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Critical Materials for the Energy Transition

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Critical Materials for the Energy Transition: Of "Rare Earths" and Even Rarer Minerals

This article first appeared in *Gravel2Gavel*, August 10, 2022

by Robert A. James, Ashleigh Myers, Shellka Arora-Cox and Amanda G. Halter

As the world pursues ambitious net-zero carbon emission goals, demand is soaring for the critical materials required for the technologies leading the energy transition. Lithium may be the most well-known of these inputs due to its usage in batteries for vehicles and consumer electronics, but roughly 50 other minerals are central to energy transition technologies. During the coming years, producers, manufacturers and end-users will be increasingly exposed to the roles played by "rare earth" elements (roughly, atomic numbers 57 to 71), platinum group metals, and other materials.

The reasons for this heightened interest are simple—even if the underlying environmental, political and technological forces at play are complex:

- **Lower-carbon technologies use different materials than carbon-intensive technologies**. The mineral requirements of power and mobility systems driven by renewable, nuclear, hydrogen and fusion energy are profoundly different from those forming the backbone of fossil fuel systems. Minerals such as lithium, nickel, copper, cobalt, and rare earth elements are vital for electric vehicles (EVs), batteries, fuel cells, electricity grids, wind turbines, smart devices, and many other essential and proliferating civilian and military technologies. For example, an offshore wind plant needs 13 times more mineral resources than a gas power plant of a similar size.

- **Ambitions for global electrification require extraordinary material production increases**. If the North American vehicle fleet goes all electric, we will need 34 times the 2020 production of key rare earths. A large share of world silver production now goes into photovoltaic systems, with demand expected to continue in the coming years. An International Energy Agency (IEA) report shows that the energy sector's overall need for critical minerals could rise by as much as six times by 2040, depending on the pace of efforts to cut carbon emissions.

- **Production, movement and supply of these materials are challenging**. Many of these materials are difficult to produce, difficult to process, and found in only a handful of hard-to-access places around the globe. "Rare earths" are not necessarily rare—lanthanum is three times more

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commonly found than lead—but they are hard to "rarefy," to separate one such element from its siblings. In many cases, the global supply of certain minerals is controlled by one country, such as China, Ukraine or the Democratic Republic of the Congo, with the actual processing capacity for extracted minerals being dominated by China. Public policies on export, import and production conditions in both the host country and the destination country will affect even the most straightforward of procurements.

- **The mineral supply chain will complicate achievement of climate and ESG goals**. The IEA warns that there is a looming mismatch between the world's strengthened climate ambitions and the supply of the minerals that are critical to realizing those very ambitions. Moreover, the carbon footprint associated with the mining and production of these minerals must also be considered and managed. Add to the logistical challenges of mining for these materials the accompanying socioeconomic concerns: How will ESG principles, for example, interact with lower-carbon technologies that increasingly depend on cobalt and other materials mined in areas with unacceptable or non-transparent labor, governance and environmental practices? Therefore, transparency and traceability throughout the supply chain will continue to grow in importance. This is reflected as well in the growing emphasis on quantitative climate-related disclosures for public companies in the U.S. and elsewhere.

Governments are taking incremental actions to encourage critical materials development and to reduce the associated risks. An example is found in the **Inflation Reduction Act of 2022**, which incentivizes U.S. production of these minerals. But the progress intended by the Act faces significant headwinds from the time- and resource-intensive regulatory reviews and environmental permitting regimes. Therefore, all participants with critical material interests and needs must seek their own counsel and take their own precautions to protect and extend their precious supply chains.

Old School Meets New School: Critical Minerals Used in Quantum Computing

This Article first appeared in *Pillsbury's InternetAndTechnologyLaw.com*, March 22, 2023
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It is not every day that the rough-and-tumble "giga" world of mining and mineral refining interacts with the rarefied and metaphysical "nano" realm of quantum physics. The lawyers at Pillsbury and other law firms engaged in each endeavor rarely darken each other's doors. But the streams are indeed converging today, as rare earths and related critical materials have been found to be uniquely suited for developments in quantum computing.

The quirky theories and discoveries of particle physics have transfixed fiction writers and real-life scientists for decades. With the recent, rapid **exploration of quantum computing**, some of these ideas are shifting from fantasy into **practical application**. Researchers and investors see a future where super-charged computers will break barriers in **industries** like finance, automotive, energy, pharmaceuticals and many more. The quantum computing market is expected to grow by **around 30%** by 2029.

Quantum technology runs on the notoriously difficult-to-stabilize qubit. Unlike binary bits in classical physical components in computers and cell phones, qubits can operate in more than one state at a time (known as superposition), and they have an uncanny ability to remain interconnected even when separated (known as entanglement). These features mean that the speed with which quantum computers can solve problems is virtually limitless—once science understands how to capitalize on their abilities, that is. An **MIT article** reports that an encryption problem that only a short while ago was thought to require billions of qubits may be susceptible to solution with a much more manageable number.

But there's a hang-up—**quantum machines are finicky**. They tend to like things quiet, still and cold, in some cases requiring a temperature around absolute zero, or about -460 degrees Fahrenheit. The quantum computing process must be isolated and protected from "decoherence." Noise in the system means that answer-checking routines consume enormous amounts of computational effort and energy.

Scientists are still working out the best ways to help quantum machines function in real-world scenarios. Regardless of the paths taken to get there, it seems a given that rare earth metals and other critical materials will prove **essential building blocks**.

Rare earths themselves are described in **our prior post** concerning their use in the energy transition. Each element has subtle differences in charge characteristics that can be isolated with precision in the beneficiation, processing and manufacturing process. That precision can in turn address this field's other biggest challenges—scalability and reproduction.

As scholars grapple with these puzzles, a number of techniques have emerged for taming otherwise rowdy qubits, each with its own material needs. Some of the elements are household names, while others are generally known only as obscure boxes on a high-school chemistry class periodic table.

- **Superconducting**: At a low-enough temperature, metals like **aluminum** and **niobium** no longer offer electrical resistance. This phenomenon makes them popular options for keeping fussy qubits stable in superconductor systems. Superconducting quantum computers are perhaps farthest along on their path to usability, with tech companies betting heavily on the approach. For example, **Rigetti Computing** is making advances in quantum computers and the superconducting quantum processors used to power them.
- **Trapped Ions**: Trapped ion quantum computing is another established path for advancing this technology. Here, ionized atoms derived from the rare earth **ytterbium** are converted into ions and then used as qubits. Such a system can remain in a specified quantum state for longer periods of time.
- **Photonics**: Crystals from **europium**, another rare earth element, have opened doors in the world of photonic quantum computing, which essentially **turns light into qubits**. Researchers think the material will be able to hold a high density of qubits in an identical and well-defined position. The U.S. Defense Advanced Research Projects Agency (DARPA) **has partnered** with a photon-based company in an effort to build the first utility-scale quantum computer.
- **Neutral Atoms**: In addition to the rare earths, the alkali metal element **rubidium** is playing a role in neutral atom computing. Still in the early stages of study, scientists aim to control the quantum state of rubidium atoms using a laser.

As the world makes a push for more mining and production of these distinct elements for energy and other purposes, they will play a surprising role in computing innovations. Lawyers familiar with quantum computing concepts will be instrumental in prosecuting intellectual property rights and expanding their application through licensing and commercialization. But the lawyers developing sources, products, and markets for rare earths and other critical material will also be involved in making the quantum leaps.

Blue Gold: Critical Water for Critical Energy Materials

This article first appeared in *Gravel2Gavel*, September 27, 2022
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As demand increases for low-carbon technologies to power the energy transition, the acquisition of critical materials—so-called given their integral role in the transition of energy activities—is becoming increasingly important. As described in our **previous post**, such critical materials include rare earth elements (REE), lithium, nickel and platinum group metals. In short, the transition endeavors to reduce use of one non-renewable resource—fossil fuel—by significantly ramping up our use of other non-renewable resources. While critical material discussions have largely centered on the availability and economic extractability of the minerals themselves, Pillsbury is also counseling on the other resources needed to bring the materials to market at the scales required for our decarbonization goals.

Chief among these resources is water. The extraction, processing and manufacture of critical materials into low-carbon technologies all require significant volumes of water. For example, up to 5,000 gallons of water are needed to produce one ton of lithium. Critical materials are often found in arid climates that are already experiencing water stress (such as the "lithium triangle" of Argentina, Bolivia and Chile, and copper in Chile), or in areas experiencing conflict and challenges to water development (such as cobalt production in the Democratic Republic of the Congo). In the U.S., development potential resides largely in the water-constrained western and southwestern states, such as Arizona (copper), California (REE), New Mexico (copper, REE), Texas (REE), Utah (magnesium, lithium, platinum, palladium, vanadium, copper), and Wyoming (REE, platinum, titanium, vanadium).

Securing water to perform these processes is a threshold hurdle, and water rights schemes vary across jurisdictions. In the U.S., each state has a separate water right permitting or allocation regime, and inter-basin transfers from water-rich to water-poor areas are not always viable options legally or practically. Interstate compacts are already experiencing conflicts over usage rights and claims among member states. Adding to the complexity is that climate change—the very risk critical materials are being deployed to combat—influences the water cycle and when, where and how much precipitation falls. These challenges increase supply chain vulnerabilities for critical materials.

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Compounding water availability concerns are water quality concerns. Both extraction and production can yield significant quantities of process wastewater, the treatment and discharge of which are subject to strong permitting regimes. For instance, the platinum group metals—used in hydrogen fuel cells—are more soluble than other critical materials. Permits for wastewater discharges to the environment pursuant to the federal Clean Water Act's Section 402 (33 U.S.C. § 1342) are necessary. Further, while some generators of aqueous wastewater streams can dispose of the wastewater in public treatment works, their impact on the biological treatment processes used by such works is being evaluated.

Water is therefore a limiting factor in critical material development, both in its inputs and its outputs. To fully unleash the energy transition, advancements are needed in reuse and recycling; incremental production; and use efficiency and treatment.

- **Reuse and Recycling**. To mitigate potential shortages and mitigate concern about contamination from discharges, critical materials developers are exploring opportunities for water reuse and recycling. Closed-loop recycling in the extractive, processing and manufacturing processes provides not only a reliable water resource, but contains the used water so it is not discharged into the environment. Regulatory oversight for water reuse and recycling varies by jurisdiction. As publicly announced, **MP Materials**, the leading producer of REE in the Western Hemisphere, has implemented tailings and concentrate dewatering methods to provide a closed-loop water resource, satisfying 95% of the company's water demand at its Mountain Pass, Calif., mine.
- **Unconventional Extraction and Recovery**. Rather than develop additional supplies using energy- and resource-intensive extraction methods, some are looking to recover critical materials from existing processes. As one such initiative, the U.S. Department of Energy announced the Critical Materials Institute is exploring methods to commercialize **lithium extraction from the brine** brought to the surface as part of the geothermal energy process before the brine is reinjected into the geothermal resource.
- **Use Efficiency and Treatment**. According to **testimony to the U.S. Senate Committee on Energy and Natural Resources**, studies are ongoing at West Virginia University regarding the recovery of REE from acid mine drainage—a common byproduct of the mining industry, the inadequate management of which can lead to significant exposures in the U.S. under the Comprehensive Environmental, Response, Compensation, and Liability Act (CERCLA, or Superfund, 42 U.S.C. § 9601 et seq.). Such a use of this drainage could aid in appropriate management of such waste, as its recovery is less water-intensive than conventional extraction methods. In fact, efficient REE recovery is not possible without at the same time bringing the rest of the mine water stream to levels that may, depending on the water quality effluent limits for the receiving water, help meet Clean Water Act Section 402 permit limits.

As the development of critical materials resources expands, the realities of water demand will be increasingly felt. Water stress and regulatory dictates may limit access to water resources needed for extraction, processing and manufacturing processes on the front end, and spur concerns over water quality on the back end. As such, water supply and permitting regimes must be considered from the outset of critical material projects. Innovative methods will be needed to mitigate supply and quality issues. Those in the critical materials supply chain should seek counsel on how to effectively deploy such measures.

Lithium for Batteries from Geothermal Brine

This article first appeared in *Gravel2Gavel*, June 10, 2024

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If all goes as planned, solar, wind and other clean energy technologies will help us abandon carbon emissions for good. But many green power sources perform their best only when nature cooperates, so an important (and sometimes overlooked) component of the energy transition is the ability to store electricity for a rainy or calm day. Lithium is the ingredient of choice for electric vehicle batteries, solar panels and grid elements. As these innovations ramp up, lithium demand is expected to **soar by 90%** over the next two decades, driving a surge in production efforts. Some experts predict a **deficit** in the mineral by as soon as 2025.

Predominant mining and extraction processes can be detrimental to the surrounding air, soil and water, in contrast to the environmentally friendly intentions of the lithium applications. But another type of renewable energy may be able to provide a solution. Hydrothermal brine, a high-saline water mixture found deep within the Earth's crust, contains lithium-rich deposits that have leached from heated rocks into underground water. Geothermal power players employing hydrothermal brine are spearheading plans to extract the valuable resource in a cleaner and more sustainable manner.

Why Lithium?

First commercially developed around 1985, the lithium-ion battery **quickly overtook** other types of batteries due to its high storage capacity. Its creators even won a Nobel Prize in 2019. As electric vehicles have come to the forefront of the energy transition, technological breakthroughs have only made these batteries more efficient and versatile. Clean technologies like wind farms and solar plants, some of the fastest growing energy sources, rely on lithium-based storage. The International Energy Agency (IEA) reported that compared to 2010, **50% more minerals** are now needed, on average, per new unit of power generation capacity—due in major part to the rising use of low-carbon innovations.

The United States has responded to the demand with the Department of Energy's (DOE) 2021 **National Blueprint for Lithium Batteries**, which states that "by 2030, the United States and its partners will establish a secure battery materials and technology supply chain that supports long-term U.S.

economic competitiveness and equitable job creation, enables decarbonization, advances social justice, and meets national security requirements." The Biden Administration has also cited **over-reliance on foreign supply chains** as a reason for boosting domestic lithium production. Meanwhile, the EU recently signed **strategic partnership agreements** with 12 countries for rare minerals, and in March, it finalized the Critical Raw Materials Act (CRMA). The law named 34 critical elements, and lithium is among the 17 elements specified as being of absolute strategic importance.

A New Extraction Plan

Lithium is found in a handful of sources: minerals, clays, oceans and brines (salt flats, geothermal brines, and oil fields including the Arkansas Smackover), with brine sources **accounting for 66%** of the world's present supply. It is extracted in the form of lithium carbonate, which is then processed so it can be used in our modern gadgets. South America is a major producer; in the region's salt flats, or "lithium deserts," saline groundwater is pumped to the surface and evaporated in large basins, where the water leaves behind salts that include lithium. The process is water-intensive and the lithium recovery rate is low. Australia and China are also leading producers and primarily use open-pit mining of hard rocks, including the lithium-bearing material. With current supplies coming almost entirely from China, Australia and Chile, U.S. leaders have set their sights on accessing domestic lithium via sites like California's Salton Sea region. And under the CRMA, Europe aims to produce 10% of lithium domestically by 2030. Currently, the region's only active lithium mine is in Portugal.

So far, evaporated and open-pit lithium extraction processes have been the "greenest" options available. But now, geothermal plants could offer a more sustainable possibility through a process known as direct lithium extraction (DLE). **Geothermal** energy, a rising star in the green energy movement, has a small physical footprint, virtually no carbon emissions, is not weather reliant and, as it turns out, can do double duty as a lithium resource. Geothermal electricity works by pumping hot salty water, or brine, up from thousands of feet below the Earth's surface and turning it into steam that powers turbines. The water is then recirculated into aquifers. That same power-producing brine contains lithium that can be extracted before reinjection of the liquid, and the process can be repeated over and over until the brine is too diluted to continue. Though lithium exists in small concentrations within the brine, the large scale of geothermal power production could yield a significant output. By one estimate, California's existing geothermal plants can produce enough lithium to fully meet **U.S. demand**, with plenty more to spare for exports.

Projects on the Horizon

On a global scale, projects and research that aim to take advantage of the lithium in geothermal brine are well underway.

- **Europe:** A **2023 study** published in *Advances in Applied Energy* reported that pilot plants in the Upper Rhine Graben region of France and Germany, an area with natural geothermal reserves, show promising results. The study noted that while geothermal operation costs will likely not drop as low as solar or wind, the revenues from lithium can offset expenses, offering a cost-effective and energy efficient solution. Vulcan Energy Resources has announced plans to start phase one of its geothermal and lithium extraction plant in this region of Germany. In addition, in the famously beautiful, coastal county of Cornwall in the United Kingdom, companies **are collaborating** on a demonstration project that will combine hydrothermal power with lithium extraction. The pilot will focus on a range of DLE technologies.

- **United States:** The Salton Sea region, a swath of California lake and desert that is brimming with rich geothermal activity deep below the surface, is home for at least a dozen geothermal power plants. The existing plants mean that a significant portion of the infrastructure is already in place to extract lithium. In January 2024, Controlled Thermal Resources **began construction** of a new facility in the area that will output both power and lithium, starting with 25,000 metric tons of lithium and ultimately producing up to 175,000 metric tons. At the John J. Featherstone geothermal plant in the Salton Sea, **EnergySource Minerals** has partnered with Ford to produce lithium in a closed-loop, sustainable process; the new approach is projected to allow the company to tap into an existing geothermal plant and remove lithium from brine that has already been used to generate geothermal power.

On a national scale, the DOE recently awarded its $4 million **Geothermal Lithium Extraction Prize** to five teams who will use the funds toward increasing market viability for direct lithium extraction from geothermal brines. The National Renewable Energy Laboratory also reported that additional lithium extraction technologies are approaching **commercial-scale demonstrations** by operators in the Salton Sea.

The chief obstacle for American brines is that impurities such as magnesium and calcium interfere with DLE lithium recovery. Recently, lithium extraction technology, using chemical reactions different from DLE, has been developed in South Korea and its efficiency and economic feasibility using the American brines has been validated. This **CULX** technology is expected to produce substantial additional quantities of lithium to support American energy transition demand.

Looking Ahead

A California State Legislature **commission on lithium extraction** reported in 2022 that the Salton Sea region likely contains the world's highest concentration of lithium in geothermal brine, a finding that could be a major boost to zero carbon goals for the United States and beyond. Researchers across the globe are also looking to tap into geothermal technology for lithium recovery, but innovating and scaling up such operations pose challenges. As Lawrence Berkeley National Lab researcher Dr. Patrick Dobson **noted**, "The key challenge now is to develop the science of extracting lithium from geothermal brines in a cost- competitive and environmentally friendly manner." Environmental impact studies, paired with development of technologies that will make DLE economically viable, will be key steps to moving forward. The two-in-one nature of geothermal resources—electric or thermal power plus a key mineral for electric power generation and storage—is an appealing energy transition solution for governments and entrepreneurs alike.

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Lunar Natural Resources: A Tour of a New Horizon

This article first appeared in *Gravel2Gavel*, September 21, 2023
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With the success of the **Chandrayaan-3** this August, India became the fourth country to land a spacecraft on the moon. Improved fabrication methods like **3D printing**, plus larger-scale production of essential materials for remote activity, have made **space technology** cheaper than ever to build. Even conservative investors are financing ventures, thanks to the moon economy's estimated **$100 billion** near-term market value. Many of the planned endeavors are exploratory in nature, but they could pave the way for the eventual commercialization of the moon—namely, establishing permanent bases and mining lunar water and regolith (lunar soil).

The White House estimates that within 10 years, nations and private entities could launch up to **150 lunar missions**. The National Aeronautics and Space Administration (NASA) plans to establish a pilot processing plant for lunar resources no later than 2032. In its Commercial Lunar Payload Services initiative, the agency has already contracted with 14 private businesses (including SpaceX, Lockheed Martin Space and Ceres Robotics) who are deep in development of the tools needed for moon infrastructure.

Other countries are pursuing similar plans. Canada is running a commercially driven program in cooperation with NASA. China has announced that in the next five years, it plans to employ a robot to lay down bricks for the first-ever **moon structures**. Even smaller nations like Luxembourg and the United Arab Emirates are seeking roles. This article digs deeper into the motivations, the methods, the critiques and the legal principles, as public and private sectors contribute to a new horizon of other-worldly enterprise.

Why Mine the Moon?

The initial motivations for space activity—scientific investigation, development of new technology, national security interests, and the sheer excitement of exploration—are still with us. But why would one undertake the expense and risk of natural resource development at such a distance?

Some resources might be economically returned to Earth. Materials rare on this planet but more prevalent on the moon, if valuable even in small quantities, could justify the round trip. Some argue that obtaining metals from space for use here is environmentally preferable to mining the **bottom of the ocean**.

The more compelling attraction is using lunar resources on the moon itself, as the springboard for further space development and travel. In-situ resource utilization (ISRU), essentially the idea of living off the land, is a common goal. That entails harvesting lunar water—for consumption, for hydroponic agriculture, and for electrolysis driving breathable oxygen and hydrogen-based energy. Hydrogen rocket fuel is expected to be the basis for transport even deeper into space.

Finally, viewed from a long-term perspective, the risks of being on only one heavenly body exposed to asteroids and comets—or catastrophes of our own making—have come into focus. The dinosaurs died for want of a "Planet B," and so would we.

Key Resources

Among spacefaring nations and businesses, the most sought-after lunar materials include the following.

- **Metals and Minerals**. Critical for technology like electric vehicles, wind turbines, cellphones and many other devices, rare earths are needed to support a low-carbon future. Scandium, yttrium and the 15 lanthanides all exist on the moon. Companies like TransAstra have set their sights on mining them and delivering them back home. Rare earths are useful in small quantities, so any level of production and transport from the moon could be an economic prospect. (In response, Julie Michelle Klinger wryly comments that only a small fraction of rare earths are being recycled today, so going to the moon and back for more of them may not be as efficient as making better use of what we already produce here on Earth.)

  NASA envisions a lunar metal-making pipeline and has put out a call for university researchers to explore applications in 3D-printing. Also in partnership with NASA, Blue Origin aims to use metals extracted from regolith to generate solar power on the moon's surface.

  The bulk of lunar material is common oxygen, silicon and aluminum. Metals are not typically concentrated, since the inert moon never experienced the geologic processes that led to our own lodes and veins. But a particular concentration rudely called "KREEP"—potassium (K), rare earth elements (REE) and phosphorus (P)—occurs in the regions known as Oceanus Procellarum and Mare Imbrium.

- **Water**. In 2008, scientists confirmed the presence of water at the moon's poles, in the form of ice in shadowy craters. For those with lunar aspirations, those ice deposits have become a holy grail of sorts. Once extracted, the ice can provide drinking water for space travelers, and molecules can be split by electrolysis into hydrogen and oxygen. Hydrogen would power rocket fuel, allowing spaceships to launch off to Mars or beyond from the moon, and oxygen would provide air for living environments. Ken Wisian, a researcher at the University of Texas at Austin Bureau of Economic Geology, has described how the combination of fluids and temperature differentials between the surface and subsurface could generate geothermal energy.

- **Helium-3**. A Chinese mission recently returned to Earth with a moon sample containing helium-3. Though helium-3 is elusive on Earth, NASA estimates the moon is home to roughly a million metric tons of it. This element has been touted as a safer option than hydrogen isotopes like tritium for nuclear energy. NASA is moving toward a small-scale prototype for an extraction system to bring helium-3 back to Earth. In the meantime, Helion Energy is developing fusion reactors that make use of this rare material. In the long term, NASA views helium-3 as a prime prospect to power nuclear energy on the moon.

The Mechanics of Moon Mining

While the allure of lunar resources is strong, excavating them is less straightforward. The paradox is that sophisticated technology is needed to get *to* the moon, but mining *on* the moon will be considerably less dependent on our modern contraptions. Davide Sivolella has colorfully described the surprisingly low-technology methods that may be used.

Reduced gravity on the moon means that earthbound techniques will not work for off-world mining. Many mechanical extraction processes depend on our gravity level, and blasting would create near-permanent dust storms. Hydraulic mining is out of the question with water being a limited resource. Wide temperature oscillations and dust would wear out equipment and seals.

One finesse around these challenges is to keep lunar mining downright primitive—such as dragging a "scraper" over regolith or ice before a resilient collection bag or a series of buckets called "slushers." Augers and plows could loosen the regolith. Other possible methods of releasing material include heat, mechanical stress, chemical reaction, electric spark, lasers, and solar power (imagine a series of mirrors and magnifying glasses like those in tomb scenes in the movies).

Once mined, these materials would likely need to be processed "dry," without water or other fluid, possibly with the help of separators, crushers or solar furnaces. Manufacturing on the moon would also likely work best if kept simple. Methods under consideration include layering or adhering metals on surfaces, akin to semiconductor manufacture, and 3D printing ("additive manufacturing").

To bring all this mining and production to fruition, a crucial component will be energy. Lunar explorers and developers will need a lot of it, produced from solar, fusion, fission or geothermal sources.

Prominent Players

With all eyes looking toward harnessing the moon's resources, the following countries and entities are among those actively planning lunar endeavors.

- **United States**. NASA's Artemis project calls for putting astronauts back on the moon **by 2026**. The U.S. has also **teamed up** with Japan, the EU and Canada, among others, to develop a space station (the Lunar Gateway) within the moon's orbit. It will serve as a support and research hub for lunar mining and production, and NASA hopes to populate it with its first astronauts in 2028. By 2032, the agency aims to establish a permanent lunar base.
- **India**. In its bid to become a world space leader, India is preparing for a **manned mission** to the moon. This step will come after it launches test rockets over the next few years. In the meantime, the nation is analyzing two weeks' worth of data about the moon's composition gathered from its Chandraayan-3 rover.
- **Europe**. In 2020, the Luxembourg Space Agency launched the **European Space Resources Innovation Centre** (ESRIC), a first-of-its-kind institution that focuses purely on the research and commercialization of space resources. It is strategically partnered with the European Space Agency (ESA). In addition to its work with the ESRIC, the ESA has been hosting an **ongoing campaign** soliciting proposals for boosting ISRU in space. Though the ESA does not have any moon voyages currently on the docket, its terrestrial work is setting the stage for future space resource development.
- **China**. The People's Republic says it will land humans **on the moon** by 2030, but it will robotically build lunar structures even sooner. It also announced it will partner with Russia to build a joint moon base by 2035, and several countries have agreed to participate in its International Lunar Research Station moon base initiative. Partners include Russia, Pakistan, the United Arab Emirates and the Asia-Pacific Space Cooperation Organization.
- **United Arab Emirates**. After its initial moon rover was presumed lost in April 2023, the United Arab Emirates Space Agency says it is **developing a second rover** and will try again.
- **Russia**. A longtime player in space exploration, Russia's latest moon mission ended in a crash landing this August. However the nation's space agency, Rocosmos, says it will **try again**, perhaps in 2025-2026. Whether its budget and capability can sustain such plans, given the country's status in the community of nations, remains to be seen.
- **Australia**. A world-leader in harnessing natural resources, Australia uses remote mining techniques in regions such as the Pilbara in Western Australia. The nation's Commonwealth Scientific and Industrial Research Organisation (CSIRO) says its terrestrial **remote mining know-how** can translate to lunar resource gathering. As such, Australia plans send its **first rover** to the moon by 2026, aboard one of NASA's Artemis missions. The rover will collect lunar soil, from which NASA will attempt to extract oxygen—a key step toward sustainable human existence on the moon.
- **Japan**. Though its recent, privately operated lunar mission failed, in early September Japan successfully launched its "**moon sniper**," officially known as Smart Lander for Investigating Moon (SLIM). The craft aims to make a precision landing (which would be a unique feat) in January or February of 2024 and investigate the composition of rocks near a small lunar impact crater. Mastering precision landing will be important for future missions to resource-rich areas of the moon, where darkness, rocks and craters make landings hazardous.

A commonality in many of these space ambitions is a collaboration with—and reliance on—private sector tech companies. The commercialization of lunar exploits highlights the importance of space law.

Is it Legal?

Despite the global enthusiasm for moon travel and development, space mining projects face skepticism, scrutiny and opposition from a range of voices. Some worry about the long-term effects of **moon dust** on astronauts' lungs, while others view the potential **exploitation** of interplanetary resources of any type as cause for alarm. **One study** even claimed that extracting resources from space could devalue those materials on Earth—disproportionately causing economic harm to developing nations. Questions inevitably arise over the priority of space exploration compared with projects closer to home.

In any event, the potential use of space for human development and for extraction and use of resources is traversing uncertain legal territory. The United Nations (UN) **Outer Space Treaty** of 1967 says that space is "not subject to national appropriation by claim of sovereignty," without being very specific about resources and how they can and will be utilized. About a decade later, the UN's **Moon Agreement** provided that celestial bodies "should be used exclusively for peaceful purposes, that their environments should not be disrupted, that the United Nations should be informed of the location and purpose of any station established on those bodies." The agreement states that when it becomes feasible to extract lunar resources, international guidelines should be established under which there is to be "**an equitable sharing by all State Parties**." But that pact was not ratified by most of the very countries that are now engaged in space exploration. In fact, Saudi Arabia has given notice of its **withdrawal from the Moon Agreement** effective January 2024.

NASA more recently laid out the **Artemis Accords**. Ratified by 29 countries as of September 2023, the Artemis Accords encourage peaceful moon exploration and contemplate "space resource activities" by the signatories. China and Russia among others are not parties.

Several countries—including the United States (with its 2015 **Commercial Space Launch Competitiveness Act**), Luxembourg, the United Arab Emirates and Japan—have independently legislated legalizing celestial mining. The U.S. statute, for example, declares that mining activity and produced materials can be owned without creating national sovereignty—an interesting juxtaposition of principles.

Mark J. Sundahl, Professor of Law and Director of the Global Space Law Center at Cleveland State University, was part of the **Hague Working Group** on the topic of space development. He and Tanja Masson-Zwaan have helpfully summarized the **current state of legal play**:

> It seems likely that international and national law governing space resource activities will continue to evolve in parallel for the near future. The Outer Space Treaty provides general principles and does not, as most would agree, prohibit commercial use of space resources; the Moon Agreement is more detailed but of limited relevance because of the low number of ratifications. International soft law fills in some of the details, especially in terms of sustainability, but leaves other issues open. ... The development of national laws has so far been limited to a few cases, but they are more or less consistent and do not contradict international law.

History—from the California Gold Rush to changes in fisheries zones to the quest for metal nodules in the oceans—teaches us that the legal regime often follows the activity driven by technology, economics, and politics, not merely the other way around. We can expect that the law not only will shape, but also will be shaped by, the conditions of resource development beyond our planet.

Conclusion

NASA has described a "**lunar goldrush**," a description that, given history, showcases both the opportunities and the challenges associated with the prospect of rapid change. Space law (and space lawyers) will play an important part along the way, as rules are both applied to and modified by the brave new world of a commercialized, human-inhabited moon. In the meantime, participants in the sector will find themselves in a soft and shifting legal terrain.

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