How U.S. Policy shifted Energy & Technology Hegemony to China

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The Pentagon recently halted the delivery of F-35 fighter jets when it was discovered that they contained Chinese rare earth components. If the Pentagon would look a little more closely, they would find that Chinese rare earth derived components are ubiquitously distributed throughout all U.S. / NATO weapon systems.

It isn't only U.S. weapon systems, China controls global access to rare earth metals and magnets (and other downstream critical materials) for EVs, wind turbines, and most other green-technology.

However, China's vision is much more ambitious than controlling the supply-chain for high-tech commodities, they are leveraging their dominance into the clean energy sector. Last month Chinese authorities authorized the startup of what should be considered the world's only Generation-5 nuclear reactor: a reactor that is inherently safe, non-proliferating, and can consume nuclear waste.

The goal of Net-Zero, and any potential economic benefits, are entirely under China's control.

China's leadership position in both of these areas can be traced back to irrational policies and legacy prejudices specific to thorium, a mildly radioactive element that is commonly found in heavy rare earth minerals.

The words that follow, detail the history of how China surpassed the U.S. with its own nuclear technology and displaced its historic leadership position in rare earths.

A short history on U.S. nuclear development

In 1963 Nobel Prize Winning scientist Glenn Seaborg responded to President John F. Kennedy's request for a Sustainable U.S. Energy Plan. The report titled "Civilian Nuclear Power" called for the development and deployment of Thorium Molten Salt Breeder Reactors.

These ultra-safe reactors are nothing like the legacy reactors that make up today's Light Water fleet (LWR). When deployed globally, many believe they will be the primary backbone of Green Energy – replacing the existing natural gas dispatchable power that makes up over 70% of the 'balance-of-power' in renewable systems.

Unfortunately, Seaborg's plan died with Kennedy. The cold-war preference for uranium and plutonium over thorium in the 1960s and 70s, coupled with the 1980s modification to U.S. Nuclear Regulatory Committee (NRC) and International Atomic Energy Agency (IAEA) regulations that also impacted how thorium is classified and processed, led to the termination of the U.S. Thorium Molten Salt Reactor program and, effectively, the U.S. (French and Japanese) rare earth industry.

Today, China controls the downstream production of rare earth metals and magnets (used in EVs, Wind Turbines and U.S. / NATO weapon systems) and is boldly pursuing Glenn Seaborg's plan for clean, safe energy. China's nuclear regulatory authorities have cleared the 2MWt TMSR-LF1, China's first Thorium Molten Salt Reactor (Th-MSR), for startup. There is no U.S. equivalent program on the horizon.

Considering that the U.S. initially developed this reactor, it begs the question of why China is leading with its commercial development. That requires a bit of a history lesson.

The goal of harnessing nuclear energy began shortly after World War II. At that time, a number of Manhattan Project scientists were tasked with quickly developing civilian nuclear power. One of the mission goals was to distribute the ongoing cost of producing bomb-making materials across our secretive Manhattan Project campuses onto a 'civilian' nuclear energy program. That program eventually morphed into the Atomic Energy Commission and then to the Department of Energy.

> *From an accounting standpoint, the DOE's primary purpose was to divert the balance-sheet cost of our nuclear weapons programs off the military's books.*
>
> *For its entire history, 70% or more of the Department of Energy's budget has been directed towards nuclear weapons development, maintenance, and research programs (and cleanup funding of legacy Manhattan Project sites). As the budget priorities demonstrate, solving America's energy needs was never the first priority of the DoE. Accept that reality, and the long history of DoE mal-investment begins to make sense.*

Results came quickly. The first reactor designs, still in use today, are essentially 'first concept reactors': something more than a Ford Model T, but possibly less than a Model A, as economies of standardization were purposely never attempted in the USA, and therefore the USA never achieved the economies of scale that comes from making only 1 type of reactor model like the French and Japanese do.

The rollout of thorium MSRs will be the equivalent of a modern-day automobile (with standardization of parts and licensing, automated assembly-line production and centralized operation permitting).

Every U.S. Light Water Reactor (LWR) facility is uniquely engineered from the ground up—maximizing its cost. Every permit application is unique. Permit requirements, timelines and outcomes are fluid. The timeline from initial funding for permitting to buildout can take decades. This equates to tying up tens of billions of dollars in financial commitments over a very long time for an uncertain outcome (a number of reactor projects were terminated during the buildout phase, with some near completion). There is an incentive to drag projects out because the EPC builders of the plan are not the operators, so they have to make all their money in the build. For example, the most recent U.S. nuclear buildout is 8 years behind schedule and at twice the estimated cost. This is a recipe for failure.

The original LWR designs, largely developed by Alvin Weinberg, boiled water under immense pressure to turn a shaft, similar to the turbines of a coal fired power plant. The use of water as a coolant is one of the largest contributors to LWR system complexity, risk and costs.

Water's liquid phase range at normal pressure is 1 to 99°C. Water's natural boiling temperature does not generate sufficient pressure to economically operate traditional steam turbines so all LWR type reactors use high pressure to force water to remain liquid at higher temperatures. The need to contain coolant failures in such a high-pressure operating environment greatly effects the safety and cost of the entire system. All water-cooled reactors have an inherent design risk, no matter how small, built in.

Weinberg knew there must be a better design, but government and military support rushed in to prop up the development of the Light Water Reactor design. Admiral Hyman Rickover was the leading advocate, quickly developing the first nuclear-powered submarine. The U.S. Army also got in the game, developing a prototype mobile field reactor. The Air Force, feeling left out, looked to Alvin Weinberg to develop a nuclear-powered aircraft.

The Air Force Reactor project required that he develop something entirely new; keeping in mind that this reactor would operate inside an airplane with a crew and live ordinance. These are truly remarkable constraints in terms of weight, size, safety, and power output. Weinberg's insight led to a reactor that used a liquid fuel instead of solid fuel rods. It was simply known as Alvin's 3P reactor, all he needed was a Pot, a Pipe and a Pump to build his new reactor design. Elegant in its simplicity, its safety was based on physics and geometry – not pumps, values, backup generators and emergency protocols.

The Air Force Reactor program was able to prove out all requirements of the program. It was / is possible to build a nuclear-powered bomber aircraft and keep the crew 'reasonably safe'. However, the development of nuclear-launch capable submarines and the Inter-Continental Ballistic Missile supplanted the need for a nuclear bomber.

The original Air Force Reactor Experiment evolved into the Molten Salt Reactor Experiment (MSRE) developed at Oak Ridge National Lab. This moderated reactor operated for 19,000 hours over 5 years. The reactor was designed to run on a thorium-uranium mixed fuel. Prior to termination of the project, all operational, safety, material science, and corrosion issues were resolved.

More importantly, the MSRE project proved that you could build a revolutionary nuclear reactor that eliminated all of the inherent safety concerns of the LWR while minimizing the spent fuel issue (what some people call nuclear waste).

The new reactor, commonly known as a Molten Salt Reactor (MSR), used heated salt with a liquid-to-boil temperature range that can exceed 1000°C (a function of chemistry), to act both as coolant and fuel. The recirculation of the liquid fuel/coolant allowed for the fuller utilization (burn up) of the actinides and fission products. The salt's higher temperature operation that did not need water for cooling, eliminated the need to operate under extreme pressures. This salt coolant cannot overheat, and meets the definition of having inherent safety – MSR's are inherently safe reactors that eliminate scores of redundant systems, significantly increasing the simplicity of the overall system while lowering risks and cost and increasing its safety profile.

Another advantage is that MSR's higher operating temperatures allow it to utilize liquid CO_2 (or other high compression gases), thus eliminating H_2O steam from the system. Moving away from the Rankine turbine system to much smaller and more efficient Brayton turbines delivers a much higher energy conversion at lower costs. The real promise of the MSR was that it produced process heat directly, for hydrogen, desalination, fertilizer, steel production - avoiding inefficient electricity production all while utilizing 100% of the heat energy directly.

Another beneficial feature is the reduced quantity and timeframe of storage requirements for spent fuel (aka: nuclear waste). Inherent to their design, MSRs use-up nuclear fuel far more efficiently than LWRs, less than 1% of the original fuel load can end up as spent fuel, and due to acceleration of decay under the recirculation of the fuel/coolant load the residual spent fuel decays to background (radiation levels equal to the natural environment) in as little as 300 years.

LWRs utilize about 3% of the available energy in solid fuels and the spent fuel does not decay to background levels for tens of thousands of years.

The most promising MSR design feature was found to be that fission criticality (a sustained chain reaction) is self-regulating due to the reactor's geometry and self-purging features that dumped the fuel/coolant into holding tanks and regulated fission rates (again, based on geometry) if the reactor exceeded design operating temperatures. These features made a reactor "meltdown" impossible and "walk-away safe".

Because the salt coolant has such a high liquid phase the system can be air cooled (in any atmosphere: the artic, the desert , even versions for space). The elimination of water from the system eliminates the primary failure-point of all conventional nuclear reactors, including explosive events that can occur with water cooled reactors.

> *NOTE: LWR reactor explosions are due to disassociation of water into hydrogen and oxygen when exposed to Zirconium at high temperatures during coolant system failure. The zirconium fuel casings act as a catalyst, causing a massive rapid atmospheric expansion. This atmospheric expansion was the cause of the explosive event associated with the Fukushima disaster.*

The elimination of any high-pressure hydrogen event excludes the potential for widespread radiation release and thus, the need for a massive containment vessel.

Alvin Weinberg's reactor design also solved another challenge of that time. Prior to the mid-1970s the U.S. government believed that global uranium resources were very scarce. This new reactor, fueled with a small amount of fissile material added to the thorium salt, could breed new fuel. In fact, it turned out that the reactor could also be used to dispose of weapons grade plutonium or even spent fuel (stockpiled nuclear waste).

Unlike natural mined Uranium, which needed intensive processing to concentrate the fissile U235, thorium is widely abundant and a byproduct of phosphate, titanium, zircon and rare earth ores. Thorium can be used in a nuclear reactor after minimal processing, all benefits that were unheeded in the 60s and 70s.

Since MSRs run at a much higher temperature than LWRs, the greatest benefit would be the direct utilization of thermal energy for industrial processes requiring thermal loads (allowing for the carbon free production of steel, cement and chemicals that make up nearly 25% of all CO_2 emissions). Possibilities seemed endless.

Glenn Seaborg's 1963 report to President Kennedy devised a national plan for sustainable civilian nuclear power. Evaluating the relative safety, efficiency, and economy of the Th-MSR vs. the LWR, Seaborg recommended that the U.S. phase out LWRs in favor of Alvin Weinberg's Th-MSR thorium "breeder reactor".

So why didn't this reactor design prevail? Considering its economic advantages, the Th-MSR would cause the phase out of the existing nuclear fleet and would be more cost competitive than coal or natural gas (and could replace petroleum via a nuclear-powered Fischer Tropes process), it is no wonder that the reactor was rejected by the prevailing political-economy of cold-war industrialism and what was primarily a hydro-carbon based economy.

The production cost for these reactors was a key concern. The relative cost of assembly line built MSRs reactor would be a fraction of traditional LWRs (these are small modular reactors). As such, MSRs could bring installed cost per megawatt in line with coal fired power plants.

> *The construction cost advantages are numerous: inherent safety based on geometry (translates into simplicity of design and construction), small, modular, assembly-line built, roll-off permitting, air cooled (eliminating the primary critical failure risk of LWRs and, thus the possibility for a wide-spread radiation event), no need for a massive containment vessel, and small Bryton turbines.*
>
> *The thorium fuel would be a byproduct of rare earths (no enrichment is necessary). Rare earths would be a byproduct of some other mined commodity.*

Regardless of the economic opposition, there was also a geopolitical conflict. Fueled with thorium, the MSR did not produce plutonium (fissile bomb making materials) or anything else that was practically usable for the production of nuclear weapons. The reactor was highly proliferation resistant—and who would not like that?

The Nixon Administration, for one. American politics in 1968 were largely influenced by the U.S.'s relative status in the nuclear weapons arms race with Russia. Nixon, a nuclear hawk, killed the MSR program and committed the country to the development of fast spectrum breeder reactors (the program was a total failure), circa 1972.
A
As early as 1970 a new, safe, clean, cost-efficient, and self-generating energy economy was technically possible but was sacrificed to the objectives of the cold war and preservation of the existing LWR fleet.

If the U.S. had followed Seaborg's advice the entire world could be pulling up to the curb of Net-Zero today and U.S. energy hegemony would be preserved long into the future.

> Instead, today, China is leading the world in the development of thorium fueled reactors and thorium based critical materials. They intend to use it as a geopolitical tool: the Chinese version of "Atoms for Peace". This would end U.S. energy hegemony.

Sadly, most Americans can't fathom how that would impact their standard of living and create a domestic energy source that would cement their position in the world.

But the story of how thorium politics and policy derailed U.S. energy and national security interests does not end there.

The story of Rare Earths

A decade later, the production and proliferation of nuclear weapons material became an international matter of concern. In 1980 the NRC and IAEA collaborated on regulations to ratchet down on the production and transportation of uranium. The regulatory mechanism 10 CFR 40, 75 applied the rules and definitions specific to the uranium mining industry to all mining activity, using the 1954 Atomic Energy Act terminology of nuclear "source material" to define the materials to be controlled.

> *Uranium, plutonium and thorium are all classified as nuclear fuel: source material. However, thorium cannot be used for nuclear weapons (thorium is fertile, not fissile).*

This caused a new and unintended problem. At the time, nearly 100 percent of the world's supply of heavy rare earths contained thorium in their mineralization and were the byproduct of some other mined commodity. Consequently, when these commodity producers extracted their target ores (titanium, zirconium, iron, phosphates, etc.) they triggered the new regulatory definition of 'processed or refined ore (under 10 CFR 40)' for these historical rare earth byproducts, causing the thorium-bearing rare earth mineralization to be classified as "source material".

In order to avoid the onerous costs, regulations, and liabilities associated with being a source material producer these commodity producers disposed of these thorium-bearing resources along with their other mining waste and continue to do so today.

Currently, in the U.S. alone, the annual quantity of rare earths disposed of to avoid the NRC source material regulations exceeds the non-Chinese world's demand by a factor of two or more. The amount of thorium that is also disposed of with these rare earths could power the entire western hemisphere if utilized in MSRs.

The scale of this potential energy waste dwarfs the collective efforts of every environmentalist on a global basis (including all of the World Economic Forum programs being forced on farmers and consumers across the globe).

As a result, all downstream rare earth value chain companies in the U.S. and IAEA compliant countries lost access to reliable supplies for these rare earth resources.

Capitalizing on these regulatory changes, China quickly became the world's RE producer.

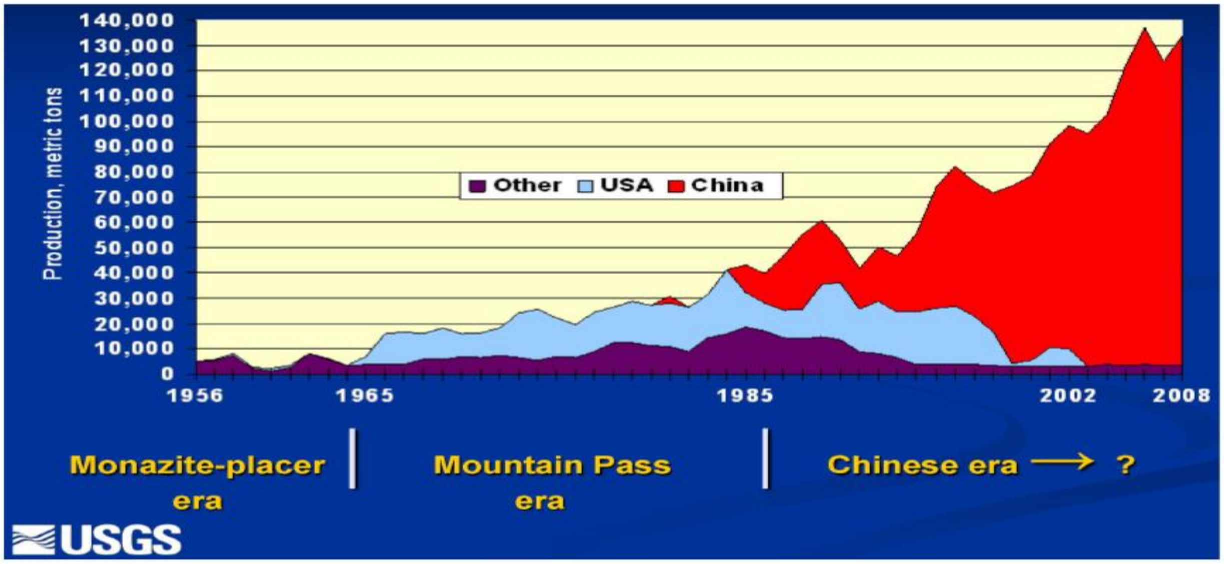


Figure 1. Global rare-earth-oxide production trends. The Mountain Pass deposit is in California, U.S.A. Graph from D.J. Cordier (U.S. Geological Survey, written commun., 2011) was updated from Haxel and others (2002, fig. 1).

During the 1980s, China increased its leverage by initiating tax incentives and creating economically favorable manufacturing zones for companies that moved rare earth technology inside China.

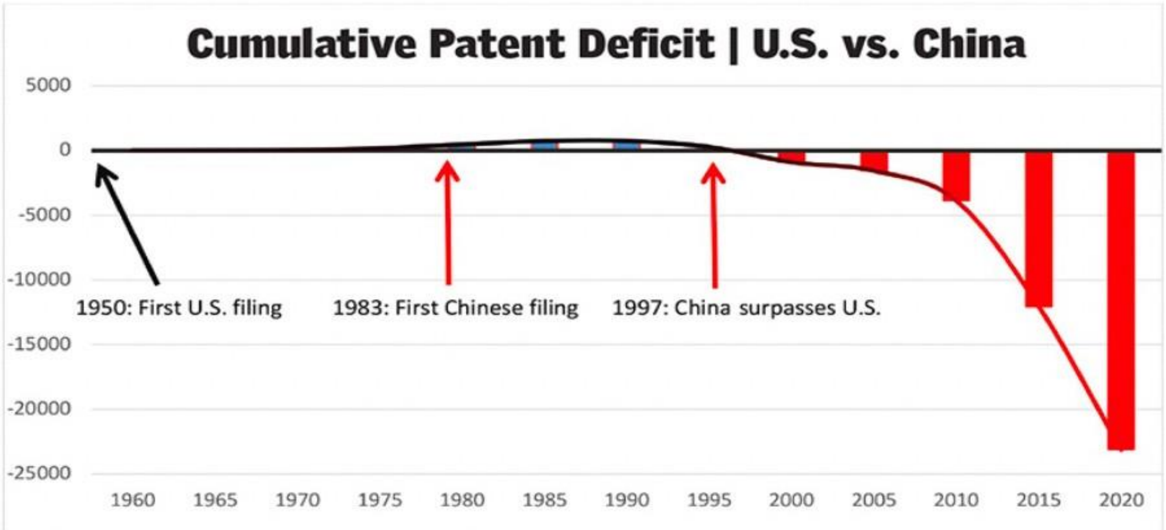
U.S., French and Japanese companies were happy to off-shore their technology and environmental risks (mostly related to thorium regulations). The 1980 regulatory change and China's aggressive investment policies allowed China to quickly acquire a foothold in metallurgical and magnet capabilities.

> *For example: China signed rare earth supply contracts with Japan that required Japan to transfer rare earth machinery and process technology to mainland China while establishing state-sponsored acquisition strategies for targeted U.S. metallurgical and magnetic manufacturing technologies.*
>
> *By 1995 the U.S. had sold its only NdFeB magnet producer, and all of its IP, to what turned out to be Deng Xiaoping's family.*

In just two decades China moved from a low value resource producer to having monopoly control over global production and access to rare earth technology metals.

By 2002 the U.S. became 100% dependent on China for all post-oxide rare earth materials. Today, China's monopoly is concentrated on downstream metallics and magnets. In 2018, Japan, the only country that continued to produce rare earth metals outside of China, informed the U.S. government that they no longer make "new" rare earth metals.

> *Japan stated the reason for terminating all new rare earth metal production is "China controls price".*



As of August 2018 China has accumulated 23,000 more rare earth patent filings than the U.S.

SOURCE: THREE CONSULTING

Thorium policy was the leading culprit in America's failure to lead the world in the evolution of the rare earth dependent technologies. From its powerful vantage point, China was able to force technology companies to move operations inside China. From a practical standpoint all past and future breakthroughs in rare earth based material science and technology migrate to China.

The best example of this is Apple. Because the iPhone is highly rare earth dependent, Apple was forced to manufacture it in China. In January 2007 Apple introduced its revolutionary iPhone. By August of the same year high quality Chinese knockoffs were being produced by a largely unknown company named Huawei. By 2017 Huawei was outselling Apple on a worldwide basis.

This story is not uncommon. It is typical of what happens to Western companies who move manufacturing inside China. Apple knew this but had no choice: developing a domestic rare earth value chain was impossible for any single company, industry, or even country by this point in the game.

Today China's monopoly power allows them to control the supply chain of the U.S. military and NATO defense contractors.

From its diminished vantage point, the Pentagon is somehow unable to understand that China's monopoly is a National Program of Industrial and Defense Policy.

Instead, the Pentagon pretends that this is a problem that can be solved by 'the free market', naively betting U.S. national security on a hodgepodge of junior rare earth mining ventures with economically questionable deposits, no downstream metal refining capabilities and no access to the critical heavy rare earths.

The Pentagon twice bet our national security on a geochemically incompatible deposit in California. The first time was in 2010. The Pentagon was forewarned that the deposit controlled by Molycorp, was incompatible with U.S. technology and defense needs, due to its lack of heavy rare earths, and that its business plan was “unworkable”. The company was bankrupt in just 5 years.

In 2020, despite the same deposit’s intractable deficiencies, Chinese ownership and a commitment to supply China, the Pentagon backed a venture capital group ‘developing’ the deposit under the name MP Materials. The new company has made the same unfulfillable promises as its predecessor but further domestic downstream capability into metallics is unlikely.

MP may remain profitable as long as it continues to sell concentrate and oxides into China, but profitable downstream refining into metallics / magnets is not possible when accounting for China’s internal cost, scale and subsidy advantages (and control over price).

The Pentagon, like so many other investors, fails to accept the reality of China’s monopoly. It is both an economic monopoly, and a geopolitical monopoly.

Consequently, there have been over 400 bankruptcies in rare earth projects since 2010. Only two western controlled rare earth mines went into production: Molycorp, mentioned above, and Lynas, the Australian company Lynas. Lynas’s success is mostly due the current environment of higher prices (ultimately under China’s control) and a modestly superior rare earth chemistry when compared with the Molycorp Mt. Pass deposit. Lynas survived the 2015 downturn through direct subsidies form the Japanese government, price supports and debt forgiveness from its customers and investors.

Today the U.S. and all western governments find themselves outmaneuvered in rare earths (and other critical materials), the green economy and thorium nuclear energy.

China is leading the world in the development of thorium MSRs. Their first two-megawatt prototype reactors was recently cleared for startup (August, 2022). China’s MSR program was built on massive direct investment by the Chinese government and the direct transfer of technology and technical support by the U.S. Department of Energy.

China’s first to market strategy can be expected to conform to their tendency to vertically and horizontally monopolize industries, like rare earths. As such, China is poised to control the global roll out of this technology—displacing the U.S. as the global energy hegemon.

Because the U.S. failed to rationalize thorium policy it has lost control of its destiny in rare earths and the future of safe, clean, affordable, and sustainable nuclear energy.

Unchallenged, China will be the global champion of net-zero energy.

What are the domestic obstacle to achieving thorium MSR?

Opposition is directly linked to the cold war policies of the past and the intersection of legacy energy producers (LWR nuclear, coal, natural gas and petroleum) and renewable energy producers. These energy sectors individually and collectively are the political constituents of the DoE. So, despite the opposing interests between each of these energy sectors, the threat of Th-MSR expresses itself as DoE opposition (that is beginning to change).

> *The other problem with Th-MSR development is the regulatory environment. Regulations are more about protecting legacy interests than public safety. In nuclear regulation it is all about protecting the legacy fleet from new entrants.*
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> *For example, the company Nuscale spent over $600 million, over a decade, to certify a new nuclear reactor design. This expense was not to build a reactor. It was the regulatory cost of permitting a new reactor design that (highly conforms to existing LWR designs).*
>
> *What people overlook is that the real cost and risk in new reactor design is a function of time, money and investor expectations.*
>
> *In the case of Nuscale, the regulatory and construction cost of a new reactor will be in the multi-billion-dollar range, with over a decade of investor money tied up in the highly speculative investment (speculative in regulatory outcomes and customer orders against existing and alternative technologies) makes this the highest investment risk imaginable.*
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> *Accounting for the magnitude of these risks and return expectations, this type of investment is at the outer bounds of what is achievable -- in the absence of a monopoly. That is why public investment was always necessary in the nuclear industry. China understands this and has acted accordingly.*

What are the domestic obstacles to a domestic rare earth value chain?

The current rare earth issue has not been a mining issue but rather a regulatory issue. The U.S. continues to mine enough rare earths, as the byproduct of some other commodity, to exceed the entire non-Chinese world demand. These resources would quickly become available if the U.S. rationalized its thorium policy.

The larger downstream problems resulting from China's massive overinvestment and negligible return requirements in its rare earth industry have yet to express themselves, as the U.S. government blindly funds non-compatible, non-viable, non-economic downstream projects.

Without a production tax credit to off-set Chinese subsides, all of these projects will fail. Balancing the comparative cost of capital and investor return expectation also must be answered.

Solutions

There are potential solutions. For rare earths there is a **production tax credit bill** that could off-set China's generous subsidies, zero-cost capital and production cost advantages (comparative labor & environmental costs). There may also soon be proposed legislation to solve the thorium problem. This same proposal would also provide a funding and development platform for a U.S. based thorium MSR reactor industry.
There are solutions, but time is running out.

To learn more about advancing U.S. interests in the development of MSRs and ending China's rare earth monopoly please visit the ThoriumEnergyAlliance.com or ThREEConsulting.com.

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