The Public Case for Thorium

By Patrick Redmond

Abstract

This proposal provides policy guidance on how the federal government would generate Thorium-based nuclear policy. This is necessary to answer the growing threat presented by energy dependence, lack of energy innovation in the nuclear sector, and climate change. Through providing two feasible policy options, and crafting a strong argument for both, this proposal concludes that a prototype Thorium nuclear reactor is the best option for the federal government to pursue to combat energy dependence, lack of energy innovation in the nuclear sector, and climate change. As such, these findings determine that through partnership with local governments, the United States as a whole can leap to the forefront of nuclear technology once again and lead the global nuclear community.

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Introduction

In 2019, the United States consumed about 100.2 quadrillion British Thermal Units (Btu). Over a third of this was petroleum (37%) and almost a third is natural gas (32%).[1] Both of these energy sources produce the most CO2 out of any of the available energy sources besides coal (11%).[2] In addition, the typical cost for an energy source such as natural gas is $2.99/million Btu.[3] This translates to a consumption of roughly $3 trillion on the lower end. As such, the United States is producing a significant amount of CO2 to meet the energy needs of her citizens. This high amount of CO2 leads to issues such as ocean acidification, increased average temperature, and destruction of ecosystems.[4] Because of this CO2 issue and the increasing energy demand, experts have examined other forms of energy that do not harm the environment as much but are still efficient and inexpensive.

As such, renewable energy sources such as geothermal, solar, wind, hydroelectric, and biomass have been explored by many public policy experts and scientists alike. However, most of these sources are unviable in certain places due to terrain, high expenses, or inefficiency.[5] One source of energy often left out of most discussion of low-CO2 energy sources is nuclear, which produces a minute amount of CO2 and other greenhouse gases while still significantly more efficient per gram than fossil fuels.[6]

Still, nuclear currently has challenges to overcome. When nuclear plants have encountered problems, the situations tend to be seriously dangerous. Three Mile Island,

[1] EIA. (2020, May 7). U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.
[2] EIA. (2020, May 7).
[3] Dvorak, P. (2015, January 21). Will thorium power be cheaper than wind power?
[4] NASA. (2011, June 16). The Carbon Cycle.
[5] Prieto, P. A., & S., H. C. (2013). *Spain's Photovoltaic Revolution The Energy Return on Investment*
[6] Sweet, W. (2006). *Kicking the Carbon Habit: Global Warming and the Case for Renewable and Nuclear Energy*.

Chernobyl, and Fukushima all come to mind anytime nuclear energy is discussed.[7] In addition to these nuclear accidents, there is radioactive waste, which stays dangerous for thousands of years. Finally, nuclear plants can produce weapon-grade plutonium, which allows bad actors access to nuclear weaponry.[8]

However, it still stands to reason that exploration of nuclear energy is a proper option for the public to pursue. As such, this paper will explore potential policy solutions to jump-start concrete government pursuance of this technology. There are two current options on the table for the Department of Energy to consider. One is to use government oversight and funding to build a prototype reactor, and the other would be to leverage the power of the free market to incentivize the construction of a thorium power plant.

To present these options, this policy proposal will be broken up into several sections. First, a basic background of thorium nuclear energy will be delved into, complete with an understanding of the positive and negative effects of this type of energy and an overview of the Oak Ridge National Laboratory (ORNL) research. Second, the two policy options of the prototype government reactor option and the market option will be covered. Third, an analysis of the two options proposed along with an exploration of the implications of the ultimate policy recommendation will be presented. Finally, a conclusion will be presented with recommendations for further research.

This paper will produce compelling evidence to the fact that the Department of Energy should pursue the construction of a prototype thorium reactor over the market option. The

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[7] Rojavin, Y. et. al. (2011). Civilian Nuclear Incidents: An overview of historical, medical, and scientific aspects. *Journal of Emergencies, Trauma & Shock*

[8] Moir, R. (2015). Nuclear weapons vs. nuclear energy. , Stoutenborough, J., Vedlitz, A., & Liu, X. (2015). The Influence of Specific Risk Perceptions on Public Policy Support: An Examination of Energy Policy

variables considered stack in favor of the prototype option. This is salient considering the primacy of timetables due to the international energy threat posed by China and Russia. In addition, the concrete construction and job generation greatly outweigh the proposed costs presented with the option.

Background

It is imperative that the differences between this special type of energy be understood in relation to other sources so that the benefits and the drawbacks are clear. First, a brief history of the first foray into thorium nuclear technology, in the form of the ORNL, will be discussed. Following that, this section will provide a basic explanation of how nuclear reactors function in relation to public wants as well as the relative benefits gained from utilizing thorium nuclear power specifically in relation to other sources.

ORNL Experiment

In the 1960s, nuclear scientists pioneered what was then called the Molten-Salt Reactor Experiment (MSRE).[9] This type of reactor used liquid fuel based on thorium rather than solid fuel based on uranium. This reactor is known by its more popular name, Liquid Fluoride Thorium Reactor (LFTR). LFTRs provide a variety of benefits over their uranium counterpart of Light Water Reactors (LWR). [10] This reactor was operational for a total of five years from 1964 to 1969 and reached a maximum of 7.4 MW in May of 1966.[11]

Being the first reactor of its kind in the United States there were some issues such as a failure of one of the main cooling blowers and plugged gas filters. In addition, there was intergranular cracking in the surfaces exposed to the molten salt due to tellurium which is generated in the fuel. This would become a problem on a commercial reactor over thirty years

[9] Robertson, R. C. (Ed.). (1971). Conceptual Design Study of a Single-Fluid Molten-Salt Breeder Reactor.
[10] Hargraves, R., & Moir, R. (2010). Liquid Fluoride Thorium Reactors.
[11] Haubenreich, P., & Engel, J. (1970). Experience with the Molten-Salt Reactor Experiment

and needs to be addressed by nuclear engineers to properly insulate the reactor from this issue. The main goal of demonstrating the viability of the MRSE was accomplished.[12]

Benefits

The design of the LFTR prevents major meltdowns from occurring. Since liquid fuel is used, the LFTR design has an emergency drain plug in case the reaction reaches too high of a temperature. This means that even if technicians were to walk away, the reaction would still be relatively safe.[13] This type of reaction also produces significantly less nuclear waste than uranium, and the waste is less radio-toxic. [14]

LFTRs used thorium, which is more than three times as common as uranium. Conveniently, the United States has the second-largest deposit of thorium (only behind Australia), at 9.36 percent of the world's supply, or 595,000 tons.[15] In addition, the mining process of thorium is not only more eco-friendly than uranium but is also better for the miners' health. Thorium mines are open pits rather than underground mazes, which means there is not a high level of toxic radon in the air, and there is a lower risk of dangerous cave-ins. Per ore vein, there is a higher concentration of thorium than uranium.[16]

In addition to these benefits, the use of thorium itself mitigates other problems with uranium. With LFTRs, thorium is fertile rather than fissile, which means it requires a steady stream of neutrons to be fired for the reaction to continue. This provides another fail safe in the

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[12] Haubenreich, P., & Engel, J. (1970).
[13] Hargraves, R., & Moir, R. (2010).
[14] Hargraves, R., & Moir, R. (2010)., Shamanin, Igor, Bedenko, Sergey, & Gubaydulin, Ildar. (2015). Advantages of Thorium Nuclear Fuel for Thermal-Neutron Reactors.
[15] International Atomic Energy Agency, World Thorium Occurrences, Deposits And Resources, IAEA-Tecdoc-1877, IAEA, Vienna (2019).
[16] Ross, R. (2017, March 01). Facts about thorium.

threat of a meltdown.[17] Thorium also does not require expensive fuel enrichment, as nearly 98 percent of naturally occurring thorium can be used as fuel, as opposed to less than 1 percent of naturally occurring uranium.[18] In the LFTR fission process, thorium produces uranium-232 as opposed to uranium-233, which is used in LWRs. This is important as U-232 is more difficult to convert into the necessary components for a nuclear weapon, which assuages the security concerns surrounding nuclear energy. [19]

Issues with Thorium Nuclear energy

While the research seems to support the notion that these types of reactors would be an obvious benefit every community, there is an apparent dearth of them across the world. This is due to the history of nuclear energy. Basically, the first model that was produced was a LWR model due to its relative simplicity relative to LFTR models. This fact coupled with the ability to produce weapons-grade materials as a byproduct, which was useful during the Cold War, really allowed LWRs to outshine LFTRs.[20] The concept of LFTRs only took off in the scientific community after LWRs were already developed. The inertia was already behind the less complex LWR design and overhauling the entire nuclear power development program with newer LFTR models was not deemed worth the effort, time, and money. The lack of substantial nuclear weapon biproducts in LFTRs also was not a major concern at the time and therefore did not tip the scales in favor of LFTRs.

However, this lack of inertia behind LFTRs did not prevent them from being tested by the United States. In the 1960s, the ORNL was created with the goal of testing the viability of the

[17] Hargraves, R., & Moir, R. (2010).
[18] International Atomic Energy Agency. (2019).
[19] Moir, R. (2015).
[20] Sorensen, K. (2012, December 05). A brief history of the liquid-fluoride reactor.

LFTR design, among others. The LFTR design was built in 1964, went critical in 1965, and henceforth operated until 1969. This specific design used U-235 and U-233. Its maximum heat reached 650 degrees Celsius and operated for about one and a half years at full power. This project resulted in a simple, reliable reactor that demonstrated the practicality of a full-scale LFTR model.[21] There was one major issue with this experiment, which was the storage design used by ORNL.[22] However, modern LFTR models take this into consideration.

The documents produced by ORNL are publicly available online, and some outside actors have taken advantage of this. Currently, China is producing two LFTRs in the Gobi Desert with the goal of finishing by 2020 and having them commercially available by 2030.[23] The completion of this project could shift the international energy economy to China's benefit. In addition to China's projects, Canada, India, and Norway are also exploring the feasibility of thorium power using the results of the ORNL thorium reactor.[24] However, the United States has fallen behind the curve.

Why This Has not Been Done Yet

In 2009, Republican Senator Orrin Hatch and Democratic Senator Harry Reid brought forth an act that was very similar to the stated goals of this paper.[25] This act was called the Thorium Energy Independence and Security Act of 2008 with the eventual goal of domestic thorium nuclear power generation. It called for $250 million over five years to have a new regulatory administration under the Nuclear Regulatory Commission and Department of Energy. This bill was read twice in the Senate and then referred to the Committee on Energy and Natural

[21] Robertson, R. C. (Ed.). (1971).
[22] Oak Ridge National Labratory. (1999). Ending the MSRE., Oak Ridge National Laboratory. (2006, April 8).
[23] Evans-Pritchard, A. (2011, March 20). Safe nuclear does exist, and China is leading the way with thorium.
[24] Stenger, V. (2012, March 10). LFTR: A long-term Energy solution?
[25] Speckman, S. (2008, October 04). Sens. Hatch, Reid support Thorium nuclear power.

Resources where it languished. Interestingly enough, this bill also looked to work with the head of the Idaho National Engineering Laboratory to utilize the naturally occurring thorium located there.[26]

It is unclear why this bill died in committee, but it could have been the result of two factors that this proposal addresses. First, the bill was a lot vaguer than this project in the sense that it did not provide a structured framework like this project will. Second, it was exploratory in nature and only called for an expansion of the federal government with no clear benefit. These two issues with the bill likely led to its death in committee.

In addition to Hatch and Reid's bill, Rep. Joe Sestak, D-PA, also introduced a bill that requested the Secretary of Defense to carry out a study on using nuclear reactors for naval power.[27] It is unknown exactly why this was not brought to the floor as well, but it does point to the same idea that Congress has had proposals in the past, but they are typically exploratory in nature and tend not to get very far.

Recently, there is renewed interest in future nuclear technologies. In 2019, President Trump initiated the Versatile Test Reactor (VTR) with the goal of testing advanced fast neutron nuclear reactor technology.[28] This reactor project is geared towards modernizing American nuclear energy initiatives and is the result of the Nuclear Energy Innovation Capabilities Act of 2017. This act included provisions for a Versatile Neutron Source, which would allow for a fast neutron spectrum testing facility that the United States has not had for over 20 years.[29] This

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[26] GovTrack.us. (2021). S. 3680– 110th Congress: Thorium Energy Independence and Security Act of 2008.
[27] GovTrack.us. (2021). H.R. 1534 – 111th Congress
[28] Secretary Perry Launches Versatile test reactor project to MODERNIZE nuclear research and development infrastructure. (2019, February 28).
[29] Secretary Perry Launches Versatile test reactor project to MODERNIZE nuclear research and development infrastructure. (2019, February 28).

production of the VTR points to growing acceptance of the return of nuclear energy, and a revival in interest in future nuclear energy technologies.

This proposal is different in nature and is insulated against these previous proposals in the sense that it is much more concrete in what it is requesting, and it offers tangible results. It has two clear options with varying levels of viability. In addition, in the last ten years there has been significant progress in understanding thorium as an energy source, and many more corporations have developed the capacity to work with thorium. It is unlikely that the same problems will plague this proposal as the previous two mentioned.

A final point in the realm of these previous proposals is that both Republicans and Democrats have worked together on proposals of this type. This suggests that there is potential for bipartisan support if the proposal is calibrated to suit the needs of both parties. For their own reasons, both parties seem to have an interest in energy independence in a more environmentally friendly mode.

Prototype Proposal

The prototype option is viable to pursue at this time. Before this option is to be pursued, several considerations must be considered. Among these considerations are the type of reactor used, the location, and the ability to work with localities to secure energy contracts and materials that are needed. In addition, a comparison needs to be drawn between this option and the market option to quantitatively weigh them. As such, this section will cover these important considerations in addition to the key aspects of how the plan compares to the market option along with the critical elements of analysis.

Costs, Safety and Waste Management variables

To assess the prototype reactor accurately, the specific reactor model needs to be identified. The analysis of Pauzi et. al.[30] provides a great starting point for understanding the exact cost and breakdown of the ten most popular models proposed by private corporations as of 2018. They examine three key elements for determining the best recommended model, which are economics, safety, and waste management. These three key elements will be discussed first to provide a critical understanding of exactly what is to be expected as a result of this prototype reactor.

As defined by Pauzi et al., economics is a combination of four prices per output of electricity in the categories of size, neutron spectrum, fuel state/type, and working fluid. Knowing the exact output in terms of wattage is dubious at a conceptual stage, which is what Pauzi et al. works with, and as such ought to be considered an educated estimate. However, their

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[30] Muhamad Pauzi, Anas, Abdul Wahid, Azril Wasim, & Md Saad, Juniza. (2019). Preliminary quantitative feasibility analysis of proposed Thorium-based nuclear reactor.

conclusions and data are based on real-world projects and provide a decent idea regarding what the expected cost could be.

Therefore, when considering cost, it is most likely best to consider the data presented. As the prototype will be on the smaller side of things, this would make it less economical in the long run. Pauzi et al.[31] show that with a correlation of .80, the larger the weightage of the plant, the lower the construction cost per watt. In their data set, the cost of the plants ranges from $24.4 billion to $13.5 billion, with average cost of $18.78 billion. Using the model provided by Pauzi et al.[32], the estimated cost per megawatt capacity would be $4.861 billion, which is lower than estimates for uranium nuclear plants[33]. Depending on the actual size and location of the plant these figures might fluctuate, but even at the lower end of the scale the difference between uranium nuclear energy and thorium nuclear energy is roughly $2 billion USD less to build a thorium plant, per mwh.

However, size is not everything when it comes to thorium nuclear power. The difference in neutron spectrum set-up affects how much a plant would cost. Plants built in Japan, Russia, and India use the fast neutron spectrum and plants built in UAE, Bangladesh, and Turkey use the thermal neutron spectrum.[34] The thermal neutron spectrum provides better cost efficiency but usually at a higher overhead price as the plants are larger and more complex. As such, plants such as the Japanese BN-1200 operated at a cost of $4.918 million per megawatt with a capital cost of $6 billion USD. This is generally a smaller plant.[35] As such, it would be best to use this

[31] Muhamad Pauzi, et. al (2019).
[32] Muhamad Pauzi, et. al (2019).
[33] Schlissel, D., & Biewald, B. (2008, July). Nuclear Power Plant Construction Costs.
[34] Muhamad Pauzi, et. al (2019).
[35] Muhamad Pauzi, et. al (2019)., Schlissel, D., & Biewald, B. (2008, July).

fast neutron spectrum since the proposed plant will be on the smaller side, and the initial capital cost will be significantly reduced from the previous estimate of $18.78 billion.

In addition to neutron spectrum, the fuel state and type play a role in assessing the efficiency of the plant. There are two types of fuel for such a plant—solid and molten. Molten fuel is easier to manufacture as uranium hexafluoride can be mixed and used inside the reactor, skipping the processes of conversion, fuel fabrication, and enrichment that are necessary when working with strictly thorium. As such, many reactors that use thorium utilize enriched uranium in some way during the initial startup process. As such, since this project is geared towards not using uranium at all, or using minimal amounts, there is most likely an increase in cost as in plants that utilize this process expect roughly 57 percent of the total cost of fuel preparation to be this process, which leads to roughly a 233 percent increase in cost for this method to be utilized.[36] While this may seem initially like a significant amount, the cost to refuel a typical reactor is roughly $40 million every 18 months.[37]

Finally, the fuel has to be suspended in a working fluid. There are two options presented by Pauzi et al.—salts and metals. As such, these working fluids come with their own costs. As previously mentioned, the model used will most likely be a molten salt model to follow in the footsteps of the MSRE at ORNL, even though they are roughly twice the cost of metal working fluid.[38] Therefore, a mixture of FLiBe will be used with a composition of two-thirds LiF and one-third BeF for a total cost of $0.68 per gram of working fluid. Typically for a normal nuclear reactor, the cost of the working fluid is a fraction of the total cost of the reactor, yet it is still an

[36] Muhamad Pauzi, et. al (2019).
[37] Get a reliable unbiased source for this - https://atomicinsights.com/Nuclear-energy-is-cheap-and-disruptive-controlling-the-initial-cost-of-Nuclear-power-plants-is-a-solvable-problem/
[38] Muhamad Pauzi, et. al (2019).

important line item. For a ton of working fluid, this would then cost $680,000, which is not much considering the large size of the project.

Considering these data, the total cost of the reactor itself will most likely be around $8 billion. The fast neutron model from the Japanese BN-1200 will be utilized with a molten salt core and primarily looking at solid fuel to minimize the need for extracting U-233 to jumpstart the reactor. As such, using these more expensive methods to minimize both the scale and use of U-233, the price is expected to rise, along with the notion that this is the first thorium reactor built in almost 50 years in the United States.

The output of this reactor is based on size, with estimates range anywhere from 200 megawatts[39] to 500 megawatts[40], which are significantly more megawatts for a lower price tag than other LWR models and rivaling that of fossil fuel plants. The long-term return on investment is very attractive, but the upfront cost is a significant burden. Regardless, it is clear that this plant will comfortably be able to supply enough energy to power the city of Salmon, ID, if not the entire surrounding region for a low, long-term cost. Salmon, Idaho, was selected for a variety of reasons that will be explained more in depth later on in the paper, however, it is important to note that this city is rather close to a large store of Thorium and has a sizeable amount of undeveloped land to use for a power plant.

However, cost is not everything. Pauzi et al.[41] also examined safety and waste management. Overall, Pauzi et al.[42] concluded that the molten salt working fluid presents

[39] THMSR. (2019). In depth: Costs.
[40] Graham Templeton on March 13, 2. (2013, March 13). The 500MW molten salt nuclear Reactor: Safe, half the price of light water, and shipped to order
[41] Muhamad Pauzi, et. al (2019).
[42] Muhamad Pauzi, et. al (2019).

significantly more safety benefits than the liquid metal working fluid. Liquid metal presents the issues of solidification when reactors are at a lower temperature and a higher risk for corrosion within the reactor itself. Molten salt working fluids also operate at a lower pressure and higher temperature, and remove gas, which reduces chemical reprocessing and other passive safety features.[43]

In addition to these safety features, spent fuel management is also an important component. There are four main concerns with spent fuel management: decay heat, spontaneous neutron emission rates, radiotoxicities per discharge assembly, and volume of spent nuclear fuel. It would be reckless to store spent fuel in a standard storage location as all four of these concerns play a major role in procuring proper storage facilities. Spent fuel must be stored with strong shielding in a remote location to contain the gamma ray production. However, an entire mountain such as Yucca mountain may not be necessary as the volume of spent fuel is considerably lower than with U-based nuclear plants. In addition, storage may only be necessary for up to 20 to 30 years as the SWaB reactor by Seaborg Technologies predicts a significantly shorter half-life with their advanced technologies.[44]

Location

It would be recommended to build a reactor as close to the thorium deposits in the United States as possible to reduce travel costs to and from the mines. According to a geological survey conducted in 1979, thorium can be found in the United States in three types of deposits. These

[43] Muhamad Pauzi, et. al (2019).
[44] Seaborg. (2020).

are veins, massive carbonatite bodies, and placer deposits. Each of these will be considered with relevant information from the 1979 study. [45]

In addition, each of these three were then divided further into three different tiers in relation to how expensive it is to extract a pound of ThO_2. This is categorized by less than \$15, between \$15 and \$30, and more than \$50, calculated for the entire extraction process. Greater consideration is given to deposits that are the cheapest to extract. There is an estimate of potentially up to 505,000 short tons of ThO_2 with half of these resources being produced at less than \$30 per pound.[46] Total potential distribution can be seen in *Figure 1*.[47]

Figure 1

Of the three sources, veins are the most economical as they are not only the highest grade source in the United States but also make up 142,000 tons of the total reserves (out of 188,000)

[45] Staatz, M., & Geological Survey , issuing body. (1979). *Principal thorium resources in the United States / by M. H. Staatz [and seven others]; prepared on behalf of the U.S. Department of Energy.* (Geological Survey circular ; 805).
[46] Staatz, M., & Geological Survey , issuing body. (1979).
[47] Staatz, M., & Geological Survey , issuing body. (1979).

and 343,000 tons of the potential reserves (out of 505,000). About 90 percent of this can be produced at less than $15 per pound. There are currently seven veins that have been evaluated with most of them concentrated in the Rocky Mountains region (CO, WY, ID, CA), especially in Idaho. The best vein to look at for total producible ThO_2 is the Lemhi Pass in Idaho where 68,000 tons of ThO_2 can be produced at less than $15 a pound.[48] As an added bonus, rare earth elements are also commonly found in these veins and can be used for high demand consumer products such as phones and computers. Further information such as the total reserves and the cost per pound of each reserve is present in *Figure 2*.[49]

TABLE 2.—*ThO_2 reserves and probable potential resources in short tons from seven thorium vein districts in the United States*

District	Total reserves	Total probable potential resources	Total producible at less than $15/lb		Total producible at between $15 and $30/lb		Total producible at between $30 and $50/lb	
			Reserves	Probable potential resources	Reserves	Probable potential resources	Reserves	Probable potential resources
Lemhi Pass, Idaho-Mont.	70,500	133,000	68,000	124,000	1,650	3,330	507	1,840
Wet Mountains, Colo.	64,200	160,500	54,000	141,000	2,540	10,100	7,280	8,880
Powderhorn, Colo.	1,900	8,500	1,300	6,700	300	1,000	200	700
Hall Mountain, Idaho.	4,580	26,300	4,540	26,100	0	0	0	0
Diamond Creek, Idaho.	250	13,000	117	12,200	115	660	0	0
Bear Lodge Mountains, Wyo.	55	275	0	0	0	0	15	85
Mountain Pass, Calif.	280	1,500	175	685	0	0	0	0
Total	141,765	343,075	128,232	310,685	4,605	15,090	8,002	11,505

Figure 2

The next best source is the massive carbonite bodies found in Colorado and California. These are essentially large bodies of low-grade thorium that are a byproduct of exploiting these carbonite bodies for rare earth elements or niobium. These elements are in high demand and typically the thorium mined as a byproduct is not, which also could reduce the cost of acquiring

[48] Staatz, M., & Geological Survey , issuing body. (1979).
[49] Staatz, M., & Geological Survey , issuing body. (1979).

it. As demonstrated in *Figure 3*[50], a majority (roughly 80 percent) of thorium is found in the Iron Hill carbonite body. The extraction of ThO_2 would be a byproduct and is economical at $15 per pound. Some mining facilities already exist in the Sulfide Queen deposit, and to extract ThO_2 there would only need to be additional mechanisms inserted into the extraction process.[51] This is because typically these mining facilities view ThO_2 as a waste product, rather than the actual goal of the operation.

TABLE 3.—*ThO_2 reserves and probable potential resources in short tons from two massive carbonatite bodies in the United States.*

District	Total reserves	Total probable potential resources	Total producible at less than $15/lb: Reserves	Total producible at less than $15/lb: Probable potential resources	Total producible at between $15 and $30/lb: Reserves	Total producible at between $15 and $30/lb: Probable potential resources	Total producible at between $30 and $50/lb: Reserves	Total producible at between $30 and $50/lb: Probable potential resources
Where ThO_2 is the sole product								
Iron Hill, Colo.........	31,080	0	0	0	0	0	0	0
Sulphide Queen, Calif........	9,750	9,750	0	0	0	0	9,750	9,750
Total........	40,830	124,650	0	0	0	0	9,750	9,750
Where other economic products are recovered								
Iron Hill, Colo.........	31,080	114,900	31,080	87,300	0	0	0	0
Sulphide Queen, Calif........	9,750	9,750	9,750	9,750	0	0	0	0
Total........	40,830	124,650	40,830	97,050	0	0	0	0

Figure 3

Finally, the weakest candidate are the placer deposits found in the Carolina region. Even with this being the weakest candidate it is worth examining as a potential expansion in the future. The reserves of these deposits total 5,270 tons of low-grade ThO_2, and the Piedmont placer specifically is too small for it to be worth the effort. Essentially, it would cost more than $50 per

[50] Staatz, M., & Geological Survey , issuing body. (1979).
[51] Staatz, M., & Geological Survey , issuing body. (1979).

pound to extract ThO_2 in this region. The Hollow Creek placer has about 2,040 tons of ThO_2 that could be produced at $15 to$30 per pound. In this location, there are also rare earth elements and uranium as well that would be extracted along with ThO_2.[52] The extraction of ThO_2 would be arduous and only recommended in the case that there needed to be ThO_2 to supply reactors on the Eastern seaboard. *Figure 4*[53] contains a map of these placers.

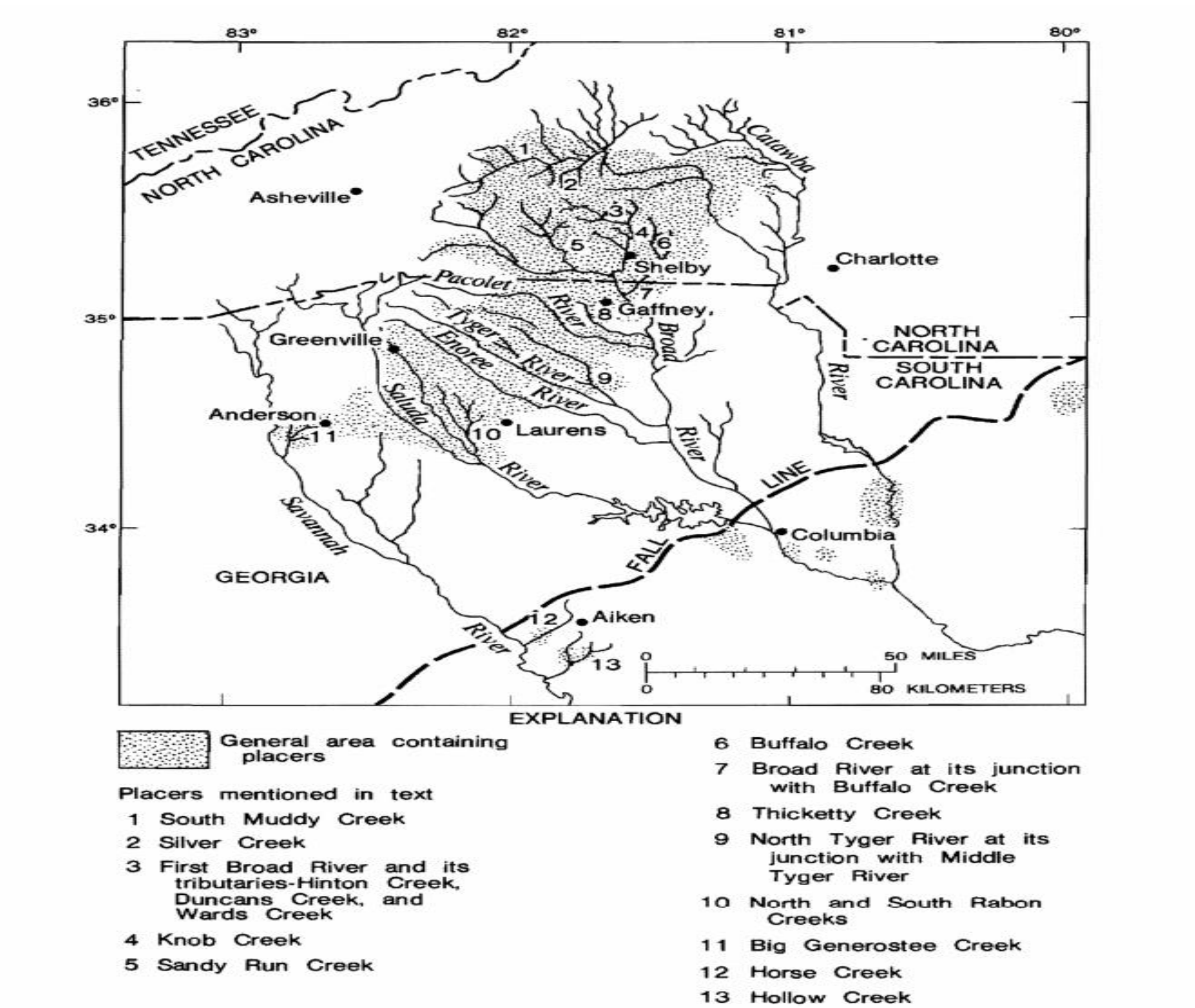

Figure 4

52 Staatz, M., & Geological Survey , issuing body. (1979).
53 Staatz, M., & Geological Survey , issuing body. (1979).

This information from the 1979 geological study provides a great insight into where mining operations would have to take place to fuel the reactor. The most economical option would be the vein located in Lemhi Pass Montana-Idaho because the most amount of high-grade ThO_2 can be produced for less than $15 a pound there.[54] In addition, not as many byproducts are found there as compared to placers or carbonite bodies, and thus it would require less separation. Therefore, these veins would be the best place to start while other options can be considered for the future if this project expands across the United States in a larger capacity.

While this does narrow the location down, there still needs to be further discussion of how this would work with public and local politicians. Without the support of the local populace, it would be impossible to get started on the ground, as the most critical on-the-ground policy work is done by local policy implementers and local workers. The next section will discuss working with the local politicians and populace.

Working with the local politicians

In addition to creating a workable timeline as well as securing key budget line items, the local politics of the Lemhi Pass must be considered. The nearest city of note to the Lemhi Pass deposit is Salmon, Idaho. Salmon sits roughly 33 miles northwest of the Lemhi Pass, which equates to about an hour drive.[55] As such, to reduce transportation costs, it is prudent to build and operate the plant in close proximity to Salmon to ensure the plant could feasibly power a city. This section will discuss the intricacies of working out a deal with the local stakeholders in the city.

[54] Staatz, M., & Geological Survey, issuing body. (1979).
[55] Curtright, E. (2020, March 07). The Idaho town in the middle of nowhere that's so worth the Journey: Visit Salmon Valley, Idaho.

Salmon is a city of just over 3,000 citizens with about 1,420 households needing power. This equates to a population density of about 1,335.6 per square mile.[56] Since it is implausible to travel to Salmon at this time, a viable alternative must be used instead. Salmon gets their electricity out of the Salmon River Electric Cooperative Inc. located in Challis, Idaho, down the street from Salmon.[57] This is important to note as different cities use different methods to acquire energy.

Looking at the fact that the main supplier of electricity is a co-op, as well as the population density figures, a reasonable replacement city would be Indianola, Iowa. Indianola has a population of roughly 16,000 with about 5,500 households, at about 1,314 people per square mile.[58] Their energy is provided by a co-op operated out of Nebraska called MEAN.[59] As such, with a comparable population density and similar contract position, it is reasonable to compare the two locations and draft an idea of what they would need to accept a federal contract to build a thorium plant in their area to power their city.

To gain insight, an interview that was conducted with the utilities manager of Indianola, Chris Desplanques, about this program provided a great insight into the needs of such a community. The biggest barrier to getting started on providing a federal contract would be paying off the previous contract. According to Desplanques, a good estimate for this line item would be roughly $750 million to pay off their previous debts to MEAN and be able to leave the contract. As one would assume, this is outside their budget and there would have to be incentives for them, and for MEAN, for this program to even get started. However, this then sends a ripple

[56] World Population Review. (2021). Salmon, Idaho population 2021.
[57] Salmon River Electric Cooperative. (2009).
[58] World Population Review. (2021). Indianola, Iowa population 2021.
[59] Nebraska Municipal Power Pool. (2017). Municipal energy agency of Nebraska.

effect through other members of MEAN in the sense that their budgets can be bolstered by some federal dollars coming into play as well, and that would need to be addressed properly. This is not expected to be as much of a problem considering that the Salmon River Electric Cooperative has a smaller clientele in Custer, Lemhi, and Blaine counties instead of several states like MEAN.[60]

In addition, the educational campaigns needed ought to target these benefits from a local plant in the city. According to Desplanques, while environmentalism has been a rising issue of concern for constituents, returns on investments are still the primary issue that constituents are concerned about. This is primarily due to the fact that the costs of the electricity are directly passed on to the constituents as well. Conveniently, thorium nuclear energy checks both of these boxes and would be very attractive for the utilities manager of a city like Indianola. The public would have to be notified as to these benefits as well as the decision making behind the acceptance of the program. But beyond objections from fringe groups, there is not anticipation of large-scale objection.

Also, the fluctuation in the energy market would not be much of a problem since the energy would be vertically integrated into the city and no outside company could price gouge energy to both the city and the citizens. Finally, the need consideration is the last variable that needs to be addressed by whichever energy contract is selected. Peak usage in Indianola would be 35 megawatts a month, which is typical in the summer while using air conditioning. Considering that Salmon, Idaho is significantly farther north and also a fifth the size, it is estimated that the peak usage would be well under 10 megawatts per month.

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[60] Salmon River Electric Cooperative. (2009). Salmon River Electric co-op.

After these issues are taken care of, the actual construction of the plant needs to be determined. It is possible to build the plant in the city zone, although it needs to be removed from residential zoning and as remote as possible to avoid the common, “Not in my backyard” mantra often heard with new construction projects. In Idaho, this would not be much of a problem considering the relatively small city size compared to Indianola (about 40 percent of the size). In addition, the proximity of the plant influences the overall cost of producing energy, as well as the benefits gained by the city. Generally, there is a significant cost incurred when transporting electricity from the plant to the city, and in Indianola’s case this can be as high as $10,000 a month. If the plant is close to the city, this cost decreases significantly. In addition, cost decreases the closer the plant is to the source of energy, which in this case would be the thorium mines. Finally, one of the best benefits to come from local energy generation would be the fact that the city will be insulated from the more volatile general energy grid as well, and the city would still be functional in the event of other plants failing. In light of the recent issues in Texas due to a failing grid caused by unusually severe weather, this project is relevant to the needs of the community.

NIMBY

The two values of “not in my backyard” (NIMBY) and reducing the cost of producing energy appear to be mutually exclusive. Most people want more affordable utilities, but do not want them constructed near them in such a way that reduces property value. There are ways of addressing this NIMBY problem. The first step is to gather a group of allies in the area who are in support of the new project. This involves reaching out to four groups of people. These are direct beneficiaries, indirect beneficiaries, potential users, and special interest groups. Having the support of those people campaigning and publicly supporting the project will ensure that any local opposition's concerns can be addressed. This is especially true if the media become involved because they are most likely to portray the argument favoring noble citizens versus a tyrannical government.[61]

Second, the opposition must be properly understood, and all misinformation must be combated in a friendly manner. The facts have to be properly presented to the public. Holding a town hall where the information is presented, and concerns are heard would be a great way to deal with both of these issues. There is also the added benefit of addressing the emotional needs of the public. While rational campaigns are great in spreading the truth, sometimes connecting with the public requires a more personal touch. This also involves the local government and reaching out to them as partners rather than subordinates.[62]

Finally, it is important to focus on the mutual priorities rather than conflicting values. This can be done by negotiating conflicts of interests within the community and trying to build coalitions. Persuasion and negotiation are going to be the tools of the trade with this issue. Negotiations can remove the anonymity between the opposition and the project managers. As such, negotiations ought to be used on a very personal basis, preferably with the thought leaders in the opposition.[63] These three steps will hopefully solve the NIMBY problem to an acceptable degree.

With all this information considered, the building of a thorium nuclear plant in a city such as Indianola or Salmon would be very attractive to the local population. It provides many positives with very few negatives. Based on information from Desplanques, building a localized

[61] Admin. (2017, March 15). Overcoming nimby opposition.
[62] Admin. (2017, March 15).
[63] Admin. (2017, March 15).

plant along with wiping away previous debts would be needed for the local utilities manager to accept such a contract. In return, the federal government can request the city to pay for maintenance costs with revenue generated by selling excess energy and anything left over would be returned to the government to cover the upfront costs. In addition, the Department of Energy would have analysts present to oversee the functions of the plant and verify that the terms of the contract are upheld. Policy analysts also will need to be present to ensure the energy produced meets expectations and to assess how well the local environment is functioning in both environmental and social capacity. The finer details can be worked out with the local populace once this policy is implemented in a more concrete fashion.

Timeline

The project's timeline is a critical piece of the discussion of this project. The longer it takes to build a plant, the more costly the project will be as the return on investment does not initiate until the plant is functional for a time. As such, the time it takes to build a plant could fluctuate dramatically based not only on the available infrastructure but also the legislative red tape in place that could restrict the ability to start land clearance for a plant. This section will address timeline concerns and put forth a hypothetical timeline estimate.

The typical construction timeline could take anywhere from 50 to 250 months depending on a variety of factors. However, this timeline is reduced to 50-60 months if the nation has a robust relationship between utilities, constructors, regulators, and energy planners as well as access to the technology for a long time.[64] This could also be reduced if already cleared land is used, or if a different model is retrofitted with newer thorium-based technology. However, that

[64] Moreira, J. M., Gallinaro, B., & Carajilescov, P. (2013). Construction time of pwrs.

might not be possible, so a more conservative estimate is appropriate. In addition, it is expected that the plant would reach a net benefit in cost within an additional six months.

In addition to land clearance and building time, one might inquire how long it could take both the federal government and the local government to agree on the finer details of the project. This is estimated to take up to six months[65] depending on the way the policy is implemented, through either the legislative or executive branch. While this does not have bearing on the proposed timeline of the project in the sense that the government would be concerned, this does affect how long from its conception this policy could expect to be completed. *Figure 5* illustrates this expected timeline from conception to net profit.

Figure 5

Funding

With the previous sections considered, proposed funding can be discussed. This funding would include the construction of the reactor, mining and transportation of the materials, educational campaigns, wages for workers and engineers, wages for policy makers and implementers, travel costs, and housing costs. Starting with jobs, a typical nuclear plant employs 500 to 1,000 workers with 3,500 workers at peak construction hours. Nuclear worker salaries are typically 20 percent higher than salaries in other energy generation fields, and typically labor costs are around $40 million a year. This accounts for all professions involved including

[65] Fritz, J. (2018, September 10). How long will it take for our grant proposal to be approved?

accountants, electricians, etc.[66] Since this project would take at least six years to become self-sufficient, this number should be multiplied by six. Also, with the construction of a new plant, secondary and tertiary jobs tend to crop up. It is estimated that in the energy industry, 100,000 people are directly employed with an additional 375,000 people who work to provide support and infrastructure.

In addition to labor costs, the cost of materials must be considered. The long construction timeline and high cost of the physical plant are the two most challenging aspects of building as it would take a while to recoup those total costs. As such, the previously discussed number of $6 billion will be used even though this is including labor costs in the estimate. Fueling costs are another line item for the first year and a half of operation, and it is expected that after this timeframe the plant will become self-sufficient and will no longer need funding for refueling. This would cost an estimated $40 million.[67] It is also expected that the gross cost of materials would be lower regardless as the mine is in close proximity and can be vertically integrated while also selling any rare earth minerals to increase profits to fund the reactor. Also, the working fluid, as previously discussed, would total $680,000 as well for a ton of the working fluid needed to suspend the thorium.

In addition, the average salary for a government program analyst is roughly $46,000 a year[68], and assuming a team of two analysts would work over the six years this number would need to be multiplied by 12. This would work best as a separate line item from the other labor

[66] NEI. (2020, April 30). Jobs
[67] Muhamad Pauzi, et. al (2019).
[68] Muhamad Pauzi, et. al (2019).

costs as it could go down as needed to save on cost of the program more so than the rest of the labor costs could.

Finally, it is not uncommon to run into cost overruns, so there ought to be a fund in case this happens so the program does not go over budget. A proposed refundable fund of 5 percent ought to be allowed to prevent this program from running out of funds in the event that this happens. This totals $6,111,638,160 and is represented in *Figure 6*.

Line Item	Cost
Labor Costs	$40,000,000
Construction	$6,000,000,000
Fueling Costs	$40,000,000
Working Fluid	$680,000
Analyst’s pay	$552,000
Cost Overrun insurance	$30,406,160
Total	**$6,111,638,160**

Figure 6

Market Proposal

The second option proposed is the market option. This option is essentially the government placing a monetary reward for the first company to build a thorium nuclear plant that meets preferred specifications. This option is viable to pursue at this time. However, there is some intricacy in this option that may not be initially obvious to observers. Several considerations must be considered when crafting a market-based policy. These key considerations are the evaluation of the reactor, how the money will be awarded, and what the expected time frame will be. Therefore, it is imperative to look at three key areas of consideration—criteria, awards, and public benefit.

Criteria

The criteria used to evaluate the thorium reactor are quite important. The reactor must be functional and pass an evaluation by the Department of Energy to determine its functionality. In addition, the reactor must pass a safety inspection to ensure its efficacy, safety, and reliability. While these may be basic criteria, they are necessary to include as there is a high likelihood that some companies might put forth faulty reactors in the hopes of getting additional funding. Only fully functional and safe reactors will be considered.

In addition to the basics, the reactor must use at least 90 percent thorium as the primary fuel substance. This percentage is very specific as it allows for some Thorium-MOX models produced by Thor Energy to be considered as "thorium nuclear plants" even if some Plutonium is used as fuel. These models focus more on retrofitting existing plants and are a steppingstone between LFTR models and current LWR models. The goal is to fully replace uranium in the reactor cycle. This also opens the door for existing nuclear plants to supplement the uranium cycle with thorium rather than building a new plant, which is a benefit to the nation.[69]

Finally, the plant must have a 3 percent return on investment to be considered viable for this proposal. It is imperative that the new sources of energy explored by the Department of Energy are not only environmentally friendly but also economically efficient in their operation so they can be used all over the country in different biomes. In addition, this would allow the United States to become fully energy independent and sell off excess energy to neighbors to increase security and international economic power.

Awards

The awards must be structured in such a way that incentivizes the market to participate in this policy. As calculated in the prototype section, the total cost of construction is roughly $6 billion, which is a starting point for the award. However, other methods can provide incentives to businesses for the construction of a nuclear power plant. Other incentives such as tax breaks and favorable land grants might help attract companies that have an eye toward the future.

The goal is to essentially make engagement with this program a worthwhile adventure for the company in the long term. It would also be counterproductive to offer incentives at the start of the project, such as a tax break for energy companies who begin construction, as there are too many loopholes that can be exploited. As such, the incentive structure ought to look at the long term, after completion methods which would have to be greater than the initial investment. It is also important to consider the fact that the corporation that completes this product can also sell

[69] Thor Energy. (2021, February 05). Start page.

the energy and rare earth elements similarly as the prototype section recommended with the local city utilities.

One of the first incentives to look at would be a 50 percent corporate tax break for the first $6 billion in revenue for the first six years following completion for the first company that completes the prescribed goals. This would result in a total of $3.78 billion saved in taxes for that corporation, assuming a flat tax rate of 21 percent. This would not only provide a strong incentive but would also relieve a significant amount of financial stress on the corporation for several years following completion. In addition, this would spread the financial burden across the entirety of the federal administration, rather than just the Department of Energy, and thus would make it much more manageable.

In addition, a cash prize can be offered but at a substantially lower rate than before as there would already be $3.78 billion in savings for the winning company. An appropriate offer would be $1 billion each year for three years following completion of the project. While this is roughly half the total estimated cost of the project, it still is a substantial sum of money, and coupled with the tax break exceeds the estimated cost of the project.

Finally, the government can offer exclusive short-term energy contracts with the winning company. These contracts are usually between utilities managers and energy companies. As such, the town nearest to the physical plant could set up an energy contract that benefits both parties. Therefore, the federal government could act as a middleman between the local utilities manager and the winning company and could front up to $500,000 to get a utilities manager to break their existing contract and sign a new one with more efficient local thorium generation. This would release them from any other commitments and would allow them to engage with this newer source of energy. To keep things in line with these calculations, the value of this specific incentive, as seen in *Figure 7*, will be marked as $500,000.

Incentive	Calculated benefit
Tax break	$3,780,000,000
Cash prize	$3,000,000,000
Energy contracts	$500,000
Total benefit	$6,780,500,000

Figure 7

This creates a total incentive of $6,780,500,000, which is nearly one billion more than the cost of the project and potentially much more through the sale of energy and rare earth elements found in the mining locations. This should be a sufficient incentive to get started with the project as well, and the direct cost to the Department of Energy is significantly reduced. In addition, the federal government does not have to have the money on hand for at least an estimated four and a half years after this policy is enacted, as it is nearly impossible for a company to have one of these reactors up and running in such a timeframe. This also allows for the cost to be spread out over time as a deposit until it is needed, which also reduces the financial stress.

Public Benefit

The public can benefit greatly from this policy option through a variety of primary and secondary effects. First, there will be an increase in the energy supply in the United States from the building of a new thorium nuclear plant. This will increase the overall energy independence experienced by Americans as well as making the energy grid more resilient in key locations as they are able to build new generators that are not geographically reliant, such as wind, solar and hydro are, while still maintaining the attractive environmental aspect.

Second, there will be a significant number of new, well-paying green jobs generated not only by the successful company, but by all the other companies that take part in this market-based project. Typically, there is 10 times the increase in research and development relative to the determined goal, which has a positive impact on the economy as well.[70] This increases the economic benefit well beyond the company itself or even the surrounding area that now gets to benefit from a local source of energy.

Third, this opens up new doors for other applications of nuclear technology for projects such as space flight.[71] It is unlikely that the company that develops this project will stop with one nuclear plant considering the amount of wealth that is likely going to be poured into the project. It is more likely that more plants will be built across the United States as well as transferring that technology into other areas of scientific advancement.

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[70] XPRIZE. (2021). About us

[71] Cole, M. (2018, July 30). It keeps going and going: Stirling engine test SETS LONG-DURATION record at NASA Glenn.

Comparison

With the prototype option and the market option laid out as potential policy choices, it is possible to complete a cost-benefit analysis to determine which of these two options ought to be pursued by the Department of Energy. There are a variety of variables to consider when comparing the two options. Variables such as the overall cost of the project, the timeline, the political feasibility, and the secondary effects are important considerations and will be covered in this section.

Cost and Timeline

The project cost for both of these is spread out over their respective timelines. In the worst-case scenario, the prototype option will cost a total of $6,111,638,160 over the course of six years, which equates to a little over a billion per year. For this project, that would be roughly $3,000,500,000 over seven years along with a 50 percent tax break estimated to reduce government revenue by an additional $3,780,000,000. This is not much compared to the overall budget of the federal government of over $2 trillion. However, the timeline of the market project is unknown because in the worst case no company tries to fulfill the requirements of the goal and therefore thorium nuclear technology is not developed within six years. This means China would be able to finish development on theirs first, which would put the United States behind and counts heavily in favor of the prototype option.

Political Feasibility

To be determined as politically feasible, either project has to be passed by both parties in Congress to secure funding as well as be accepted by the local population. There is the possibility of support from both major parties considering the prototype option. In recent years, the Republican party has become less stringent on government spending and will be attracted to the energy independence argument as well as the efficiency argument for this project. The Democratic party would also likely be attracted to this option due to the environmentalism attached with the project, though they might be a little wary of the perceived dangers of nuclear power plants.

In addition, the local population will respond favorably to this option as it provides a large source of jobs and revenue for them. Local leaders and utilities managers will like it as it insulates them from the wider energy market and allows them to appreciate a level of autonomy they otherwise would not enjoy. There is an additional benefit of future return on investment for the city as well once the contract is turned over to them.

On the reverse, the market project is not likely to be accepted by either party due to some critical issues. First, the Republican party would likely approve of the free market aspect of the project but would dislike the unknown timeframe that is attached to it. They would likely not see the benefit of setting a goal and letting the free market run its course. The Democratic party will likely not be in favor of the free market aspect and the lack of obvious oversight over the project. These factors are coupled with the lack of a timeframe, and the Democrats will most likely view this as a waste of time and money to even discuss since it has no immediate effects.

In addition, it is unknown how the local population will react as it is impossible to predict where any company will build their plant. While it is likely they would be in favor of a corporation moving in, it does not carry the same level of psychological security that the government might. Also, there is a likelihood that a new mining operation might be viewed in the same light as the copper barons in Idaho and Montana, and as such, would be prevented from reaching the rich veins of ThO_2 present. The idea of copper barons still has a negative connotation in Montana and Idaho due to their negative environmental impact as well as health impact on the residents there. This cuts heavily against the market project.

Secondary effects and long-term impact

Finally, the secondary effects and the long-term impact of each project ought to be considered. Both options are predicted to have positive secondary effects. First, the prototype option will produce a significant number of secondary jobs in and around the facility, thus spurring economic growth in a relatively unpopulated area. In addition, it allows for the government to proliferate thorium nuclear technology slowly across the United States, providing a significant amount of built-in resiliency and energy independence. The ultimate goal of this option is to have the government in control of a fully functional, new thorium-based power plant it could proliferate at a controlled rate across the United States.

Second, the market option will result in a significant amount of money spent on thorium research by various companies vying for this target. This also creates a significant number of green jobs as well as jobs in general across the United States, which is much more attractive to the federal government. In addition, upon completion of the goal, a brand-new energy market will be emerging and most likely will have relatively rapid proliferation across the United States and possibly the world. This could result in reduced CO_2 emissions as well as energy independence for the United States. This set of considerations cuts in favor of the market option over the prototype option for the veracity of the potential spread of technology, reduced CO_2 emissions and larger number of jobs created.

All these variables provide a concrete policy recommendation. It is clear the prototype option has a more robust analysis with more known variables as well as more potential for positive support. In addition, the known timeline plays a large factor in this recommendation because it provides a calculatable return on investment for the stakeholders and the government. Without a known timetable, there also stands a risk for international enemies, such as China, to build their plants first and leave the United States in a vulnerable position.

Furthermore, the control over the plant is important for the federal government so it can oversee the direct safety of the plant and provide a sense of psychological safety to local residents and the broader American public. It is predicted that the government taking on this project provides a better perception of control than if individual companies were to initiate the processes. There also is a risk of these companies working with outside entities that may pose a security threat to the United States, which includes leeching ideas and technology outside of American companies, with or without their consent.

Finally, it is important that there is at least the possibility of support for either project from both the political parties and the local population. The prototype option has possible support from both parties and definite support from the local leaders and citizens due to the oversight of the project. However, the market project does not have support that is known from either group. This alone restricts the possibility of this project moving forward as no member of Congress can be relied upon to take up the project and advocate for its funding. The analysis of each of these variables is present in *Figure 8*.

Category	Prototype	Market
Project Goal	Build a Thorium Nuclear Plant	Structure incentives so the free market takes up the market and builds a plant.
Overall cost	$6,111,638,160/ 6 years	$3,000,500,000/ 7 years
Project Timeline	6 years	Unknown
Support from both parties	Potentially	No
Support from local stakeholders	Yes	Unknown
Positive Secondary Effects	Yes	Yes
Long-term impact	Government control over a functional Thorium Plant, possibility to build more.	Proliferation of Thorium Nuclear Technology

Figure 8

Implications

A discussion of the implications of this policy proposal must answer three critical questions: "So what?" "As opposed to what?" and "Who cares?" To accomplish this discussion, there will be three main subsections discussing each individual question in detail. As such, the section will proceed first with a discussion of what the impact of this policy will be on the American people. Then, it will be juxtaposed with other options as any policy pursued by the government is necessarily chosen over other policies that advocate other ideas. Essentially, this section seeks to provide a rationale for why this policy ought to be invested in above others. Finally, there will be a conclusion discussing why this policy matters and why it is important to look into.

So What?

To begin, it is important to consider what the direct concrete implications of this policy will be on the American people. There are essentially three main implications of the policy for the American public: security implications, economic implications, and implications for future technology. These all are important facets of the implications for the American people and will be explored in depth.

Security is represented by the international implications of the United States becoming more resilient in its energy consumption and potential energy independence. As evidenced by the lack of resources during the 2020 Coronavirus pandemic, when important industries are locally sourced, the nation is more resilient to disruptions in international supply chains.[72] In addition, reliance on a different source of energy than internationally sourced oil also increases accessibility to energy for allies of the United States as the energy produced by these nuclear plants can be considered clean energy. This is because they produce significantly lower amounts of CO2 compared to oil and coal burning plants.[73] In addition, a significant portion of thorium can be found inside the borders of allies of the United States such as India, Canada, and Australia.[74] As such, an international energy agreement between these key nations and other allies is possible to form an energy-independent coalition against international aggressors such as Russia and China. Along the same vein, it is conceivable that if the United States is the first on the international scene with thorium nuclear energy, they can get a better foothold in the international market and push China out.[75]

Economically, there are similar effects from the pursuit of this policy. The most obvious is that this policy would greatly impact the economic status of the Idaho and Montana region and would potentially spur on population shifts to those less populated areas. This could have unforeseen effects on the United States, but one of the positives could be less pressure on more densely populated regions. Regardless, the introduction of a vibrant domestic industry with significant growth potential is good for the United States as it would bring along well-paying jobs. One of the desired outcomes of this policy is the proliferation of these reactors all over the United States, not just in the Idaho/Montana region. An increase in available energy and jobs

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[72] Sutter, K., Schwarzenberg, A., Sutherland, M., & Library of Congress. Congressional Research Service, issuing body.
[73] Roth, Michael Buchdahl, & Jaramillo, Paulina. (2017). Going nuclear for climate mitigation: An analysis of the cost effectiveness of preserving existing U.S. nuclear power plants as a carbon avoidance strategy
[74] IAEA. (2021, January 04). World distribution of Thorium Deposits.
[75] Evans-Pritchard, A. (2011, March 20). Safe nuclear does exist, and China is leading the way with thorium.

would have a positive impact on the overall economy and would reduce the overhead cost to businesses as there would be a higher supply of energy in general.

Finally, there are significant implications for future development of this kind of technology. Firstly, space travel will most likely require some form of Nuclear energy as it is the most efficient type per pound. There are a few options currently explored by NASA. The first is the use of fission reactors, which are currently used all over the world as the standard reactor design. The next option would be fusion reactors, which would produce significantly more power but would be essentially equivalent to trapping a star in a spacecraft, which is not very practical. The third is the Stirling radioisotope generator which uses the natural decay heat of radioactive materials to power the spacecraft.[76] These last two are experimental currently, but if more focus is put on nuclear energy in general, it can be expected that these and other modes of energy for space travel can become more available. In addition, with the advance of this type of technology, it is not unreasonable to expect other technologies in other fields to advance as well using interdisciplinary techniques.

As Opposed to What?

Each policy consideration necessarily takes away resources from other policy considerations, and therefore must be weighed against those other considerations. In the case of energy policy, there is a very tight budget at the Department of Energy, and a policy of this magnitude necessitates an increase to the overall budget if it is to be contained within the DoE. Regardless, three other options can be pursued instead of this policy. These other options essentially pursue different energy sources such as renewables, coal, and oil and fracking natural

[76] Cole, M. (2018, July 30).

gas. Each of these are worse options as they are damaging economically and/or environmentally. Regular uranium fission is available as well, but for the reasons covered in the background section, thorium is a superior source of energy.

Renewables pose an issue due to both their inefficiency and their inability to be adopted in a flexible manner insofar as they are dependent upon the biome they work within.[77] For example, solar panels do not work well in northern states, such as the Dakotas, whereas hydroelectric isn't going to work in places without a large river to damn. This is also not even considering the environmental impact of damming the river or the construction of massive solar fields. To compound this issue, often materials that are environmentally hazardous are used to build these generators as well. Finally, in situations such as 2012 the Solyndra Scandal, these corporations can cheat the government out of a significant amount of money, which would be avoided with the preferred policy in this case.[78]

The next option would be to focus on coal and oil. These options carry obvious issues in the sense of the environmental impact as these two sources produce the most amount of CO2 into the atmosphere and are generally unfriendly to the environment. Also, coal specifically is more radioactive than Nuclear sources as the background radiation produced by the large amount of coal unshielded at these plants is low per piece but is more in the much larger quantities used in these plants.[79] In addition, with oil specifically, it is subject to OPEC and Russia interfering with the international value of oil, which greatly affects the price of gasoline in the United States.[80] In

[77] Marcelino, Carolina G, Pedreira, Carlos E, Baumann, Manuel, Weil, Marcel, Almeida, Paulo E. M, & Wanner, Elizabeth F. (2019). A Viability Study of Renewables and Energy Storage Systems Using Multicriteria Decision Making and an Evolutionary Approach.
[78] Freking, K. (2015, August 26). Report: Solyndra misrepresented facts to get loan guarantee.
[79] Hvistendahl, M. (2007, December 13). Coal ash is more radioactive than nuclear waste.
[80] Deutsche Welle. (2021, February 11). Oil price Rise Risks OPEC+ cheaters returning to old Ways.

addition, the Middle East is a less secure region than is the United States, and the shipping lanes are more vulnerable outside of the country than inside. This makes international imports less secure. Finally, with the recent cancellation of the XL Pipeline, it is unlikely that the United States will ever produce enough oil to have a significant amount of energy security while this source is relied on upon.

Fracking for natural gas is the final option available. This option presents environmental concerns to a lesser degree when compared to oil and coal but more than renewable sources as it still outputs a significant amount of CO_2 and can damage underground water supplies[81]. In addition, public perception of natural gas is rather low as of right now, even though it is a better option when compared to coal and oil.[82] As such, it is hard to produce much of this source right now, but if nuclear were unavailable this might be the next best option. However, the political reality is that this will most likely not be pursued by the federal government and very well may be shut down in the near future.

Who Cares?

Finally, the most critical question when discussing implications is the question of why this policy matters. As previously articulated, there are significant economic and security ramifications from not pursuing this policy option. Therefore, those who care about international security as well as economic concerns ought to be invested in a policy such as this. In addition, there are significant environmental benefits to thorium nuclear policy as well. As mentioned in the background section, all activities dealing with thorium are significantly more environmentally friendly than most other sources of energy. From mining to the actual

[81] Greenpeace. (2012). Fracking's environmental impacts: Water.
[82] Union of Concerned Scientists. (2014, June 19). Environmental impacts of natural gas.

production of energy, Thorium produces a smaller carbon footprint while impacting the environment in less intrusive ways. If these values are important to Americans, then their representatives ought to care about this policy proposal to a significant degree.

Recommendations for Further Research and Conclusion

Over the course of this document, background has been provided on thorium nuclear energy as well as two potential policy options. Clearly, the variables analyzed provide support to the notion that the prototype option is the best option available for the federal government to pursue. Also, the implications have been examined for the American public and presented in a clear and concise format. This section will provide recommendations for further research in conjuncture with limitations faced by this proposal.

Recommendations for Further Research

There are still many questions that are raised in researching this policy. Firstly, other researchers ought to look into the efficiency and aggregate environmental impact from all available energy sources. Too often papers examine the CO2 output and ignore habitat destruction and radioactivity of materials.[83] These factors ought to be considered as well. In addition, an examination of the feasibility of the Stirling cycle and Thorium nuclear energy for space travel. The Stirling cycle in particular is useful for space travel as it utilizes the natural breakdown of fissile materials such as Uranium as a heat source, counterbalanced by an outside vacuum to push a piston using pressure variation. This effectively creates an infinite source of energy for a space craft, and if utilized to its fullest extent, reduce the overall weight of the fuel necessary for travel. This could be a great next step in economical space travel.

In addition, a recommendation for an actionable plan can be formed utilizing the Eightfold Path developed by Bardach and Patashnik. Of these eight steps, the first four (Define

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[83] Silva, Susana, Soares, Isabel, & Pinho, Carlos. (2012). The impact of renewable energy sources on economic growth and CO2 emissions--a SVAR approach.

the Problem, Assemble Some Evidence, Construct the Alternatives, and Select the Criteria)[84] have already been achieved by this proposal. This outline is a great start for a recommendation for future policy. As such, the other four steps will be briefly discussed.

First, the outcomes have to be properly projected in the sense of what is realistic over what is optimistic. Bardach and Patashnik suggest that step is the most difficult step of the Eightfold Path as it requires one to examine critically the policy that is desired.[85] As such, this step can be best addressed as an outcomes matrix similarly to what was done in the comparison section. However, this time it ought to be examining what the potential outcomes of the policy are, both in success and failure.

Following this, the step would be to examine the tradeoffs.[86] In this case the tradeoffs are very salient in that a significant chunk of money is funneled into this one program for this one reactor. As such, proper methodology of examining how to provide funding must be performed to understand fully the financial cost of this project. The money ultimately has to come from somewhere.

The seventh step is to narrow down the focus of the project.[87] This will most likely be accomplished by focusing on the primary reactor being built and setting aside ideas for physical expansion or sales of rare earth elements. This is done so that the policy itself is crisp and clear in its goals and capacity to achieve said goals. A problem that could arise here would be shifting the problem onto a client rather than addressing it in the formation stage, as was seen in both the 2010 and 2011 bills.

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[84] Bardach, E., & Patashnik, E. (2020). *A Practical Guide for Policy Analysis* (6th ed.).
[85] Bardach, E., & Patashnik, E. (2020).
[86] Bardach, E., & Patashnik, E. (2020).
[87] Bardach, E., & Patashnik, E. (2020).

The last step identified by Bardach and Patashnik is to tell the story of the policy.[88] This is crucial to avoid the pitfalls of the previous bills. A problem those bills could experience was that they did not make the issue of energy security or energy policy more broadly very salient to the rest of Congress. As such, a short, concise, and cogent proposal must be presented that conveys the importance of the bill, along with the specific structure of the request.

Limitations

This research did face significant limitations. The lack of a contact within the Department of Energy and within the locality of the Lemhi Pass limit the robustness of this policy proposal as it lacks the concrete needs of both sides. While the use of the local utilities manager within Indianola is beneficial and provided great insight, having these contacts would make this proposal better able to pinpoint issues and fix them. In addition, lack of technical knowledge of the intricacies of nuclear energy limits this author's ability to comprehend fully what is needed financially to build such reactors. Finally, taking this policy proposal directly to the Department of Energy would increase its robustness as they either can correct any technical errors and reformat it to work within the federal government guidelines and expectation, or they could provide guidance on how to make this proposal more feasible for them as well.

In addition, similar to the 2010 Senate bill and the 2011 House bill, this proposal runs the risk of languishing in committee and not even being brought to the floor. This would greatly limit the ability of this bill to be considered seriously. In addition, one of the reasons this might happen is because the area of energy policy and energy security is not particularly salient as of right now considering there is no current oil crisis. If OPEC or Russia precipitated another oil

[88] Bardach, E., & Patashnik, E. (2020).

crisis then it is possible energy security will become more urgent. This is further complicated by the high level of partisanship in the federal government right now. This bill would require cooperation by strong members of both parties for it not to be considered a partisan bill. The best option is to get in contact with a senator from Idaho and Montana and work with them to develop a bill to benefit their area.

Other limitations include the lack of technical knowledge regarding how energy is produced, and the in-depth knowledge of nuclear energy that only nuclear engineers have. Had this proposal been partnered with such an expert, no doubt the technical breakdown and discussion of the output would be more precise. Also, had there been a representative from the Department of Energy, their interests in the proposal would have been much clearer in how they relate to local utility managers like Chris Desplanques. As such, this paper is limited in its applicability due to the lack of relevant experts to interview in that capacity.

Conclusion

In conclusion, this proposal provided necessary research in the realm of nuclear energy and can be used as a starting point to examine the viability of thorium nuclear energy. Background was provided that examined the benefits of thorium nuclear energy over other forms of energy. A concrete policy proposal was provided that the federal government could use to start a committee on exploring the building of a nuclear power plant in the Idaho/Montana area. Finally, implications were explored as to what happens next following this policy proposal.

As explored in the further research portion, there are certain steps that will need to be taken to get this project adopted. Even after adoption, more steps will need to follow to put this plan into motion. Exploring the region and working with local politicians is a must for this plan's success. While this project does accomplish a great deal in the sense of moving this idea forward, there still is much to be done to actuate the goals of increased energy security, economic growth, and technological advancement within the United States.

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