University of Wyoming | School of Energy Resources

An Analysis of Wyoming's Rare Earth Industry Potential, Economics, and Policy Recommendations

MELISSA D. FIRESTONE

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By Melissa D. Firestone | Research Affiliate, University of Wyoming School of Energy Resources Center for Energy Regulation & Policy Analysis

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Erin Phillips | Project Manager, UW School of Energy Resources Center for Economic Geology Research

Davin Bagdonas | Research Scientist, UW School of Energy Resources Center for Economic Geology Research

TABLE OF CONTENTS

DEFINITIONS AND TERMS

Bear Lodge Deposit – the proven REE deposit located in Wyoming, owned by Rare Element Resources, Ltd.

CORE-CM – Carbon Ore, Rare Earth, and Critical Mineral(s)

DOD – United States Department of Defense

DOE – United States Department of Energy

DPA – Defense Production Act

EV – Electric Vehicle

GHG – Green House Gas Protocol

GM – General Motors

GML – General Mining Law of 1872

HREE – Heavy Rare Earth Elements

kg – kilogram

kt – kiloton, 1,000 tons

LREE – Light Rare Earth Elements

mt – metric ton, 1,000 kg, tonne

mt REO – REO content weight in mt

MW – Megawatt

NEPA – National Environmental Policy Act

NETL – National Energy Technology Laboratory

NRC – Nuclear Regulatory Commission

PRB – Powder River Basin

PUG – Physical Upgrade Plant

REE – Rare Earth Element(s)

REM – Rare Earth Metal(s)

REO – Rare Earth Oxide(s)

RER – Rare Element Resources, Ltd.

TREO – Total Rare Earth Oxide, represented as a percentage to quantify REE concentration in a mass of material such as a deposit, an REE mixed concentrate, or marketed purity products

UIT – Umwelt-und Ingenieurtechnik GmbH Dresden, an affiliate of Synchron

WSGS – Wyoming Geological Survey

Rare Earth Elements and Compounds Referenced:

Dy – Dysprosium

La – Lanthanum

Nd – Neodymium

NdPr – Neodymium-Praseodymium Oxide

NdFeB – Neodymium magnet

Pr – Praseodymium

EXECUTIVE SUMMARY

Rare earth elements (REE) have increasingly become a topic of discussion among US policy makers and in the media due to their importance and increasing application in electronic manufactured products. China's near monopoly over the global REE value chain and US' reliance upon it for both finished goods containing REE and for REE used in US based industry is being recognized as a national security concern resulting in government funding being allocated towards US based REE supply chain projects.

"An Analysis of the Current Global Market for Rare Earth Elements" (referred to herein after as "Paper I") published on January 31, 2022 provided an in-depth description and analysis of the global production of REE and highlighted both production and consumption issues that characterize the REE market. Given the anticipated continued growth in REE consumption combined with the need for supply diversity away from China/Southeastern Asia, US based resources and the build out of midstream separations and concentrations infrastructure in the US are now being actively pursued.

Wyoming's Bear Lodge REE deposit, located in Crook County and owned by Rare Element Resources, Ltd. (RER) is one of the few US based, proven REE deposits. RER has been awarded federal funding to support the build-out and operation of an REE separations and concentrations demonstration plant to refine its REE mixed concentrate into high-purity REE. While a demonstration plant is a positive development, it will produce relatively insignificant quantities of purity separated REE compared to the potential production associated with the Bear Lodge deposit and a commercial scale REE separations and concentrations plant. The demonstration plant will produce approximately 15 tons of purity REE annually whereas a commercial scale operation could generate over 250 tons/year of purity REE. The potential to scale up production at Bear Lodge presents an opportunity for the state to establish a US based REE industry. Further bolstering Wyoming's REE prospects and its many unconventional sources of REE, some of which are under evaluation and study, has the potential to generate meaningful amounts of purity REE streams.

Given Wyoming's proven Bear Lodge deposit combined with other promising unconventional sources of REE, Wyoming has an opportunity to develop a commercial scale REE value chain in the state that builds upon the foundation and momentum created RER's demonstration plant at its Bear Lodge deposit. This would provide a new revenue stream for state and local governments; but for that revenue to be meaningful, a commercial scale operation is necessary.

While Wyoming makes an ideal location for a US based REE industry, obstacles to achieving a viable industry exist on several fronts:

1. Macro market forces including the lack of firm consumers outside of the China/Southeastern Asia region and the region's objective of dominating the consumption side of the market make securing firm buyers of US sourced purity REE problematic.

2. Absence of clear federal policy regarding the strategic development of a REE full value chain including downstream consumption, combined with various federal entities directing millions of dollars in funding towards multiple REE midstream separations and concentrations projects across the US could lead to some or all the projects failing to be economically viable.
3. Lack of clarity in the General Mining Law of 1872[1] (GML) at the federal level with respect to unconventional sources of REE and leasing and royalty issues for hard rock mining on federal land could lead to project delays or negative project economics.
4. Legal and environmental uncertainty regarding the handling of the unconventional sources of REE that are considered waste or by-products of other processes at both the state and federal levels could present challenges and project delays.
5. Wyoming's agreement state status with the Nuclear Regulatory Commission (NRC) currently does not contemplate radioactive material generated as a by-product of REE mining or processing.

Ideally, federal policy makers would act but given that work is actively occurring on several projects in the US and specifically in Wyoming, state policy makers may need to be proactive in enacting measures that clarify state law and environmental regulations impacting REE and unconventional sources of REE. For the Bear Lodge deposit specifically, RER recommends that Wyoming's existing agreement with the NRC be amended to include radionuclide separation and recovery REE ores to be under the state's authority instead of the NRC. This may solve a problem that has yet to manifest, but likely will once mining and processing commence.

The bottom line is that the world is moving forward with increasing REE consumption and Wyoming is uniquely positioned to take advantage of its REE resources, contribute to alleviating a national security concern, and build a new industry contributive to Wyoming's economy. Timely action is key and should begin now.

Introduction

Rare earth elements (REE) have important strategic value in many sectors of the US economy, but also present supply chain and national security risks given that nearly all production is outside the US. Wyoming has many attributes that could support a domestic REE industry, but significant policy support will be needed to ensure the industry succeeds in establishing REE production, refining, and consumption operations. While more work is needed, some steps have already been taken.

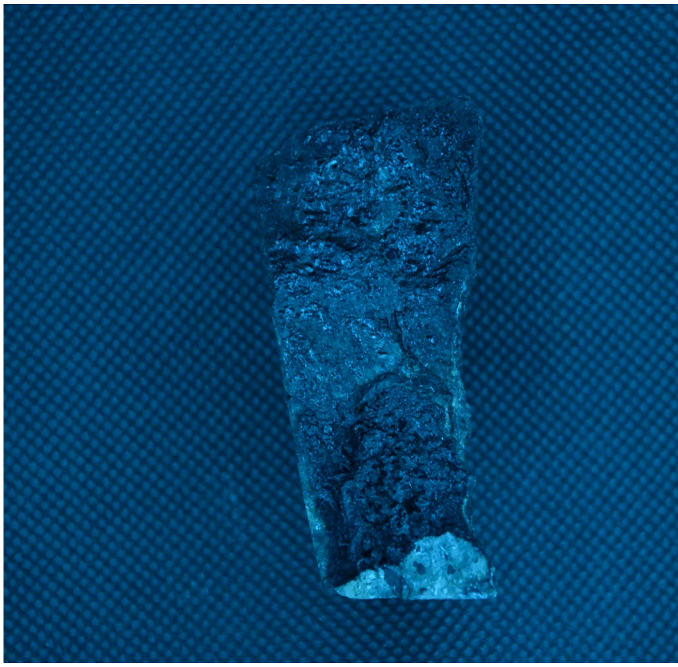
A detailed description of the status of the global market for REE as of 2021 was provided in, "An Analysis of the Current Market for Rare Earth Elements"[2] (herein after referred to as Paper I) published in January 2022. The paper provides important background information regarding the REE market and China's monopolistic control over the fully integrated global REE value chain. US dependence upon China/Southeastern Asia for purity REE products, combined with growing global demand for REE used in permanent magnets, led to recent federal policy action and funding directed towards the development of a US based REE supply chain as will be detailed in the Market Dynamics section of this paper. More specifically, because the US does not have any operational REE separations and concentrations capacity, the federal government allocated funds towards REE separations and concentrations projects in the US. There are at least seven REE midstream construction projects receiving government funding and in the process of finalizing development plans.[3]

Among the projects being funded, in October 2021, the Department of Energy (DOE) awarded RER $21.9 million to fund approximately half of the construction of a rare earth separation and processing demonstration plant.[4] RER is now working on the various permitting, engineering, and logistical issues to move the project forward. According to RER consultants,[5] the Bear Lodge demonstration plant is currently scoped to process 3 tons/day of mixed concentrate exploration samples. Project construction and implementation is estimated to take 40 months. Half of the purity product output will be the property of the DOE, with the remaining half, RER's. The demonstration project is much smaller compared to the production potential of the Bear Lodge REE deposit but is a necessary step to understand the scale-up requirements for a commercial size facility.

The Bear Lodge deposit is one of the few proven REE deposits located in the US.[6] Its location in Wyoming presents a unique opportunity for the state to host and grow a new and emerging industry in the state. Wyoming's mining history, access to interstate rail transport, and business friendly tax environment make it an optimal location for a US based REE industry. In addition to the Bear Lodge deposit, as detailed in the Unconventional Sources of REE section of the paper, Wyoming hosts unconventional sources of REE that could also be exploited. Wyoming possesses human capital with established institutional expertise in the mining value chain. Wyoming also has physical infrastructure in place that would support efficient operations of an REE industry.

The Chinese government is taking proactive measures to position its REE industry for growth and insulate it from coming foreign competition. At the end of 2021, China's State Assets Management and Supervision Commission announced its plan to consolidate the REE mining sector, approving the merger of three of the six state-owned REE producers in China into one company to be called China Rare Earth Group.[7] The three companies included in the merger focus on HREE (Heavy Rare Earth Elements) mining. By consolidating HREE producers into one company, the single entity will theoretically be better positioned to take advantage of economies of scale and scope, reduce production costs, and increase market power over HREE. Furthermore, China's Northern Inner Mongolian region plans to increase its REE production value by five times the value established in 2020 by 2025, or an increase of ~30%/year.[8] Wu Suhai, the deputy chief of industry and technology, highlighted the region's goal of expanding its permanent magnet industry and becoming akin to the "Silicon Valley" in the production of permanent magnets.[9]

China's control over the current global REE value chain and its focus upon dominating the permanent magnet industry cannot be ignored. For a commercial scale Wyoming based REE midstream industry to be successful, particularly in the face of planned Chinese consolidation and build out of additional permanent magnet manufacturing capacity, there must be firm market support for the purchase of the industry's purity REE products. In addition, there are other midstream concentrations and separations projects being funded in the US with which a Wyoming based operation will have to compete.



Wyoming's Bear Lodge REE deposit has significant production potential, particularly for the REE used in the growing permanent magnet industry. But for the full economic potential of the deposit to be unlocked, a commercial scale operation must be established.

Section I

Wyoming's REE Resource Potential

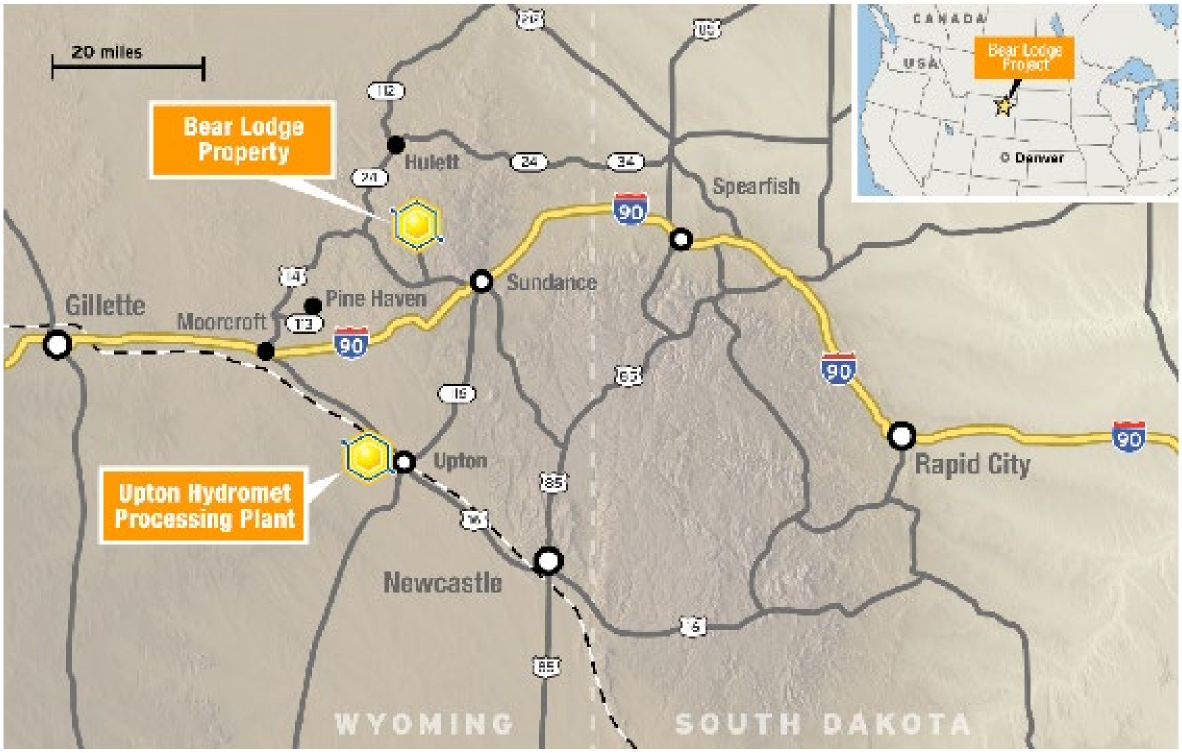
Wyoming hosts the REE-bearing Bear Lodge deposit and other potential unconventional sources of raw material.

A. Bear Lodge Deposit

The Bear Lodge Deposit is one of the largest unproduced conventional REE deposits in the United States. Resource estimates suggest the deposit holds more than 15 million metric tons of ore in a zoned and disseminated tertiary carbonatite complex with an average rare earth oxide (REO) content of 2.78%[10] [11].

The Bear Lodge Deposit, located in central Crook County, Wyoming, is owned by RER (Figure 1):

Figure 1: Bear Lodge Deposit[12]



From about 2009 through 2015, RER contemplated the building and operation of a REE mining operation, a REE physical upgrading facility, and a midstream separations and concentrations plant. In 2014 RER commissioned Roche Engineering to conduct a prefeasibility study of the project.[13] The study described the project scope as follows:

> The Bear Lodge Project consists of three principal components: 1) the small open-pit mine operation at the Bull Hill and Whitetail Ridge deposits and associated support facilities, located approximately 12 miles (19 kilometers) by road north of Sundance, Wyoming; 2) a physical upgrading (PUG) plant for mineral pre-concentration located adjacent to the mine; and 3) a hydrometallurgical (Hydromet) plant, located near Upton, Wyoming, for further concentration of the rare earth elements into a mixed [total rare earth oxide] (TREO) … concentrate.[14]

The pre-feasibility study published in 2014 contemplated a commercial scale project that would produce a mixed REO product that would be marketed and sold. The study estimated that the total proven and probable mineral reserves of the Bear Lodge complex to be 15.6 million tons (14.15 million mt) at 2.78% TREO. Total estimated material weight within the pit inclusive of waste rock and reserves is over 148 million tons. The project design in the study targeted daily mining rates of 10,000 tons with 500 to 600 tons/day of pre-concentrate from the PUG plant to be fed into the Hydromet plant to produce between 6,000 to 10,000 tons/year or ~16 to 27 tons/day of a mixed REO product. The project economics contained in the study showed a total annual average revenue stream of ~$167 million over the 45-year project life. Total capital cost for the project was estimated at $453 million with a project life of 45 years.

The project was, for all intents and purposes, suspended in 2016 due to lack of funding and unfavorable market dynamics. Since that time, the global landscape for REE has shifted with increased global demand for REE, China net importing REE mixed concentrate from abroad, and stronger REE prices.

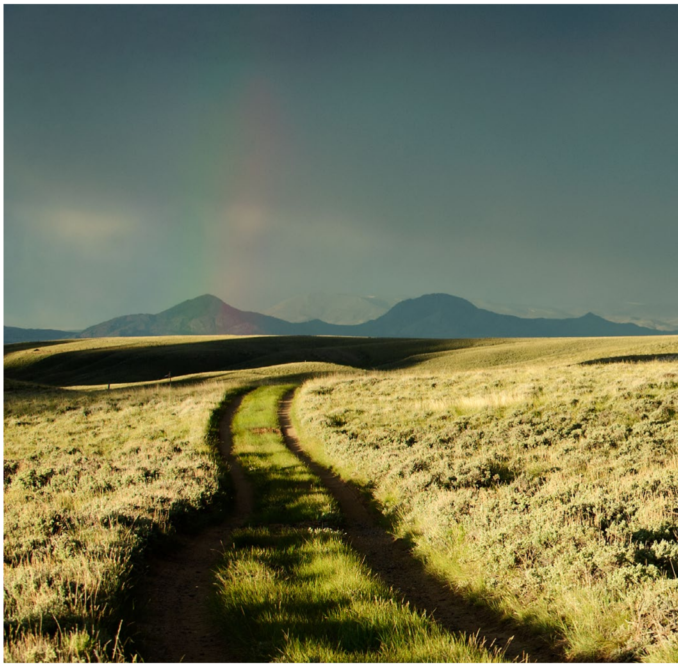
In early 2019, RER engaged with Umwelt-und Ingenieurtechnik GmbH Dresden (UIT), an affiliate of Synchron, to develop a pilot plant in Germany to verify its midstream extraction technology using concentrate sourced from the Bear Lodge deposit.[15] In December 2019, RER announced the successful separation of a stable Neodymium-Praseodymium (NdPr) solid product at the pilot plant. The plant was also designed to produce Lanthanum (La) oxide, and a mixed mid and heavy REE concentrate. RER planned to work with UIT to further test the technology and develop a plan for building a demonstration plant.[16]

In August 2020, RER announced the results of its initial production at the pilot plant in Germany and the intent to further optimize its process and scale-up the technology to develop a demonstration plant. At that time, RER estimated that after securing funding for a demonstration plant and finalizing plant design, construction of the demonstration plant could commence and would take 18-

24 months to complete. After this, RER estimated it would take an additional twelve months for the operation of the plant to generate separated streams of purity REE.[17] From August 2020 until January 2021, no additional information was provided by RER regarding its planned demonstration plant.

US federal government interest in exploring US based sources of REE most recently culminated into federal funding being directed to various REE research and development projects. RER submitted a proposal to the DOE in mid-2020 under the Critical Materials Funding Opportunity Announcement for the design and construction of a REE separations and concentrations demonstration plant at its Bear Lodge deposit.[18] In January 2021, RER announced that it received notice from the DOE that its REE midstream separations and concentrations demonstration project had been selected to negotiate a potential financial award.[19]

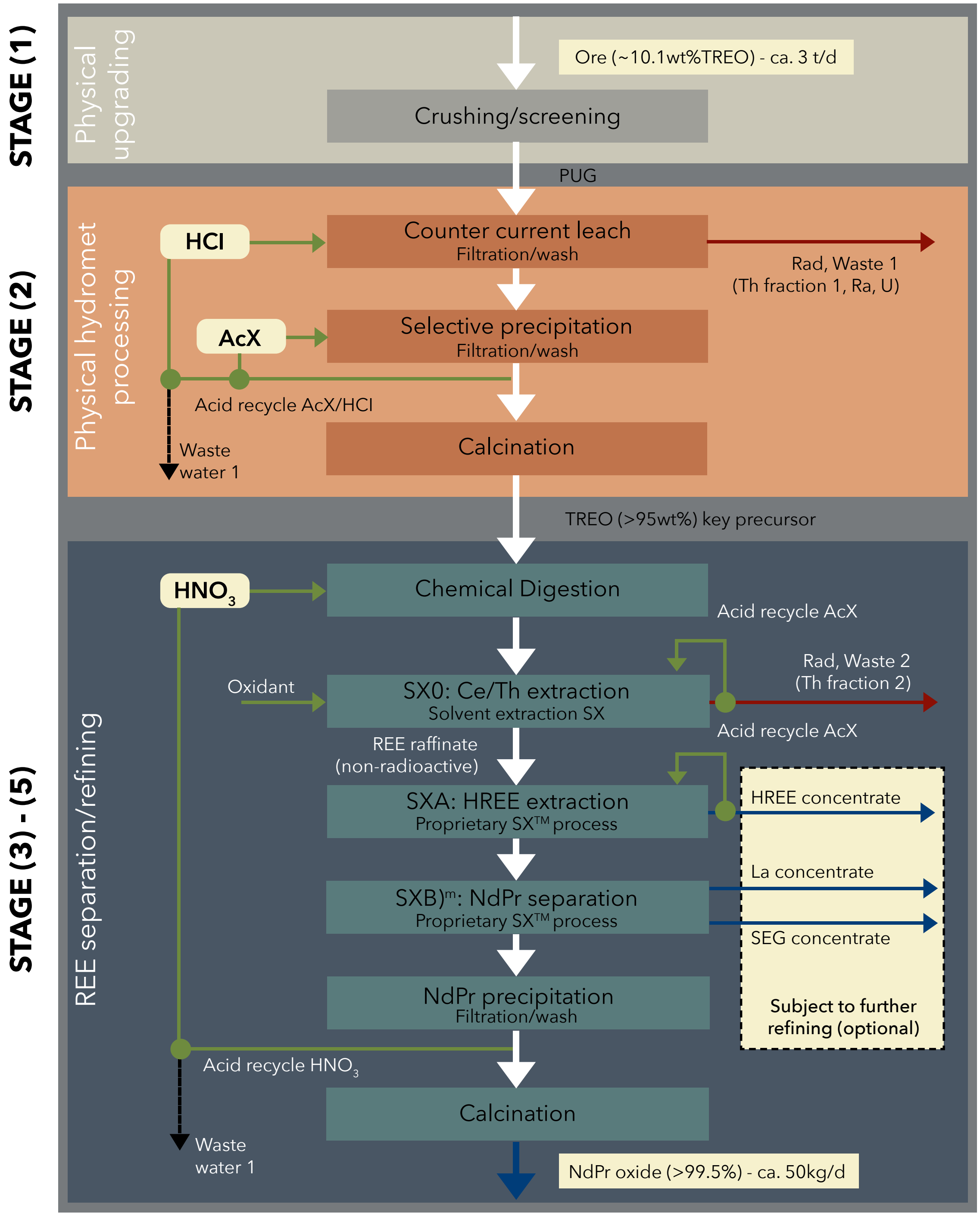
As noted in the introduction, in October 2021, RER was awarded $21.9 million in funding for approximately half of the estimated project cost from the DOE to contribute to the build out and operation of the Bear Lodge REE processing demonstration plant. With a total project cost estimate at ~$44 million, RER raised the necessary additional funding at the end of 2021 through a private equity offering.[20]



The successful operation of the pilot separations and concentrations plant in Germany coupled with government funding being secured, allows the RER Bear Lodge demonstration project to move forward.

The demonstration project differs from the project contemplated in the 2014 prefeasibility study. Unlike the originally scoped project, the demonstration project: (1) is much smaller in scale in terms of processing capacity; yet (2) goes further by incorporating a separations facility to generate purity REE products whereas the prefeasibility study envisioned that the produced product would be a mixed concentrate.[21]

The project scope for the demonstration plant is outlined in RER's June 2021 Corporate Presentation (Figure 2).



As can be seen, the demonstration plant will produce a few separate streams of purity REE concentrates, including a NdPr product. According to a RER consultant, the demonstration plant will process up to 1,095 tons/year and yield up to 15 tons of NdPr at >99.5% purity as well as an HREE concentrate, that will be available for further refining.

The project possesses a 1,000 ton stockpile of an exploration sample of mixed concentrate that was excavated in 2015.[23] Therefore, the midstream concentrations and separations demonstration plant can quickly commence operations without the need to recommence mining operations.

The demonstration project, being small in scale, does not represent the commercial potential of the Bear Lodge deposit, but will generate data that will be used in the design of a commercial sized facility. The demonstration project will produce only 15 tons/year of purity NdPr and an unknown stream of other HREE. At current market prices for NdPr oxide, 15 tons per year yields ~$2.8 million.

The Bear Lodge deposit has the proven reserves to support significant REE production growth, far above the volume contemplated in the demonstration project scope. Constructing and operating a midstream REE separations and concentrations demonstration plant in Wyoming is only one step in advancing an REE supply chain in the state.

B. Other Potential Conventional REE Sources

The Wyoming State Geological Survey (WSGS) identified occurrences of REE across the state in its 2016 Report on Rare Earth Elements in Wyoming.[24] The most significant conventional REE deposit in Wyoming is the Bear Lodge deposit, as discussed above. Few other truly enriched areas exist across the state based upon historical sampling.

However, Wyoming hosts several other potential conventional sources of REE that include:

- Igneous rocks that commonly host higher than average REE concentrations and include alkaline igneous rocks, pegmatites, and carbonatites.
- Placer deposits, which are formed by the weathering, erosion, and transport of rocks and minerals, and paleoplacer deposits, which are ancient, consolidated placer deposits, can contain minerals that host REE. The REE content of a given placer or paleoplacer deposit is dependent upon its source rock type. In Wyoming, such deposits are found in portions of the Flathead Sandstone and Mesaverde Formations.
- Sedimentary phosphates, including the Phosphoria formation in Wyoming.
- Uranium deposits.

Further testing in areas where prior sampling showed higher concentrations could be accomplished, as well as attaining sampling in areas that were not covered in geologic survey reporting. There are certainly additional opportunities worth researching, with recent REE claims already placed on some locations across the state. The relationship between REE and Wyoming's sedimentary phosphate deposits and uranium roll-front deposits is currently being investigated.[25]

C. Unconventional Sources of REE

Unconventional sources of REE include both geological materials like sedimentary phosphates, uranium roll-front deposits, coal sediments, and industrial waste streams produced from geological materials processed in other industries, such as fly ash produced from the combustion of coal at power plants. Other materials exhibit promising REE concentrations, extraction potential, and/or total volume, like phosphates, which provide a proven and often discussed potential resource for REE[26] based on concentration alone. These materials are also relatively abundant and occur across the US.

Materials identified as potential unconventional REE resources have one or more of the following qualities: higher-than-average REE concentrations, large total volumes of materials, materials availability, and ease of extraction of REE from the material. Most recently, the DOE has focused on unconventional REE resources with total REE concentrations at or above 300 ppm.[27]

Wyoming possesses promising unconventional sources of REE. All coal basins in Wyoming and the adjacent regions are currently being investigated for REE potential under the DOE-funded Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) initiative, as well as being evaluated prior to CORE-CM by both federal and state funded projects. Additionally, phosphates, uranium roll-front deposits, and other geological and industrial waste products have been initially assessed for REE potential.

A description of Wyoming based unconventional sources of REE follows.

i. Coal Materials and Coal By-products from the Powder River Basin (PRB) and Greater Green River and Wind River Basins

Of the various unconventional sources of REE in Wyoming, coal and coal by-products offer significant potential for REE extraction and are the subject of DOE funded research. The DOE funded CORE-CM Initiative focuses on catalyzing basin-wide economic growth and job creation around all parts of the carbon ore, REE, and critical mineral value chains. In 2021, the DOE funded[13] CORE-CM projects focused on fossil fuel-producing regions; two of the projects focus on Wyoming basins – (1) the PRB and (2) the Greater Green River and Wind River Basins.

Perhaps the most researched unconventional REE resource in Wyoming is PRB derived coal and PRB derived coal by-products. PRB coals are shown to contain basinally-distributed REE resources that are dispersed in a predictable fashion,[28] providing the possibility for resource estimations in the near future.

Current work on this topic includes researchers across the US working in collaboration to reach a point where accurate estimation of the in-place resource can be made. REE anomalies in PRB coal are apparent in volcanogenic air-fall ash and clay-bearing humic material. Clay bearing humic material hosts concentrated REE at the top and bottom of coal seams and is enriched in middle and heavy REE.

> **"In fact, calcium-enriched PRB coals constitute the largest percentage of current US coal by-product stocks, and are shown to be conducive to high recovery, low energy REE extraction."**

Of all potential unconventional REE resources in Wyoming or hosted from Wyoming based materials, coal fly ash and legacy fly ash landfills provide the most easily quantifiable target(s). As PRB is the largest U.S. based coal basin, there are vast quantities of this material sitting at coal fired power stations across the country. In fact, calcium-enriched PRB coals constitute the largest percentage of current US coal by-product stocks, and are shown to be conducive to high recovery, low energy REE extraction.[29] [30] The geochemical consistency between stocks recorded from different locations over time suggests that accurate basin-scale REE assessments of PRB coal by-products can be developed. Full characterization and estimation of the volume of the REE resources in coal and coal by-products in the PRB is ongoing. Extensive research has studied the chemistry of these materials and suggested viable pathways to realize fly ash and landfill materials as REE prospects, especially those derived from PRB hosted materials,[31] but more importantly current extractive processes developed by the National Energy Technology Laboratory (NETL) have been tailored to these materials[32] and have shown favorable results. The processes developed by NETL to extract REE from Wyoming's high-calcium fly ash successfully requires less effort than most other fly ashes derived from U.S. sources;[33] the processes are currently being optimized to best economics. These materials have similar chemistry to what is described from Wyoming sourced samples by Bagdonas[34] and have been identified to have favorable extraction properties by Stuckman.[35]

The Greater Green River and Wind River basins are also being evaluated and studied. Initial evaluation of certain coals has yielded positive results in identifying REE behavior similar to occurrences elsewhere in the region. Currently, both basins are included in the current CORE-CM effort with a large part of that project focused on preliminary understanding of potential unconventional REE resources associated with coal sediment systems.[36]

ii. Phosphoria Formation

Sedimentary phosphate (phosphorite) deposits are potential sources of REE and the extraction of REE from these deposits can be less complex than traditional processes.[37] Sedimentary phosphate deposits in Wyoming, including portions of the Phosphoria formation, are currently being investigated to better understand the potential resource, the concentration of REE within different portions of the Phosphoria formation, and the distribution of REE within different mineral phases in sedimentary phosphates.

iii. Uranium Roll-Front REE Associations

REE are commonly associated with uranium deposits. The types of uranium deposits in Wyoming that may have REE associations include tabular, unconformity-related, roll-front, and paleokarst carbonate hosted deposits. REEs in such deposits can be directly incorporated into uranium-bearing minerals (such as monazite, zircon, and xenotime), or alongside them in separate REE-bearing minerals. The latter case (and best researched relatively) includes many Wyoming roll-fronts, where uranium and REE are predominantly held in minerals containing one but not the other, respectively. REE concentrations in Wyoming roll-fronts have thus far not proven to be economic. Research gaps persist related to REE concentration and mobility, and regarding fluid chemistry, temperature, and pressure variations in different uranium deposits in Wyoming. Specific work has been completed on uranium roll-front deposits in the PRB[38] and the Greater Green River Basin,[39 40 41] which help to shed light on the different conditions that may affect REE concentration and mobility.

Section II

Building a Wyoming Based REE Industry

Given the proven and potential REE resource base in Wyoming, the state is both a logical and attractive location for a US based REE supply chain. As will be explained below, Wyoming possesses other specific qualities, that make the state an ideal location for a US based REE industry. While Wyoming's environment is most conducive for an REE supply chain, for it to be a significant contributor to Wyoming's economy, such an operation needs to be a commercial scale operation. Such a project will require a significant capital investment and a lead time of three to five years to build. To ensure the project is successful, downstream firm buyers of the purity REE are necessary.

> "Wyoming possesses many relevant inherent strengths that uniquely position the state to support a thriving REE industry."

Building out an REE value chain in Wyoming is a unique opportunity for the state with several potentially significant positive economic impacts for Wyoming communities and the state. Wyoming possesses many relevant inherent strengths that uniquely position the state to support a thriving REE industry. Time is limited however, as there are other commercial scale REE midstream projects underway in the US.

A. Wyoming's REE Attributes

Hydrogen is a natural fit for Wyoming energy production, as the state's natural resources and existing infrastructure are well-suited to launch a hydrogen economy. Its long history of hard rock mining, with significant expertise in the coal mining sector, imbues the state with very important structural and institutional advantages. Wyoming has:

- *Access to reliable and proven transport networks* - Given the state's dominance in coal production, which is primarily exported to other states,[42] functional inter- and intra-state transport networks are in place to transport processed REE material and/or final end-use goods containing REE to other areas of the country. Wyoming's ready access to rail is a valuable asset that could ensure REE purity products and/or REE containing manufactured items can affordably and reliably be delivered to consumers.
- *Established and experienced workforce* – Wyoming is home to hundreds of residents who have experience and expertise in the mining industry.[43] There are experts in the state on all aspects of the value chain – from physical removal of the ore to the legal and environmental requirements for such an operation. The state government employees have extensive expertise in dealing with the intricacies of the operations of the mining industry. This institutional knowledge while intangible, is particularly valuable, in that Wyoming should be able to move more nimbly in staffing and establishing an REE operation.

- *Reliable energy supply* - Wyoming is a net exporter of its energy production. Wyoming has significant firm and reliable power resources. As of 2020 per the EIA, the state exported 60% of the electricity it generated.
- *Developable land* – Wyoming has significant amounts of developable land to support an REE industry.
- *Business friendly environment* - The state has low taxes for the population it supports. With no income tax, individuals and companies can keep their income and spend and invest it freely. Property taxes in the state are among the lowest in the nation.[44]

Outside of other general market issues, given Wyoming's resource base and overall conducive environment for a thriving REE industry, the advancement of a commercial scale REE supply chain and related downstream industry appears to be only a matter of will.

"Outside of other general market issues, given Wyoming's resource base and overall conducive environment for a thriving REE industry, the advancement of a commercial scale REE supply chain and related downstream industry appears to be only a matter of will."

B. Market Dynamics

A Wyoming based REE industry must confront various factors that characterize the current REE market. One is the overall global market supply/demand dynamic, which at present is dominated by China. Another is the fact that there are several other US based midstream projects either in progress or in the pre-construction phase, many of which are also receiving federal funding. Once in service, Wyoming's project(s) will have to compete not only globally, but also with other US based operations. In addition, there are permanent magnet projects being pursued in the US, some of which are directly connected to midstream projects and will go in service when the midstream facilities come online. A third issue is the coming demand growth in the US for products that require REE to meet various state environmental policy mandates such as renewable portfolio standards and zero emission goals.[45]

Currently, the US exports nearly 100% of the mixed REE concentrate it produces, as the production from the Mountain Pass mine in California is sent to China for further processing. The US imports purified REE from abroad for its own consumption. But the US' own consumption is relatively small (approximately 21,500 mt out of the global consumption estimated in Paper I of 568,000 mt). US based REE midstream operations will face a similar circumstance given the concentration of REE demand in China; output will have to be exported out of the country and likely to China.

There is limited manufacturing capacity in the US that requires REE. According to the USGS 2017 Minerals Yearbook, there are a few US-based processors of rare-earth magnet alloys and rare-earth magnets. However, in 2017, of the total estimated REE consumption in the US, only about 10% was consumed in the US metals and alloying sector. And as of 2020 there were no operational Neodymium Iron Boron (NdFeB) manufacturing facilities in the US.[46]

Examples of US based REE midstream separations and permanent magnet projects follow:

- Lynas Corp Ltd. is building two rare earth separations facilities in the US, one for light rare earth elements (LREE) and the other for HREE. In July 2020, Lynas received funding from the Pentagon to support the building of an HREE processing facility in Texas. It is partnered with Blue Line Corp. for the project. In February 2021, the Department of Defense (DOD) awarded $30.4 million to Lynas for a separate LREE processing project.[47] Both projects will be built in Hondo, Texas and receive REE concentrate from Lynas' Mt. Weld mine in Australia. The projects are still in the planning and design stage.
- MP Materials, Corp. (owner and operator of the Mountain Pass mine) is working on two projects:
  - In November 2020 it was awarded $9.6 million from the DOD related to the Defense Production Act Title III technology investment program to support an LREE processing plant project. The project is expected to result in separated NdPr Oxide. In late 2021, MP Materials announced a strategic partnership with GM to build a permanent magnet manufacturing plant in Texas. GM will purchase the finished permanent magnets as production ramps up at the plant. The plant is designed to produce 1,000 mt of finished Neodymium-iron-born magnets a year, or enough to power approximately 500,000 EV motors annually.[48] Targeted production rates from the LREE separations facility are anticipated in 2023. According to current plans, the permanent magnet facility will ramp up production beginning in 2023.
  - MP Materials, Corp. also received $35 million in funding from the DOD on February 22, 2022 to support the building of a commercial scale HREE processing facility. MP Materials plans to invest $700 million by 2024.[49]
- USA Rare Earth, the developer of the Round Top Heavy Rare Earth and Critical Minerals project in Texas, announced the purchase of the neodymium iron boron manufacturing equipment located in North Carolina from Hitachi Metals America, Inc. Production capacity is approximately 2,000 mt/year of permanent magnets. USA Rare Earth estimated the project could supply 17% of the US market for permanent magnets.[50]
- In July 2020, "the Department of Defense entered into a $28.8 million agreement with Urban Mining Company, to assist in developing a domestic source for NdFeB rare earth permanent magnets."[51] In November 2020, the Pentagon also provided funding of $2.3 million to TDA Magnetics and an additional $860,000 to Urban Mining to focus on rare earth magnet manufacturing.

Federal funding is also being directed to the unconventional REE industry. On Feb 22, 2022, the DOE announced it will be providing $140 million in funding to support the "construction and operation of a new facility to demonstrate the commercial feasibility of a full-scale rare earth element (REE) and critical minerals (CM) extraction and separation refinery using unconventional resources."[52] The DOE issued a request for information that "solicits feedback on demonstration facility features, supply chain considerations, research and development needs, business models, and potential societal impacts and benefits. The information requested will also help inform a site-selection process that emphasizes active community outreach and consultations with historically underrepresented communities and prioritizes environmental justice."[53]

As noted previously, Wyoming is particularly rich in the unconventional sources of REE being the largest coal producer in the country.

US energy policy, consumer preferences, and related factors are anticipated to lead to increased domestic demand for large volumes of products that require REE. State policy mandates and corporate car manufacturer decisions being made to shift to electric motorized technologies alone will require as surge in permanent magnet production.[54] The state of California has banned the sale of combustion engine vehicles in 2035 and requires that 100% of its electricity come from zero-carbon resources by 2045.[55] "Thirteen states—New York, Massachusetts, Vermont, Maine, Pennsylvania, Connecticut, Rhode Island, Washington, Oregon, New Jersey, Maryland, Delaware, Colorado—and Washington, D.C., have adopted California's Green House Gas (GHG) standards and/or Zero-Emission Vehicle (ZEV) program under the authority of Section 177 of the Clean Air Act."[56] Massachusetts and New York recently adopted California's planned ban on combustion vehicle sales in 2035.[57]

General Motors (GM) announced that it would transition to manufacturing zero emission vehicles by 2035.[58] "Audi has declared that it will stop producing internal-combustion-engine vehicles by 2033 as it transitions to a full-EV lineup. Volkswagen will stop selling internal-combustion-engine[] vehicles in Europe between 2033 and 2035."[59] Other car manufactures are also establishing goals for the partial or complete phase-out of internal combustion engines in their car manufacturing.[60]

Nearly every wind turbine requires REE as well.[61] State renewable portfolio standards and related policies will support continued growth in wind infrastructure build out in the US.

To meet the coming demand, countries around the world will need more purity REE production and more permanent magnet manufacturing capacity. China is already ramping up both. With REE midstream projects underway in the US, part of problem should be solved. However, absent domestic demand or demand from countries outside of China, the marginal production streams will necessarily flow there. China's monopolistic control over the global REE value chain and its ability to influence prices could easily threaten a US based producer without a firm buyer in place.

For REE midstream operations in the US to be viable and competitive, US-based downstream manufacturing capacity needs to be planned and built. Given the anticipated US-based demand growth for products requiring REE will occur over the next 10 to 25 years, timely action will permit the build out of both the midstream REE processing capacity and the downstream manufacturing capacity. The construction of the facilities would ideally occur in tandem so that once the processing facilities are operational, domestic buyers are in place to purchase the product.

> **"For REE midstream operations in the US to be viable and competitive, US-based downstream manufacturing capacity needs to be planned and built."**

C. Economic Impacts of a Wyoming REE Industry

Wyoming's REE economic potential hinges largely upon (1) the success of the Bear Lodge demonstration project and RER's ability and desire to increase the scale of the facility to be a commercial operation and (2) if Wyoming's vast amounts of unconventional sources REE can be exploited.

Wyoming would receive a few different sources of tax revenue from a REE mining and midstream processing operation: (1) severance tax revenue of 2%[62]; (2) property tax revenue for land at 9.5%[63]; (3) property tax revenue of 11.5%[64] on the industrial facility; and (4) ad valorem tax.[65] For a permanent magnet manufacturing operation, Wyoming would receive all revenue sources as noted for the mining and midstream operation, except for severance tax.

According to RER consultants, the current demonstration project contemplates employing fifteen to seventeen skilled laborers and maybe four to five salaried technical/managerial employees. The plant will produce 15 tons/year of >99.5% purity NdPr, as well as unknown amounts of Lanthanum, Samarium, Europium, Gadolinium, and a HREE concentrate. The plant will process 3 tons/day (2.72 mt/day, or 6,000 pounds/day) or 1,000 tons/year. Half of the plant output will be the property of the DOE and will yield no revenue to RER.

Compared to a commercial scale operation, the Bear Lodge demonstration plant will generate less revenue and related tax stream, particularly for the first year of operation. With 1,000 pounds of excavated material already available, there are little to no direct mining costs, so the severance tax revenue will be zero; in addition, until such time that purity REE product is produced and sold, there will be no ad valorem tax revenue. Tax revenue will be limited to property tax revenue on the facility and the land. Severance tax revenue will occur once mining operations recommence at the mine site and when the product is sold.

Recall that the current project scope contemplates a NdPr stream of 15 tons/year. The 2014 prefeasibility study provided a methodology for estimating revenue by REE using the recovered distribution of REE in a 1,000 gram sample of concentrate.[66] The report shows NdPr to be 23.2% of the total; the other LREE comprise 72.9%; and HREE the remaining 3.9%. If NdPr is assumed to be 23.2% of the output stream then using the 15 tons of NdPr output, implies total output of ~65 tons.[67] Assuming recent REO prices yields a total annual revenue stream of ~$3.3 million. Half of that will be the property of the DOE. Assuming DOE material does not incur severance tax or ad valorem tax, RER would in theory, realize $1.65 million in revenue subject to severance tax and ad valorem tax.

To estimate annual tax revenue from the demonstration plant, estimates for each tax's cost basis must be calculated. In its 2014 prefeasibility study, RER estimated its severance tax expense using the state's "direct cost method."[68] The direct cost method takes the ratio of direct mining costs and the total of all direct costs associated with mining, transport, and processing; the ratio is applied to the revenue received for the sale of the material at the outlet of the processing plant. In the 2014 study, the ratio of direct mining costs to total annual average mining costs was 14.5%.

Tax revenue from the demonstration plant during a year that RER runs the full operation – mining, processing, and sale – includes severance tax (@ 2%) and ad valorem tax (@ 6.15% in Weston County) that would be limited to tax on 14.5% of the $1.65 million, or a cost basis of $236,046; and property tax on the land of 9.5% and on industrial plant of 11.5%. Table 1 shows that annual tax revenue from the estimated ~65 ton/year full demonstration plant operation would be ~$445,370 (before depreciation is employed on plant).

Table 1: Estimated Annual Tax Revenue from Demonstration Plant @ 65 tons/year REE Output

DEMONSTRATION PLANT ANNUAL TAX		
Property	Cost Basis	Tax Revenue
land @ mine and upton	$6,000,000	$43,320
demo plant	$43,800,000	$382,812
Total Annual Property Tax		$426,132
Sev Tax	$236,046	$4,721
Ad Val Tax	$236,046	$14,517
Sev & Ad Val Tax		$19,238
Total Tax Revenue		**$445,370**

A commercial scale operation could generate multiples of this revenue, depending upon the final scope of the project and dollars invested in the requisite property and plant.

It is understood that scaling up plant output will require a significantly larger investment and different levels of technical equipment and consequently the requisite increase in investment level does not directly correspond to the increase in output. Put another way, there is not a 1:1 correlation between the increase in investment and the related product output.

MP Materials is in the process of building a separations facility that will generate purity streams of NdPr and other REE. MP Materials provided a copy of a prefeasibility study completed in accordance with the U.S. Securities and Exchange Commission (SEC) regulations regarding its separations project as part of its SEC 2021 10-K[69] filed on February 28, 2022. According to the material, MP Materials has capitalized over $167 million on the project between 2019 and 2021 and the pre-feasibility study estimates an additional ~$210 million in capital remains to be spent. According to the 2022 pre-feasibility study, the plant will produce ~18,000 to 19,000 mt/year of purity streams of oxides during years three through nine of operation, of which ~5,000 to 6,000 mt will be NdPr.[70]

The 2014 pre-feasibility study for Bear Lodge resulted in 6,000 to 10,000 tons/year of a purity mixed concentrate.[71] If a commercial scale separations facility were built to process 6,000 tons/year, using 5.4% TREO and the product profile employed previously, implies NdPr oxide production of 66 tons/year and total oxide production of 285 tons/year.

To illustrate the potential tax revenue associated with a commercial scale operation, consider the following hypothetical[72] scenario: Assuming the capital investment required to process 6,000 tons/year and generate 285 tons/year in purity oxide streams is at least 50% of MP Materials estimated capital cost of ~$377 million, yields ~$188.5 million in plant investment. Estimating the possible tax revenue during the peak year of operation, includes the new plant capex and the PUG plant value (as the plant will be necessary to generate the concentrate that will enter the separations facility). This project scope, where the full value of the output is taxed, could generate an initial annual tax to Wyoming state and local entities as follows:

Table 2: Potential Tax Revenue Associated with a Commercial Scale Operation

6,000 TON/YEAR CONCENTRATIONS PROJECT		
Property	Cost Basis	Tax Revenue
land @ mine and upton	$6,000,000	$43,320
plant - PUG	$12,011,000	$104,976
plant	$188,500,000	$1,647,490
Total Annual Property Tax		$1,795,786
Sev Tax	$2,083,380	$45,183
Ad Val Tax	$2,083,380	$138,937
Sev & Ad Val Tax		$1,979,906
Total Tax Revenue		**$3,775,692**

Purity Neodymium (Nd) output alone from such an operation could support the production of over one hundred permanent magnets for wind turbines or thousands of permanent magnets for electric vehicles. For reference, a 3 Megawatt (MW) direct drive wind turbine requires 2 tonnes of rare earth permanent magnets.[73] The typical permanent magnet for a wind turbine contains ~28.5% Nd and 4.4% Dysprosium (Dy).[74] Electric Vehicle (EV) batteries require 1-2 kg of permanent magnets[75] which tend to be comprised of 24% Nd, 7.5% Dy, and 6% Praseodymium (Pr).[76] There is tax revenue upside if a permanent magnet manufacturing facility were established in WY to consume the separations facility output.

Unconventional REE economic potential remains under study but holds promise particularly given recent federal funding directed towards those resources. There are many different possibilities for the application of REE from unconventional sources.[77] Integrating such streams into a commercial scale separations facility at Bear Lodge or retrofitting the demonstration plant to employ those materials could be explored.

Wyoming possesses the potential to support a fully integrated REE industry; transforming the potential into reality requires timely effort by industry and support from policy makers.

> **"Wyoming possesses the potential to support a fully integrated REE industry; transforming the potential into reality requires timely effort by industry and support from policy makers."**

Section III

Policy Support to Achieve an REE Industry in Wyoming

Ideally there would be cohesive and well thought out federal policy regarding the development of a US based REE value chain. While federal government interest in a US based REE supply chain is manifesting itself in government-funded projects and other individual pieces of proposed legislation, it has yet to develop or adopt overarching policy regarding REE or an organized strategic plan that contemplates the full value chain.

On March 31, 2022, President Biden invoked the Defense Production Act (DPA) with respect to domestic REE supply chains.[78] Under the DPA, the President determined:

> [S]ustainable and responsible domestic mining, beneficiation, and value-added processing of strategic and critical materials for the production of large-capacity batteries for the automotive, e-mobility, and stationary storage sectors are essential to the national defense;
>
> [W]ithout Presidential action under section 303 of the Act, United States industry cannot reasonably be expected to provide the capability for these needed industrial resources, materials, or critical technology items in a timely manner; and
>
> [P]urchases, purchase commitments, or other action pursuant to section 303 of the Act are the most cost-effective, expedient, and practical alternative method for meeting the need.

Based on those determinations, the President directed the "Secretary of Defense [to] create, maintain, protect, expand, or restore sustainable and responsible domestic production capabilities of such strategic and critical materials by supporting feasibility studies for mature mining, beneficiation, and value-added processing projects; by-product and co-product production at existing mining, mine waste reclamation, and other industrial facilities; mining, beneficiation, and value-added processing modernization to increase productivity, environmental sustainability, and workforce safety …."[79]

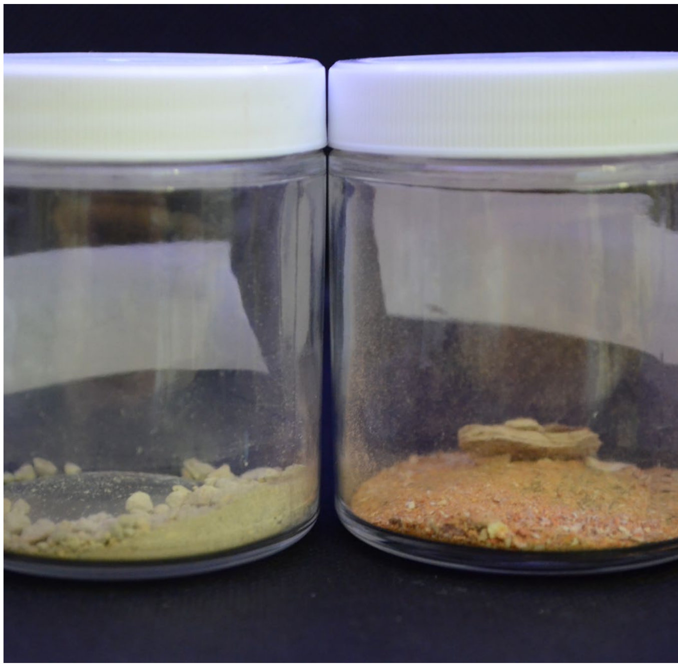
While federal action is vital to launching a robust domestic REE industry, these initial steps do little to coordinate or build upon the REE research and projects already underway in the US. Additionally, by focusing solely on the Department of Defense, it does not provide direction for coordination among the various branches of the government already funding REE projects. Most importantly, it fails to address the primary factor in establishing a viable REE industry in the US, namely the build out of consuming manufacturing capacity in the US. A key finding of this paper is the fact that for there to be a robust and secure US based REE supply chain, there must be consumers for the purity REE outside of China and ideally located in the US.

Attempts have been made to address the lack of US based manufacturing capacity. On August 13, 2021, HR 5033 – the Rare Earth Magnet Manufacturing Production Tax Credit Act of 2021[80] - was introduced in the US House of Representatives; the bill would allow for a tax credit on the production of rare earth magnets. On January 14, 2022, S. 3525 -- the Restoring Essential Energy and Security Holdings Onshore for Rare Earths Act of 2022[81] – was introduced in the US Senate; the bill would require US government contractors supplying weaponry to the US military to stop sourcing REE from Chinese based suppliers by 2026.[82] Neither bill has progressed.

In addition to new policy, existing federal mining and environmental law may require modification, streamlining, or at a minimum clarification

- GML does not address unconventional sources of minerals and it currently does not have royalty or leasing provisions for hard rock mining like it does for coal and gas development on federal land.[83]
- Under GML the National Environmental Policy Act (NEPA)[84] permitting process can take years to complete which can cause a project to become uneconomic as investment considerations and circumstances can shift significantly.
- For unconventional sources of REE the law is unclear if byproduct or waste streams meet the locatable/leasable/saleable definitions in GML.[85]
- There are several environmental laws and regulations in place that impact unconventional sources of REE given that some are likely considered hazardous or non-hazardous waste streams or other industries.
  - Resource Conservation and Recovery Act[86]
  - Clean Water Act[87]
  - Comprehensive Environmental Response, Compensation, and Liability Act[88]
  - Toxic Substances Control Act[89]

At the state level, there are also existing laws and regulations in place that impact REE mining on state lands and mining operations generally.[90] The Wyoming Department of Environmental Quality oversees three divisions related to mining: Land Quality Division, Industrial Siting Division, and the Solid and Hazardous Waste Division. In terms of unconventional sources of REE, similar issues identified at the federal level exist at the state level with a web of regulatory requirements for the treatment of waste streams. Clear policy regarding REE mining and processing could be an important objective for state lawmakers, if they agree that establishing an REE industry in the state is in its best interest.



For Wyoming (and likely other states with REE resources), an important consideration highlighted by RER is the state's agreement with the NRC regarding the handling of radioactive material. Given that the current agreement does not currently include radioactive material generated as a byproduct of REE mining and/or processing, it ideally would be amended to include radionucleotides generated as a byproduct of REE mining and processing.

State lawmakers familiar with the NRC amendment process note that it could take years and potentially millions of dollars to advance such a change through the current protocol. It took Wyoming three years to receive final approval of Governor Mead's request submitted at the beginning of 2015 "to regulate source material involved in uranium or thorium recovery or milling facilities and byproduct material as defined in section 11e.(2) of the Atomic Energy Act of 1954, as amended."[91] It was not until September 30, 2018, that Wyoming officially had the authority it requested.[92]

Whether such an amendment is required is a legal question. It is interesting that the process was apparently much easier in 2007 when California requested a change in its agreement.[93] In March 2007, the Governor of California submitted a letter to the NRC that modified its agreement to include byproduct material as defined in Sections 11.e(3) and 11.e(4) and the NRC approved the change in November of the same year.[94] Therefore, perhaps Wyoming's government could directly contact the NRC Chairman regarding this issue to identify a mechanism that expedites the requisite change(s) to Wyoming's agreement that will encompass radionucleotides associated with REE mining and processing.

Other actions state government can take include:

- Adopt a resolution that establishes the development of a Wyoming based commercial scale fully integrated REE value chain in the public interest; directs the Secretary of State to coordinate with the Department of Environmental Quality, the Wyoming Mining Association, and UW's School of Energy Resources researchers working on CORE-CM projects to identify key issues and develop practical policy solutions to address those issues that can be implemented in a timely manner; and allocates sufficient funds to the relevant state entities to support such endeavors. The legislation could adopt a timeline and identify specific deliverables and/or action items. (e.g., a provision that requires coordination with private industry to identify specific measures that can be implemented to streamline and enhance regulatory approvals and other policy requirements that impact the citing and building of commercial scale capacity).

- Identify and allocate funding sources to support the establishment of a REE value chain. Potential resources through with such funding may be processed include the Wyoming Energy Authority, Wyoming Business Council, other loan facilities, or funding for infrastructure development in the Town of Upton or Weston County.
- Work with the Wyoming federal delegation to develop policy that can be proposed in Washington to support the establishment of a US based fully integrated REE value chain that addresses the current void of such policy at the federal level and that specifically targets the establishment of downstream consumption capacity on US soil. Provisions of such legislation could include: a timeline and requirements for US sourced REE in various manufactured items, such as EV components; requirements for REE employed in military and US defense applications; incentives for producers of REE materials and manufactured products and the states where such operations occur; etc.

CONCLUSION AND RECOMMENDATIONS

While global market demand for REE is indeed increasing, predominately for the REE used in permanent magnets, China/Southeastern Asia controls nearly all off the globe's consumption for permanent magnet manufacturing - 87% of permanent magnet manufacturing capacity resides in the region.[95] Given China's dominance and its current proactive REE market consolidation, a US based REE mid-stream industry must have downstream buyers in place to mitigate the potential monopolistic market implications that in the worst case could lead to the bankruptcy of a nascent US based REE industry.

> **"Coordinated policy at the federal and state level that aids in accelerating and easing existing legal and environmental hindrances, will be essential."**

Wyoming possesses a plethora of REE resources. With the Bear Lodge deposit being one of the largest proven conventional REE deposits in the US and RER in process of finalizing its demonstration project scope, a foundation is being laid that could support a much broader full-scale commercial REE industry in the state. However, time is of the essence; preparation and planning for building a sustainable REE industry needs to occur now.

The void of a federal strategy or comprehensive policy regarding the development of a fully integrated REE value chain in the US, combined with conflicting provisions among existing mining and environmental law at both the federal and state levels, is likely to become an impediment to REE project completion. Coordinated policy at the federal and state level that aids in accelerating and easing existing legal and environmental hindrances, will be essential.

This paper is a call to action for Wyoming's policy makers, but its recommended actions can be applied by other state policy makers with REE resources or that wish to establish downstream manufacturing capacity in their states. In addition, federal representation from those states and Wyoming's could coordinate and develop federal legislation that addresses the many issues identified in this paper that are or will likely contribute to a delay in project completion and/or the inability of those projects to be successful long term.

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