

[6] U.S. Environmental Protection Agency. *Draft of Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-D-24-001, Washington, D.C. 2024.

[7] Madhumitha Jaganmohan, "Apparent Consumption of Lithium in the United States from 2010 to 2022," Statista, April 2024, https://www.statista.com/statistics/606481/estimated-lithium-consumption-in-the-united-states/.

[8] Groundwater Protection Council, US Produced Water Volumes and Management Practices in 2021, Prepared by ALL Consulting, https://gwpc.org/uploads/2021/09/2021_Produced_Water_Volumes.pdf.

[9] Madalyn S. Blondes et al., "U.S. Geological Survey National Produced Waters Geochemical Database," U.S. Geological Survey Data Release. Washington, D.C. 2023, https://doi.org/10.5066/P9DSRCZJ.

[10] Christopher Gammons et al., "Geochemistry of the Rare-Earth Elements and Uranium in the Acidic Berkeley Pit Lake, Butte, Montana," *Chemical Geology* Chemical Geology 198, (2003): 269–288.

The goals for this programmatic concept include the evaluation of technologies capable of efficiently recovering:

- Ammonia (or ammonia with phosphorus) as a high-quality feedstock for direct input to fertilizer supply chains or hydrogen carrier markets
- Critical minerals that can displace metal ore production or overseas procurement for domestic use

Capable technologies will be energy efficient, highly selective, and durable over extended use. Processes will involve few sequential steps and will be easily automated, easily adaptable to existing or new wastewater facilities, and scalable (e.g., modular).

ARPA-E seeks input from environmental, chemical, mechanical, electrical, biological, and systems engineers, organic and inorganic chemists, microbiologists, and others with relevant expertise. Additionally, ARPA-E seeks input from prospective end users or beneficiaries of such technologies. These include, but are not limited to, water and wastewater utilities, metals mining and processing companies, oil and gas developers, semiconductor facilities, intensive animal farmers, fertilizer producers and distributors, and raw metal suppliers.

This RFI is focused on soliciting input regarding novel approaches to recover industrial-grade high energy-value materials from wastewater that can directly enter existing supply chains. Such approaches may include but are not limited to:

- Highly selective separations that use adsorbents or membranes;
- Electrochemical, pressure, or thermal-driven separations;
- Catalytic, electrocatalytic, or biologically-facilitated reactions that promote recovery;
- Novel process designs that minimize energy use and maximize recovery; and
- Approaches to evaluate technical, economic, environmental, and technology-to-market feasibility of these strategies.

The questions towards the end of this document are intended to seek input from two key categories of stakeholders: 1) new technology developers, and 2) technology end users, assessors, and/or beneficiaries. The questions fall under the category areas provided below.

1. New Technology Developers
    1a. Ion Selective Adsorbents and Membranes
    1b. Water-Gas Selective Membranes
    1c. Electrochemical Separation and Catalysts
    1d. Temperature- or Pressure-Driven Separations

2. Technology End Users, Assessors, and/or Beneficiaries
    2a. High Energy-Value Wastewater Streams and Compositions
    2b. Wastewater Treatment Operation
    2c. End User Uptake of New Technologies

Areas Not of Interest for Responses to this RFI:

- Work focused on basic research aimed purely at discovery and fundamental knowledge generation;
- Efforts to recover only phosphorus with incomplete recovery of ammonia;
- Work focused on valorization of organics in wastewater; and
- Photocatalytic-driven redox reactions.

RFI Guidelines:

CAREFULLY REVIEW ALL RFI GUIDELINES BELOW.

Note that the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME.**

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future research programs. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI without any attribution to the source. This RFI provides the broad research community with an opportunity to contribute views and opinions.

No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E will not respond to individual submissions or publish a compendium of responses. **Respondents shall not include any information in the response to this RFI that could be considered proprietary or confidential**.

Responses to this RFI should be submitted in PDF format to the email address **ARPA-E-RFI@hq.doe.gov** by **5:00 PM Eastern Time on June 5, 2024.** Emails should conform to the following guidelines:

- Insert "<your organization name> - Response to Recovery of High Energy-Value Materials from Wastewater" in the email subject line;
- Include your name, title, organization, type of organization (e.g., university, non-governmental organization, small business, large business, federally funded research and development center [FFRDC], government-owned/government-operated [GOGO]), email address, telephone number, and area of expertise in the body of your email;
- Responses to this RFI are limited to no more than 10 pages in length (12-point font size); and
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential materials, designs, or processes.

Technical Background:

Enormous quantities of high energy-value materials are generated to grow food for human consumption and livestock production, to provide metal feedstocks for manufacturing, and to power everyday activities. Invariably, these processes generate aqueous waste streams that are collected and often treated before discharge to the environment.

In some cases, energy is used to capture for disposal or destroy these high energy-value materials. Aeration can be used to convert ammonia in municipal wastewater to nitrate at an energy cost of 0.05 kilowatt hours per cubic meter of wastewater, corresponding to approximately 0.1 quads/yr in the U.S.[11]

Chemicals are frequently added to wastewater to precipitate metals in sludge for disposal or land application.[12] As shown in Table 1, many metric tons of critical materials are lost in wastewater streams. Replacing these materials requires energy, increases GHG emissions, and increases reliance on imports. Lithium is a prime example: The U.S. imports 90% of its supply while simultaneously disposing of produced water and seawater reverse osmosis (RO) concentrate rich in this critical element.[8,9,13,14] Further, GHG emissions can be exacerbated by non-carbon dioxide releases from underlying treatment processes, such as large nitrous oxide emissions during nitrification and denitrification.[15] Nitrogen, phosphorus, and metal discharges also contribute to environmental degradation and associated costs. For example, at least 0.5 MMT of nitrate and 0.1 MMT of phosphate are discharged from municipal wastewater treatment plants and contribute to eutrophication and hypoxia in lakes, rivers, and coastal oceans.[16,17] Eutrophication negatively impacts fishing and tourism along the U.S. Gulf coast, while metals accumulate in aquatic biota and contribute to toxicity.[18,19]

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[11] Alexander Siatou, Anthoula Manali, and Petros Gikas, “Energy Consumption and Internal Distribution in Activated Sludge Wastewater Treatment Plants of Greece,” *Water* 12, no. 4(2020): 1204.

[12] Eduardo Balladares et al., “Neutralization and Co-Precipitation of Heavy Metals by Lime Addition to Effluent from Acid Plant in a Copper Smelter,” *Minerals Engineering* 122, (2018): 122–129.

[13] U.S. Geological Survey, *Lithium,* Brian W. Jaskula. Mineral Commodity Summaries, 2023.

[14] Basel Abu Sharkh et al., “Seawater Desalination Concentrate—A New Frontier for Sustainable Mining of Valuable Minerals,” *npj Clean Water* 5, (2022): 9.

[15] “Estimated Animal Agriculture Nitrogen and Phosphorus from Manure,” EPA.gov. U.S. Environmental Protection Agency, 2023, https://www.epa.gov/nutrientpollution/estimated-animal-agriculture-nitrogen-and-phosphorus-manure.

[16] Michal Preisner, Elena Neverova-Dzipak, and Zbigniew Kowalewski, “Analysis of Eutrophication of Potential of Municipal Wastewater,” *Water Science Technology* 81, no. 9 (2020): 1994–2003.

[17] “Sources and Solutions: Wastewater,” EPA.gov. U.S. Environmental Protection Agency, 2023, https://www.epa.gov/nutrientpollution/sources-and-solutions-wastewater.

[18] Robert J. Díaz and Rutget Rosenburg, “Introduction to Environmental and Economic Consequences of Hypoxia,” *International Journal of Water Resources Development* 27, no. 1 (2011): 71–82.

[19] Zarith Sufiani Baharom and Mohd Yusoff Ishak, “Determination of Heavy Metal Accumulation in Fish Species in Galas River, Kelanta and Beranang Mining Pool, Selangor,” *Procedia Environmental Sciences* 30, (2015): 320–325.

Table 1. Example concentrations of high energy-value materials in wastewater, with estimated energy and CO_2 eq associated with replacement from conventional sources in the U.S.

Wastewater Source	Resource	Representative Concentration (mg/L)	Losses in Wastewater (Tonnes/yr)[i]	Energy to Replace Losses (Megajoules/yr)	GHGs to Replace Losses (Tonnes CO_2 eq/yr)[i]	Percent Imported (%)
Municipal[20,21]	NH_3–N	20	10^6	4.7×10^{10}	2.1×10^7	13
Livestock[22]	NH_3–N	15	6.4×10^6	3.2×10^{11}	n/a	13
Produced Water[23,24,25,26]	Li	7	4.8×10^4	6.0×10^6	3.4×10^5	90
Seawater RO Concentrate[27,28,29,30]	B	4.5	490	28	1.4×10^4	0
	Ge	6.0×10^{-5}	6.5×10^{-3}	19	1.9×10^2	50
	Rb	0.2	19	n/a[ii]	n/a[ii]	100
Semi-conductor[31,32]	Mo	2.9×10^{-2}	n/a[iii]	n/a[iii]	n/a[iii]	100
	Ag	3.0×10^{-5}	n/a[iii]	n/a[iii]	n/a[iii]	50
	W	0.4	n/a[iii]	n/a[iii]	n/a[iii]	50
Mining[33,34]	Zn	550	n/a[iii]	n/a[iii]	n/a[iii]	0
	Y	2.5	n/a[iii]	n/a[iii]	n/a[iii]	n/a[iv]
	Nd	3.5	n/a[iii]	n/a[iii]	n/a[iii]	93
	Dy	0.5	n/a[iii]	n/a[iii]	n/a[iii]	100

i. Tonnes = Metric Tons
ii. Energy and GHG data for Rb were not available.
iii. Element concentrations are for a single location and cannot be generalized to all wastewaters.
iv. Percent imports for Y were not available.

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[20] "Sources and Solutions: Wastewater," EPA.gov. U.S. Environmental Protection Agency, 2023, https://www.epa.gov/nutrientpollution/sources-and-solutions-wastewater.

[21] Metcalf & Eddy. *Wastewater Engineering: Treatment and Resource Recovery.* New York: McGraw-Hill, 2014.

[22] Patricia M. Gilbert, "From Hogs to HABs: Impacts of Industrial Farming in the US on Nitrogen and Phosphorus and Greenhouse Gas Pollution," *Biogeochemistry* 150, no. 2 (2020): 139–180.

[23] Carleton R. Bern, Justin E. Birdwell, and Aaron M. Jubb, "Water-Rock Interaction and the Concentrations of Major, Trace, and Rare Earth Elements in Hydrocarbon-Assisted Produced Waters of the United States," *Environmental Science: Processes & Impacts* 23, no. 8 (2021): 1198–1219.

[24] C. William Yeung et al., "Analysis of Bacterial Diversity and Metals in Produced Water, Seawater and Sediments from an Offshore Oil and Gas Production Platform," *Marine Pollution Bulletin* 62, no. 10 (2011): 2095–2105.

[25] Charles Nye, Davin Bagdonas, and Scott Quillinan, "A New Wyoming Basin Produced Waters REE Normalization and Its Application" (Proceedings, 43rd Workshop on Geothermal Reservoir Engineering, Stanford, CA, February 12–14, 2018).

[26] ALL Consulting. *US Produced Water Volumes and Management Practices in 2021* (Groundwater Protection Council, Oklahoma, 2022) Groundwater Protection Council, US Produced Water Volumes and Management Practices in 2021, Prepared by ALL Consulting, https://www.gwpc.org/wp-content/uploads/2021/09/2021_Produced_Water_Volumes.pdf.

[27] Basel Abu Sharkh et al., "Seawater Desalination Concentrate—A New Frontier for Sustainable Mining of Valuable Minerals," *npj Clean Water* 5, (2022): 9.

[28] Mike Mickley "U.S. Municipal Desalination Plants," United States (2018). https://doi.org/10.7481/1787564.

[29] Michaela Peterková et al., Extraction of Valuable Metal Ions (Cs, Rb, Li, U) from Reverse Osmosis Concentrate Using Selective Sorbents," *Desalination* 286, (2012): 316–323.

[30] Xin Zhang et al., "A Review of Resource Recovery from Seawater Desalination Brine," *Reviews in Environmental Science and Bio/Technology* 20, (2021): 330–361.

[31] Qi Wang et al., "Environmental Data and Facts in the Semiconductor Manufacturing Industry: An Unexpected High Water and Energy Consumption Situation," *Water Cycle* 4, (2023): 47–54.

[32] Shih-Chieh Hsu et al., "Tungsten and Other Heavy Metal Contamination in Aquatic Environments Receiving Wastewater from Semiconductor Manufacturing," *Journal of Hazardous Materials* 189, no. 1–2 (2011): 193–202.

[33] Christopher Gammons et al., "Geochemistry of the Rare-Earth Elements and Uranium in the Acidic Berkeley Pit Lake, Butte, Montana," *Chemical Geology* Chemical Geology 198, (2003): 269–288.

[34] Qiuting Yan et al., "Recovery and Removal of Rare Earth Elements from Mine Wastewater Using Synthesize Bio-Nanoparticles Derived from *Bacillus Cereus*," *Chemical Engineering Journal* 459, (2023): 141585.

To reduce energy demands and GHG emissions associated with obtaining virgin resources and treating associated aqueous waste streams, ARPA-E is seeking information on developing new technologies to recover high energy-value materials from wastewater. As illustrated in Figure 1, ARPA-E is interested in technologies that can be applied to both existing and anticipated wastewater treatment facilities across a range of industries, that either improve or do not alter effluent water quality, recover supply-chain ready materials at a lower energy demand and cost relative to conventional resources, and are scalable across a range of wastewater treatment facility sizes.

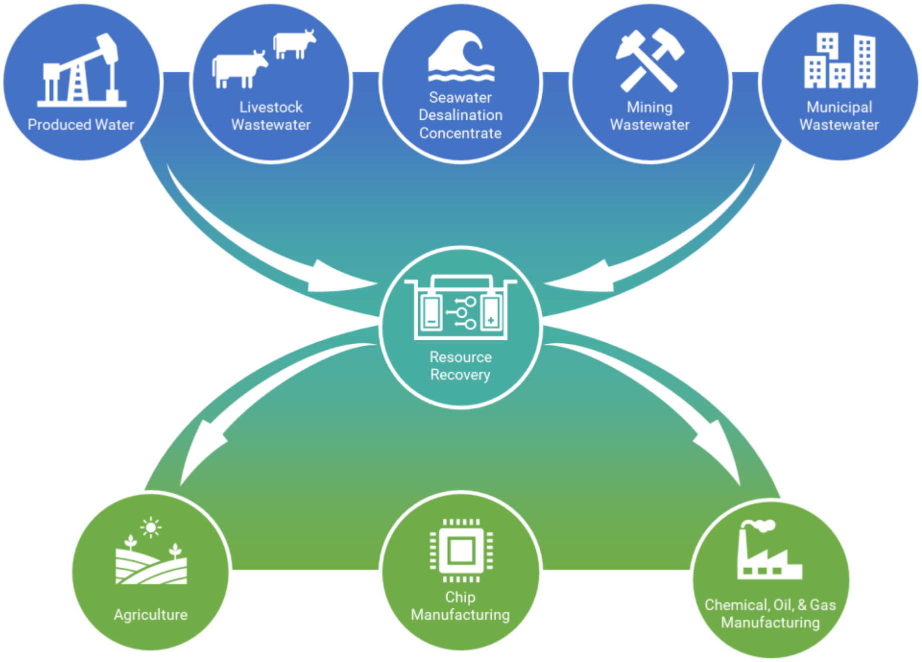

Figure 1. Examples of wastewaters and supply-chain streams for high energy-value materials.

RFI Questions:

The questions posed in this section target new technology developers, as well as technology end users, assessors, and/or beneficiaries; however, all questions are open to all respondents. **ARPA-E does not expect any one respondent to answer all or even many of the prompts in this RFI; only address those questions that are relevant to your interests.** In your response, indicate the group and question number in your response (e.g., 1a.ii, 1b.i). Appropriate citations are highly encouraged. Respondents are also welcome to address other relevant issues or technologies that are not outlined below, except for those that fall under the “Areas Not of Interest” noted above.

1. New Technology Developers

1a. Ion Selective Adsorbents and Membranes

High energy-value materials are often present as ions in aqueous streams, such as NH_4^+, phosphate ions, and critical mineral ions. Ion exchange resins and other adsorbents, and ion exchange membranes, can be designed to capture or select one or more of these ions over others with high specificity. For example, nitrate and perchlorate selective resins have been developed with high specificity.[35,36] Design principles often rely on tailoring functional groups to interact with specific ions, tailoring pore size to exclude some ions over others, or selecting naturally derived proteins or analogs to impart specificity. As part of an integrated technology, ARPA-E is interested in new adsorbent and membrane materials that are highly selective for one (e.g., NH_4^+, lithium ions) or a related group (e.g., heavy REEs) of high energy-value materials over other ions in representative wastewater streams. The new adsorbents and membranes must also be robust to regeneration and reuse. Questions of interest include:

i. What are the recent advances and present challenges for adsorbent or membrane selectivity for one or a group of high energy-value cations (e.g., NH_4^+ or critical mineral ions) over other ions in a target wastewater (e.g., municipal, livestock, industrial, RO concentrate, mining)?
ii. What opportunities and limitations are therefore fouling prevention and/or regeneration of adsorbents or membranes in a target wastewater?
iii. What are the primary challenges for one-step separation of individual high energy-value cations from a target wastewater into product streams that are ready for entry into commercial supply chains without further treatment?

1b. Water-Gas Selective Membranes

Water-gas selective membranes can be used to separate NH_3 from solution into either the gas phase or into an acidic medium for recovery as a salt. These membranes are usually hydrophobic or omniphobic and their use is intended to separate ammonia from water and from the ions in water.[37,38,39] Ideally, such membranes would separate ammonia from other volatiles for a concentrated ammonia stream that can directly enter commercial supply chains. Other volatiles include water vapor, natural organic matter, organic pollutants, carbon dioxide, oxygen, and nitrogen. Membrane design principles to select for ammonia over these volatiles follow those for ion selective membranes and can involve tailoring functional groups that specifically interact with NH_3, tailoring pore size, and possibly selecting proteins or analogs to impart specificity. As part of an integrated technology, ARPA-E is interested in new water-gas membranes that are highly selective for NH_3 over other aqueous constituents, and robust to regeneration and reuse, all in representative wastewater streams. Questions of interest include:

i. What are the recent breakthroughs and prevailing issues for water-gas membrane selectivity for NH_3 over other aqueous constituents in a target wastewater?
ii. What are the recent advances and ongoing challenges for preventing fouling and/or regeneration of water-gas membranes used in a target wastewater?
iii. What are the primary challenges for one-step separation of ammonia from a target wastewater into a commercially viable product stream without further treatment?

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[35] Haiou Song et al., "Selective Removal of Nitrate from Water by a Macroporous Strong Basic Anion Exchange Resin," *Desalination* 296, (2012): 53–60.

[36] Baohua Gu, Gilbert M. Brown, and Chen-Chou Chiang, "Treatment of Perchlorate-Contaminated Groundwater Using Highly Selective, Regenerable Ion-Exchange Technologies," *Environmental Science and Technology* 41, no. 17 (2007): 6277–6282.

[37] Anna Kogler et al., "Long-Term Robustness and Failure Mechanisms of Electrochemical Stripping for Wastewater Ammonia Recovery," *ACS Environmental Au* 4, no. 2 (2024): 89–105.

[38] Sha Yu et al.," Nafion-PTFE Hollow Fiber Composite Membranes for Ammonia Removal and Recovery Using an Aqueous-Organic Membrane Contactor," *Separation and Purification Technology* 271, no. 15 (2021): 118856.

[39] Jiaxin Guo et al., "Enhanced Ammonia Recovery from Wastewater by Nafion Membrane with Highly Porous Honeycomb Nanostructure and its Mechanism in Membrane Distillation," *Journal of Membrane Science* 590, (2019): 117265.

1c. Electrochemical Separation and Catalysts

Electrochemical methods can be used to promote ion migration across an ion exchange membrane, or to drive redox chemistry to promote high energy-value materials recovery (e.g., water splitting or oxygen reduction to alter pH, NH_4^+ or NH_3 conversion to hydrogen, reduction of metal ions for precipitation). Challenges to electrochemical methods for ion separation include mass transfer limitations, high membrane or solution resistance, and concentration polarization, all of which act to increase energy demands.[40,41,42] Challenges for driving relevant redox chemistry are the expense of commonly used precious metal catalysts, catalyst fouling and regeneration with continued use, and competition with unwanted reactions that consume energy.[43,44,45] As part of an integrated technology, ARPA-E is interested in advances in electrochemical systems that enhance the selective recovery of high energy-value materials over other ions/constituents in representative wastewater streams. Questions of interest include:

i. What are the recent developments and present barriers for electrochemical reactions of interest that promote selective recovery of high energy-value materials in a target wastewater?
ii. What are opportunities and limitations for selective electrochemical separations of high energy-value materials in a target wastewater?
iii. Possible solutions will need to create a product stream that can directly enter commercial supply chains without further treatments. What is the recent progress and present limitations in the design of electrochemical reactors for long-term and continuous recovery of high energy-value materials in a target wastewater for such a goal?

1d. Temperature- or Pressure-Driven Separations

Pressure or temperature can be used to drive separation and recovery of high energy-value materials in wastewater. For example, either a vacuum or elevated temperature can be used to enhance ammonia transport across the water-gas interface or a water-gas membrane, elevated temperature can be used to reduce REE solubility for precipitation-induced recovery from solution, and eutectic freeze crystallization can be used to selectively recover metal salts.[46,47,48] Also, these processes can be driven by

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[40] Chenxu Yan et al., "Scalable Reactor Design for Electrocatalytic Nitrite Reduction with Minimal Mass Transfer Limitations," *ACS ES&T Engineering* 1, no. 2 (2021): 204–215.

[41] Jan-Max Arana Juve et al., "Electrodialysis for Metal Removal and Recovery: A Review," *Chemical Engineering Journal* 435, no. 2 (2022): 134857.

[42] Manuel César Martí-Calatayud, Montserrat García-Gabaldón, and Valentín Pérez-Herranz, "Mass Transfer Phenomena During Electrodialysis of Multivalent Ions: Chemical Equilibria and Overlimiting Currents," *Applied Science* 8, no. 9 (2018): 1566.

[43] Anna Kogler et al., "Long-Term Robustness and Failure Mechanisms of Electrochemical Stripping for Wastewater Ammonia Recovery," *ACS Environmental Au* 4, no. 2 (2024): 89–105.

[44] Laisa Candido, and José Antonio C. Ponciano Gomes, "Evaluation of Anode Materials for the Electro-Oxidation of Ammonia and Ammonium Ions," *Materials Chemistry and Physics* 129, no. 3 (2011): 1146–1151.

[45] Xiao Shang et al., "Recent Advances of Nonprecious and Bifunctional Electrocatalysts for Overall Water Splitting," *Sustainable Energy & Fuels* 4, (2020): 3211–3228.

[46] Lennevey Kinidi et al., "Recent Development in Ammonia Stripping Process for Industrial Wastewater Treatment," *International Journal of Chemical Engineering* 2018 (2018).

[47] Saurajyoti Kar et al., "Life Cycle Assessment and Technoeconomic Analysis of Nitrogen Recovery by Ammonia Air-Stripping from Wastewater Treatment," *Science of The Total Environment* 857, no. 3 (2023): 159499.

[48] Yiqian Ma et al., "Application of Eutectic Freeze Crystallization in the Recycling of Li-ion Batteries," *Rare Metal Technology 2021*, (2021): 3–10.

waste heat, or combined with pressure and/or temperature recovery technologies, such as isobaric energy recovery or mechanical vapor recompression. As part of an integrated technology, ARPA-E is interested in advances in energy efficient pressure- and temperature-driven separation processes for recovery of high energy-value materials in wastewater streams. Questions of interest include:

i. What are the recent advances and current challenges in temperature- and pressure-driven separation technologies that are relevant to selective recovery of one or a similar group of high energy-value materials over other constituents in a target wastewater?

2. Technology End Users, Assessors, and/or Beneficiaries

2a. High Energy-Value Wastewater Streams and Compositions

Wastewater stream compositions can be highly variable with respect to both high energy-value material types and amounts, as well as unwanted constituents that challenge recovery efforts. For example, mining wastewater composition depends on the geochemistry of ore deposits being mined, and produced water composition depends on the geochemistry of an oil and gas formation. Municipal or livestock wastewater composition can vary with changes in population, dietary intake, and/or commercial versus residential development. ARPA-E is interested in learning which wastewaters represent promising opportunities for high energy-value materials recovery, the concentrations and loads of target materials in these wastewaters, and the concentrations and loads of constituents that are expected to challenge recovery efforts. Questions of interest include:

i. Which wastewater stream(s) represents a promising source of ammonia or critical mineral(s), and what are the representative concentrations of the target(s) versus common interfering ions/constituents?

2b. Wastewater Treatment Operation

Wastewater facilities employ a variety of processes to eliminate particulate and soluble organics, ammonia, phosphorus, and other pollutants. For example, coagulants are used to precipitate metals and phosphorus, activated sludge treatment is applied to oxidize organics and drive nitrification, and anaerobic treatment is effective for digesting sludge and creating biogas. In the context of an integrated treatment system for recovery of high energy-value materials, ARPA-E is interested in how existing wastewater treatment facilities can be managed to maximize recovery, how new wastewater treatment facilities can be designed for this same purpose, and how the economic and environmental value of a recovery technology can be assessed in the context of wastewater treatment or disposal. Questions of interest include:

i. What are the challenges or opportunities in operations using existing infrastructure at a target wastewater facility to promote selective recovery of one or more high energy-value material(s)?
ii. What are the recent advances and current challenges for the design of a new facility to treat a target wastewater to maximize selective recovery of high energy-value materials?
iii. What are the opportunities and limitations for using technoeconomic assessment and life cycle assessment tools to determine the economic and environmental impacts of new technologies for selective recovery of high energy-value materials in wastewater?

2c. End User Uptake of New Technologies

New technology adoption requires uptake by end users, which is affected by multiple factors including product form, purity, and amount, ease of technology adoption, ease of technology operation, cost, market conditions for the recovered product, available purchasing and distribution networks, and financing. ARPA-E requests input from end users, assessors, and other possible beneficiaries of new technologies for high energy-value materials recovery to better identify and quantify these factors to help determine technology performance metrics. Questions of interest include:

i. What information and data would need to be included in a value proposition to make high energy-value materials recovery attractive to wastewater facility managers?
ii. What forms, purity, and amount of recovered ammonia or critical minerals are needed from wastewater recovery so that they can directly enter existing supply chains without further treatment?
iii. What price targets are appropriate for adoption of new technologies for ammonia and critical minerals recovery from wastewater?
iv. Which factors are essential to include in any assessment of a technology, so that it may inform end user decision making, risk management assessments, and determination of suitability for financing?