Factors in Thorium Fuel Adoption

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Introduction

The countries of the world, based on environmental and economic events, are under growing pressure to find solutions to their energy problems through effective public policy. Effective policy decisions must take into account the current limitations of solar, wind, and other renewable energy sources that make them potentially economically inefficient compared to the alternatives. Given the current technology, policy and regulatory framework, the most viable alternatives to nuclear energy for base-load power are coal and natural gas, both of which emit carbon dioxide and other pollutants, as well as having other harmful effects. The demand for electricity is growing, as are concerns about the country's dependence on oil and gas imports and the effects of price volatility and supply disruptions on the economy and national security

Nuclear energy has many benefits that make it attractive as a primary power source. When compared to power plants that use oil, coal, and natural gas, nuclear-fueled power plants (NFPP) do not produce carbon and other green house gases during the process of producing energy. And while solar, wind, and other renewable energy sources also produce power cleanly, they do so only intermittently and usually at a considerable distance from the major sources of demand. NFPPs are capable of almost continuous operation, which makes them ideal as a source of base-load electric power. Of course, NFPPs' drawbacks are also well known: these include high construction and permitting costs, risks to human health from radiation, costs and safety issues in the disposal of waste, and risk of nuclear proliferation. Most NFPPs use oxides of enriched uranium, or a mixture of uranium and plutonium, as the fuel; having been in widespread use since the 1960s, the technologies are well understood, as are their considerable risks. Yet there is an alternative technology that has the advantages of conventional NFPPs but with fewer risks: the thorium fuel cycle. Developed in the US in the 1950s and 60s but subsequently abandoned in favor of uranium, systems based on thorium, a radioactive element similar to uranium but in far greater abundance, hold great promise as a reliable, safe, and cost-effective source of base-load electric power. While the US has remained committed to uranium, India, China, and other countries are pressing ahead with thorium technology, building on research done earlier in the US. The US faces a policy choice: resume research and development, and initiate demonstration projects, targeting the thorium cycle; or continue the present technological trajectory based on uranium, which, given the high costs of building plants and continuing public concerns about safety, would likely place severe constraints on the contribution of NFPPs to the country's energy supply.

This project will assess the potential for the development of a NFPP technology using the thorium cycle in four consistently pronuclear countries and the US. Although present energy policy in the US supports civilian nuclear power through federal loan guarantees, tax credits, risk insurance, and research in the national laboratories, it is largely focused around fuel cycles using uranium, almost all of which is imported, and whose conversion yields large amounts of highly radioactive waste and unburned uranium that must be recovered and recycled. Shifting the emphasis to the thorium cycle will require not only the mobilization of political resources but also an assertion of leadership and public support rarely seen in the energy policy area. Through case studies of countries that have made varying commitments to civilian nuclear power and the thorium cycle, this paper will identify characteristics shared by countries that have pursued comparatively activist policies. It will then assess the policy framework in the US in relation to these characteristics. Finally, it will draw conclusions about the prospects for a policy-mediated shift to the thorium cycle in the US based on the results of comparison with other countries.

The paper begins with background and theoretical methods used in this study. Next, the theoretical framework will be used to explore and compare the national-level characteristics of five countries, including the US, that have not only demonstrated national commitment to civilian nuclear technology but have also used public policies to shape and reshape nuclear technologies in ways that support national goals. Finally, the paper discusses the results of the comparison, focusing on the extent to which characteristics associated with effective policies, especially those targeting development of NFPPs using thorium, are present in the US. The concluding section assesses the likelihood that US will be able to orchestrate a shift in the public policy framework from one focused almost exclusively on uranium (U 235) to one that embraces thorium as a primary nuclear fuel. A comparison of these countries' characteristics with those demonstrated by the United States is conducted, and ending with conclusions regarding the nature of the United States and thorium technology is presented.

Background Research

Renewable energy sources are an attractive alternative to the greenhouse gas emitting power plants that are currently in operation. The ability to utilize energy that is naturally replenished and has no greenhouse gas emissions from creating the energy makes them a possible solution to climate change that rivals nuclear power as a primary energy source. Energy from these sources, however, has technical and economic drawbacks that limit the ability to compete with nuclear power. Biofuels are considered a possible replacement to oil and natural gas. Bio matter, usually plants like sugar can and corn, is processed and burned in an engine to produce energy. Concerns over altering the supply of food have been voiced by some opposed and emissions still may have a harmful effect locally. Hydrogen is also a fuel that can be stored for later use. It is also costly to separate the hydrogen from oxygen. Solar power uses panels to catch energy directed from the sun in order to produce energy. The current cost of solar panels is prohibitive, and it may take decades to bring down costs to the point where solar voltaic systems are competitive with other sources, especially for base-load power[1]. The process of producing the panels also uses poisonous gas, which is dangerous for manufacturers. China and several European manufacturers have the technological advantage in large-scale production; firms in the US, which excels in research, will find it difficult to compete in manufacturing without implausibly large and sustained subsidies[2]. Geothermal energy uses the heat within the earth to generate electricity. There is far less greenhouse gas emissions but contaminants may need to be pumped back into the reservoir. As with terrain sensitive sources, geothermal needs to be in close proximity to heat to be most effective. Hydroelectricity is used extensively in Brazil due to terrain common in the country. Despite the cost effectiveness of the electricity, requiring a

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[1] Weiss, Charles and William B. Bonvillian. (2009). *Structuring an energy technology revolution*. Cambridge, Massachusetts: Massachusetts Institute of Technology. 67-68.

[2] Weiss, Charles and William B. Bonvillian. (2009). *Structuring an energy technology revolution*. Cambridge, Massachusetts: Massachusetts Institute of Technology. 67-68.

proper location is restrictive, making transportation for consumption costly or necessitates that consumers operate around the facility. Environmental damage to wildlife is also a primary concern especially to fish that need the rivers flowing for use to the dam[3]. Wind and tidal power are generated by turbines that are pushed by wind or tidal currents, respectively, and thus require these forces to be active when the electricity is needed. Turbines also tend to be placed farther out from where the energy will be consumed, requiring long cables to reach the consumer. Aesthetic concerns have prompted law makers to avoid placement near populated areas.

In sum, most renewable energy technologies have drawbacks that severely limit their potential to supply the electrical grid with large, reliable, and uninterrupted supplies of power. Despite high construction costs and concerns about safety, NFPPs continue to provide large amounts of base-load power, and they do so reliably, safely, continuously, and at far lower operational costs than can be obtained with coal and gas-fired plants, let alone exotic renewable technologies[4]. NFPPs can operate continually, and because fuel (thorium fuel in particular) is inexpensive compared to energy output, it is a better choice as a primary electricity generation technology.

Nuclear energy has been anticipated to be the next primary energy source for some time. The energy is derived from a base load generator that does not require specific environmental conditions to operate. The fuel for the reactor has been priced

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[3] Sims, G. P. (1991). Hydroelectric energy. *Energy Policy, 19*(8), 776, 780. doi:DOI: 10.1016/0301-4215(91)90047-R

[4] Piore, A. (2011). PLANNING FOR THE BLACK SWAN. *Scientific American*, 304(6), 48-53. Retrieved from EBSCO*host*.

more consistently in the market although the cost of recycling fuel is expected to increase. As the demand for uranium increases and the supply decreases the price will eventually increase, making uranium a more expensive fuel to consider especially in comparison to thorium[5]. Thorium can be found in large quantities around the world with an estimated three times the quantity of uranium and only half as common as lead. Predictions place the amount of thorium to power the world for a thousand years before the world's supply is depleted[6]. Nuclear technology, in particular thorium based technology, has great potential against competing energy sources.

The first commercially viable reactor designs were the light water and heavy water designs. These reactors are designed to send slow moving neutrons to split uranium 235. This process, while being most efficient for energy production concerns, leaves approximately 95% of the fuel unused, with the unused material sent out as a waste product along with the actual refuse from the successful fission processes. The process also produces small quantities of plutonium, which is both extremely toxic and a potential source of material for nuclear weapons, making it a safety and national security concern. The waste is very dangerous and due to the potential for weapons usage is considered to be a national security issue. While this early design was the most effective for energy production, it is not a viable long-term solution.

The idea behind the fast neutron design was to use faster neutrons instead of slow ones to split the uranium 235 but also have the capacity to break up the heavier atoms

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[5] Gutmann, H., Hansen, U., Larsen, H., & Neef, H. J. (1976). The high temperature reactor in the future fuel market. *Annals of Nuclear Energy, 3*(2-3), 116. doi:DOI: 10.1016/0306-4549(76)90007-4

[6] Kursunoglu, Behram N., and Teller, Edward (1 August 2001). *Global warming and energy policy*. Kluwer Academic/Plenum Publishers. p. 4. ISBN 9780306466359.

that would remain as waste if only slow moving neutrons were used to split them. This process would aim to eliminate the large excess waste product and further utilize the remaining unspent 95% of the fuel that is introduced[7]. This would decrease the amount of waste and eliminate the weapons grade materials from the costs equation. The primary "inefficiency" of the fast neutron reactor in the United States was that although the higher weighted uranium would be able to be consumed as fuel through conversion to plutonium, the risk that the waste would be stolen and used to produce a nuclear weapon was considered excessive. This was supported by energy economics. The large amounts of uranium and other fossil fuels available made it so that reprocessing uranium was deemed unnecessary to conserve the resource[8].

Thorium has little energy production use in its common state, thorium 232, but when seeded with neutrons becomes the viable uranium 233. It was among three originally sought nuclear materials during the 1940's but did not receive as much attention as uranium due to several factors including energy productivity and weapons capability. Thorium has returned as a contending fuel due in part to the economic need for energy sources and its abundance compared to uranium. It also lacks the ability to be made into a weapon, which was once thought to be a limitation but is now considered strength. Technology has also been improving in regards to nuclear power production, allowing for thorium to act as a more powerful fission fuel.

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[7] Hannum, W. H., Marsh, G. E., & Stanford, G. S. (2005). Smarter Use of NUCLEAR WASTE. *Scientific American*, 293(6), 85-86. Retrieved from EBSCO*host*.

[8] http://www.world-nuclear.org/sym/1999/wilson.htm

Fast breeders had been desired for their ability to create plutonium and reprocess spent fuel but had been stalled by opposition in the United States in the 1970's under Carter to the production of plutonium[9]. The risk of terrorists obtaining the material to make a weapon was perceived to be too great. Although, the process has begun to regain steam recently by environmentalists whose push for the total use of fuel to reduce waste has been a growing issue[10].

Thorium can be set so that it absorbs the neutrons given off by uranium to become uranium 233 for use as a productive fuel that thorium itself could not. The atoms can then be used in a fast neutron reactor for use with uranium if desired and consumed with little waste product. The waste from the uranium 233 is less radioactive and only lasts for approximately 100 years as opposed to millions of years due to the type of elemental waste that is produced[11]. The capability as an effective fuel combined with the large supply (native supply in the case of India, Brazil, and the United States), and a less destructive waste product make thorium a perfect contender for primary energy source. The extra cost to take thorium through its fuel cycle is not expected to increase the cost of

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[9] Hannum, W. H., Marsh, G. E., & Stanford, G. S. (2005). Smarter Use of NUCLEAR WASTE. *Scientific American*, 293(6), 85-86. Retrieved from EBSCO*host*.

[10] http://www.world-nuclear.org/sym/1999/wilson.htm

[11] Furukawa, K., Arakawa, K., Erbay, L. B., Ito, Y., Kato, Y., Kiyavitskaya, H., . . . Yoshioka, R. (2008). A road map for the realization of global-scale thorium breeding fuel cycle by single molten-fluoride flow. *Energy Conversion and Management, 49*(7), 1842. doi:DOI: 10.1016/j.enconman.2007.09.027

production beyond other fuel sources[12]. Thorium is currently being classified as a radioactive waste product and therefore a burden on mining operations because of the disposal costs incurred.

The newest variation is the molten salt reactor (MSR in this case but called other names as well), which is one of the primary uranium 233 utilizing reactor designs. It uses liquid fuel, which includes instead of fuel rods and unlike the slow neutron reactors that use water to stop meltdowns from occurring use salt that flows as part of the fuel to prevent temperatures from increasing to dangerous levels. The salt will automatically be administered into the system through the process of large heat melting the stopper. This removes the need for external power or personal management from causing an event such as the Fukushima disaster from occurring. This model's design is also undergoing examination into the possibility of mass manufacturing given that the plant is constructed the exact same each time as opposed to previous installations that require individual design and as a consequence more costly construction and decommissioning costs. This model further improves the benefits of using thorium as a nuclear fuel by adding more cost reduction and safety measures that negatively stigmatized previous nuclear technologies.

Theoretical Methods

This research study was conducted in the form of a comparative policy study. For this category of study each national system is examined (in this case by exploring the sociopolitical and economic aspects of policy decisions) to draw conclusions of policy

[12] Gutmann, H., Hansen, U., Larsen, H., & Neef, H. J. (1976). The high temperature reactor in the future fuel market. *Annals of Nuclear Energy, 3*(2-3), 117. doi:DOI: 10.1016/0306-4549(76)90007-4

outcomes under certain circumstances. By this method of analysis the study of different political and economic environments can shed light on the outcomes of policies[13]. In this way a policy can be determined to be accepted or not depending on the variables involved in each national structure. Given that the goal of this study is to determine whether or not thorium is feasible as an alternative nuclear fuel in four pronuclear countries and the United States, the comparison between the United States and other countries who have already demonstrated a desire to utilize this technology makes the comparative policy analysis the ideal tool for making such a determination.

The social sphere has a tremendous influence over technological development and policy. This is further manifested in both economics and politics. Because of the influence these factors have, technology in of itself cannot be considered when determining if it will dominate in the market. Path dependence is a term used to describe how these social factors cause preexisting technologies to remain dominant despite the alternatives. The primary economic concern is that firms that produce or rely on the current technology will lobby to have it remain in use and oppose any competition that removes the advantage that the old technology provides them. This can also have an effect socially. The commonly used example being the "qwerty" keyboard design that Valentine and Sovacool mention[14]. Another more recent example is the use of certain computer programs requiring access to an older, established operating system or network

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[13] Heidenheimer, A. J. (1985). Comparative public policy at the crossroads. *Journal of Public Policy, 5*(4), pp. 442. Retrieved from http://www.jstor.org/stable/3998397

[14] Valentine, S. V., & Sovacool, B. K. (2010). The socio-political economy of nuclear power development in japan and south korea. *Energy Policy, 38*(12), 7971-7979. doi:DOI: 10.1016/j.enpol.2010.09.036

connection. New software technologies that do not work with the prevailing standards and technologies have a high chance of failure in the marketplace unless they're made compatible with existing standards. . The established technology is said to be "locked-in" by the social, technical, and economic factors that impose high costs on those that shift from the older to the newer technology.

This paper attempts to act as a follow up study to Valentine and Sovacool 2010. In the paper they describe six different factors that contributed to the development of nuclear energy in Japan and South Korea. These six factors are: a strong state involvement in guiding economic development, centralization of national energy policymaking and planning, campaigns to link technological progress with national revitalization, influence of technocratic ideology on policy decisions, subordination of challenges to political authority, and low levels of civic activism. The authors then state that the factors that were derived from their study may not apply to all pro-nuclear countries and that "untethered countries" (countries that have been inconsistent regarding nuclear energy such as the United States) may be "catalyzed" by changes in these factors to either become pro or antinuclear energy and that more study would be necessary to determine if these factors are, in fact, consistent in determining a countries success in nuclear development. The research questions are precisely as Valentine and Sovacool ask at the end of their paper. Do the six factors that their study produced also apply to a broader range of nuclear states? What factors appear to have the "catalyzing" effects on an untethered nation?

This study examines five countries that have been active in nuclear development and have shown an interest in thorium as an alternative nuclear fuel. India, Brazil, France, Japan, and the United States of America have been chosen because of their shared interest and past or current experience in producing thorium based fuel cycles[15] and differing economic backgrounds (India and Brazil are developing countries); with the exception of the United States, all have maintained public policies supportive of NFPPs as a significant source of electric power (although policy in the US was once strongly supportive of civilian nuclear power, it shifted after the accident at Three-Mile Island to a framework that has been far more cautious and more oriented toward regulation than to promotion.) In this study a country in which the government controls civilian nuclear facilities and works together with the private sector to develop a nuclear power industry is called "pronuclear." These five countries are also representative of different geographical and cultural backgrounds. India represents South Asia, Japan represents East Asia (and provides a comparison piece from the original paper), Brazil represents South America, France represents Europe, and the United States represents North America. Germany and China were not considered as representatives because they would create a duplication of a representative for a region and individual factors that would make it difficult to assess or are not qualified based on prior criteria. Germany has exhibited tendencies that make it appear more untethered than pronuclear while France has remained pronuclear and also can represent the European region. China shares the East Asia region with Japan and given concerns of access to information regarding nuclear activities was also not considered.

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[15] Furukawa, K., Arakawa, K., Erbay, L. B., Ito, Y., Kato, Y., Kiyavitskaya, H., . . . Yoshioka, R. (2008). A road map for the realization of global-scale thorium breeding fuel cycle by single molten-fluoride flow. *Energy Conversion and Management, 49*(7), 1832-1848. doi:DOI: 10.1016/j.enconman.2007.09.027

The four pronuclear countries will be tested to determine whether they share common characteristics across the six factors noted above and to want extent they differ in these characteristics. Because the United States is an untethered nation, it acts to test which factors are associated with a switch from pronuclear to antinuclear. Thorium acts as a proxy for nuclear development because it is a nuclear technology and therefore has the same requirements for policymaking to occur, is a potential solution to current energy and environmental problems, and it is the method of nuclear technology that has enough research to be valid but has not been put into practice as a primary commercial method of energy production.

This study combines the six factors as presented by Valentine and Sovacool into three variables. The government centralization variable describes the extent of centralization of national energy policymaking and planning and subordination of challenges to political authority. The economic characteristics variable category describes the extent of state involvement in guiding economic development and influence of technocratic ideology on policy decisions. The last variable, societal organization, describes the level of societal support for nuclear power, propensity for civic activism, and ease with which social groups can mobilize and bring political pressure to bear on the relevant political authorities.

Operationalization of each of these groups was determined based on the case study data from the original study. Included in the government centralization variable are indicators of decision making power consolidation at the policy making level, limitations of economic actors to act as agenda setters, presence of oligopolistic or monopolistic energy providers, and the ability to suppress dissent in the public on matters of nuclear energy. The economic characteristics variable includes the control of economic policy, evidence of government agency's influence, or other government control over aspects of the economic sector or technocrats (nuclear engineers, scientists, and elites in the field of nuclear industry) influencing policy decisions. The societal organization variable includes the degree of public support for nuclear power, nature of the connections between social groups and policy makers, and responsiveness of policy makers to changes in public opinions and perceptions.

Nuclear technology in particular is sensitive to these variables because of the requirements on regulation and need for government finance to offset the large cost of initial design, construction, and permitting of NFPPs through, as an example, low interest loans. The countries were chosen based on their previous involvement with nuclear energy and the diversity of their backgrounds along with their involvement in nuclear research using thorium. Brazil and India represent developing countries while Japan and France are models for the developing countries.

Energy Consumption from Various Sources for the Countries in this Study

Energy Consumption					
	India (2007)	Brazil (2008)	France	Japan (2008)	United States (2008)
Nuclear	0.70%	1%	77%	11%	8.50%
Coal	40.8% (Coal/Peat)	5%		21%	22.50%
Oil and other liquids	23.70%	50%	10%	46%	37.50%
Natural Gas	5.60%	8%		17%	24%
Other renewables	0.20%	2%		1%	5%
Hydroelectric	1.80%	34%	13%	3%	2.50%

India

Government Centralization

After gaining independence, India made extraordinary commitments in their policy decisions in order to catch up with the rest of the world and become a leading nation. As a part of this policy surge was not only investment into economic measures targeting energy and unemployment but national goals similar to those of the United States during its Cold War conflict with the USSR:

> Indira Gandhi's science policy stressed industrialization with capital-intensive industries like steel (which have yet to become profitable), and exotic sciences like space and nuclear technology...[16].

The exotic sciences were a rallying point that the country would support in a unified plan to reinvigorate their nation. Specific goals like the support for industry and economic prosperity were worthy of achieving but would not be sufficient in creating the national support structure needed to be a global power. Through these policies, centralized control emphasized nuclear research and the long term goals of the plan were of satisfactory quality that nuclear industry was able to survive the introduction of the Indian nuclear weapon in 1974.

The rivalry between India and Pakistan has increased the military desire for nuclear weapons and as a consequence has negatively impacted the ability to produce nuclear energy production. Tensions have been maintained between the two states since their independence from the British in 1947. Short term wars over the territory between Pakistan and India was the first with later conflicts arising over support for Hindu groups

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[16] Ghaswala, S. K. (1977). INDIAN JOURNAL. *Sciences*, 17(6), 28. Retrieved from EBSCO*host*.

by the Indian government after Pakistan took lands from them and handed it to Muslim populations. The divisiveness of the history and intermixed populations in both countries continue to spur disagreement. The conflict and the construction of the nuclear weapons program called "Smiling Buddha" in the 1970's caused India to refrain from signing The Nuclear Non-proliferation treaty. The result was an inability to access nuclear resources. Despite the continuing hostility between the two countries, Pakistan and India, the United States has provided India with a trade agreement that will allow for the operation of 10 new power plants in the near future and four more are planned for construction[17].

Economic Characteristics

The nuclear program in India may have originated as a national attempt to enlarge its image at home and abroad with growth into the military development of nuclear weapons with the conflict with Pakistan but it also allowed for economic opportunities as well. Nuclear energy was designed to eventually take the place of other energy sources:

> The promise offered by the DAE [Department of Atomic Energy] is not only that nuclear power would form an important component of India's electricity supply, but that it would be cheap. As early as 1958, Homi Bhabha, the chief architect of the programme, projected ''the contribution of atomic energy to the power production in India during the next 10 to 15 years'' and concluded that ''the costs of [nuclear] power [would] compare

[17] http://www.eia.gov/countries/cab.cfm?fips=IN

very favourably with the cost of power from conventional sources in many areas'' (emphases added) [Bhabha and Prasad, 1958][18].

Nuclear power served a dual purpose, which made it initially worthy of investment but also was speculated to become the more efficient energy source. The India nuclear program, as established by Homi Bahba, was planned for three phases that would lead to thorium based nuclear energy[19]. Uranium powered light water reactors were the obvious first choice that used the local uranium. This would be followed by the fast breeder reactors that would use the waste of the first generation (plutonium) along with uranium 233 from thorium. The last phase was the introduction of thorium as a fuel to replace the use of uranium and allow India to operate the nuclear program using uranium 233 from the large natural thorium reserves. The largest quantity of thorium known is within India and the cost is inexpensive. The existing reactors would assist the transition form breeding uranium to breeding thorium while molten salt reactors are produced. The one flaw that has affected this plan is the poor realization of the phases which leaves little energy as a percentage of energy production in India coming from nuclear. With the set up not ready for thorium the system has been slowed.

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[18] Ramana, M. V., D'Sa, A., & Reddy, A. K. N. (2005). Nuclear energy economics in india. *Energy for Sustainable Development, 9*(2), 35. doi:DOI: 10.1016/S0973-0826(08)60491-3

[19] Bhargava, G. S. (1992). Nuclear power in india the costs of independence. *Energy Policy, 20*(8), 735-743. doi:DOI: 10.1016/0301-4215(92)90034-Y

Societal Organization

The introduction of nuclear technology with the intent of using the nation's thorium reserves began with the policies established by Indira Gandhi to make India a global power. These policies were quickly accepted by the Indian people and took form not only as a long term government action but a public impulse. Despite current disputes regarding the continued implementation of uranium fueled power after risks of this earlier technology have been reintroduced into the public consciousness there is still the perceived need for nuclear technology to grow. From a survey entitled "India's energy security: A sample of business, government, civil society, and university perspective":

> Finally, two respondents also mentioned in the open ended question that nuclear energy is a key solution for the energy security issue. All of these results go to show that nuclear energy systems are considered important for energy security in the Indian context[20].

The previous intent of using nuclear as a tool to rally behind has diminished with the failure to achieve goals on time. The emphasis placed on the prospects of efficient use and self-sustainable energy production from thorium has not.

Because of the disaster in Japan, plans to build the largest nuclear power facility in the world in India have been met with opposition[21]. The opposition however has not been successful in changing policy due to procedures in place. The focus of the protestors has been to change these policy rules first before they can successfully

[20] Bambawale, M. J., & Sovacool, B. K. (2011). India's energy security: A sample of business, government, civil society, and university perspectives. *Energy Policy, 39*(3), 1261. doi:DOI: 10.1016/j.enpol.2010.11.053

[21] http://news.yahoo.com/s/csm/20110511/wl_csm/381987

challenge nuclear growth. Despite some visible opposition to nuclear power, the state remains in control because of the regulatory framework in place.

Brazil

Government Centralization

Brazil has pushed for nuclear technology through its focus on nationalism especially in the face of the threat from Argentina until the fall of the dictatorship in 1985. The result is a push toward nuclear technology but in many ways a push against the use of thorium as a nuclear fuel. The benefit of the dictatorship, however has contributed in the early stages of nuclear development the kind of centralized structure needed to create a long lasting policy for nuclear development that due to its sunk cost made it difficult to completely discard when power was shifted to the new civilian government.

The goal of the Brazilian regime was not just the mastery of all forms of nuclear technology in general but also more impactful towards policy and the primary goal of many countries who attempt to gather nuclear technologies: nuclear armament[22]. Also not surprisingly Brazil was involved in a conflict with another nation at the time that promoted nuclear armament as a primary goal of the government. Brazil shared the same bordering nation conflict with Argentina that India has with Pakistan that drove much of the policy making in nuclear technology. This not only started the process of obtaining

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[22] Jewell, J. (2011). Ready for nuclear energy?: An assessment of capacities and motivations for launching new national nuclear power programs. *Energy Policy*, *39*(3), 1041-1055. doi:DOI: 10.1016/j.enpol.2010.10.041

nuclear technology but continued to fuel the need to continue for the sake of military ends:

> The ambitions to have nuclear weapons were nurtured by the regional rivalry with Argentina, which at the time was also under a military regime and was developing its nuclear program[23].

This process continued until the change in government and the shift back toward nuclear energy from thorium. Although this process of national support for nuclear from a national perspective from conflict appeared to end with the willingness to agree to non-proliferation treaties with Argentina, it provided enough time and investment into the policies, programs, and resources for the new civilian government to continue to promote nuclear technology for peaceful reasons. Unofficially the military, which acts as an autonomous group, by their interpretation of their constitution signed in 1988, appears to continue to move funding towards the nuclear refinement process and the eventual development of weapons technology unsupported by the civilian government[24]. Despite civilian policy, the military is using their constitutional powers to establish their own policies that center around maintaining Brazil's culture which, in their opinion, does include nuclear weapons research.

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[23] Cabrera-Palmer, B., & Rothwell, G. (2008). Why is brazil enriching uranium? *Energy Policy, 36*(7), 2573. doi:DOI: 10.1016/j.enpol.2008.02.033

[24] Krasno, J. (1994). Brazil's secret nuclear program. *Orbis, 38*(3), 433. doi:DOI: 10.1016/0030 4387(94)90006-X

Economic Characteristics

While the options for energy in the modern Brazilian economy are great, especially with the research into biofuels and the country's own large stockpiles of natural resources, nuclear technology is being touted as a primary energy producer. The ability for natural resources to be used, including harvest, refinement, and distribution are not at a level to support a developing economy like Brazil's. Fuel options like biofuels, while supported, are not at a stage that can be used efficiently. As a result Brazil has been forced to use foreign resources to power its economy:

> The official arguments for a Brazil's nuclear programme, in essence, maintain that the country's dependence on imported fuel is large enough to make the nuclear option not only sensible but urgent[25].

It is currently accepted that the applications of nuclear power are necessary if only to sustain options for providing energy:

> The figures presented here for the availability of non-nuclear energy sources suggest that, in terms of energy requirements, the scale of the Brazilian nuclear programme is open to question. A small programme, to enable experience to be gained of nuclear power and to keep the nuclear option open, would be incontestable on energy policy grounds[26].

Nuclear power initially was considered economically beneficent due to the large quantities of uranium and thorium present within the country. This allowed access to the

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[25] Duayer, M., Gummett, P., & Green, K. (1981). The brazilian nuclear power programme: A case not proven. *Energy Policy, 9*(4), 323. doi:DOI: 10.1016/0301-4215(81)90009-4

[26] Duayer, M., Gummett, P., & Green, K. (1981). The brazilian nuclear power programme: A case not proven. *Energy Policy, 9*(4), 325-326. doi:DOI: 10.1016/0301-4215(81)90009-4

natural resources to construct the nuclear program without the importation of uranium, although the technologies including centrifuges were being sought after from Germany. Thorium in large quantities did allow for the option of reactors powered by this fuel but, because the government was motivated almost solely by national security, was not a primary goal of nuclear research.

The primary source of Brazil's electricity is from hydroelectric power. Brazil also possesses a large biofuel industry that derives its product from sugar cane. Because of the use of hydroelectric power, crops and the local population have been unharmed by the emissions of burning biofuel or another green house gas emitter. This fact combined with the need to operate power plants closer to their customers (which hydroelectric power already has a difficult time with) makes using the strong biofuel industry an inopportune choice in comparison to a thorium based nuclear facility that can avoid emissions and effectively keep waste from creating environmental hazards. This also allows industry in Brazil such as the aluminum production industry to become more mobile instead of being restricted to locations with hydroelectric power.

Societal Organization

During the period of the dictatorship Brazil had centralized control over nuclear research that led to advances in its nuclear capability but had not sought out thorium as a nuclear fuel at that time because nuclear weapons were the main desire of the military in its fight with Argentina. When the government switched toward civilian control in the 1980's the emphasis shifted. Nuclear technology was not to be abolished but the direction was meant to be changed:

> The military dictatorship ended in 1985, and the new democratic constitution, approved in 1988, stated that all nuclear activity in national territory would only be for peaceful purposes and under the approval of the National Congress. This implied the termination of any activity related to acquisition of nuclear weapons. However, the end of the weapons program did not mean that Brazil was renouncing its uranium enrichment efforts[27].

The goal of improving nuclear technology reverted to an energy production goal and with it the desire to renew thorium based programs. Governing nuclear peace had become a primary concern for the two rival governments who instead of building arms to challenge one another established evaluation methods to ensure that nuclear weapons programs were being dismantled in an appropriate fashion. The social connection therefore falls into two parts. The first is the need to use nuclear technology that was a sign of military might as a civilian energy program. The second is the peaceful resolution of the previous regime and its weapons aspirations.

France

Government Centralization

France created its current energy infrastructure by creating a policy team comprised of "a relatively small circle of politicians and entities, mainly located in Paris" to establish a

[27] Cabrera-Palmer, B., & Rothwell, G. (2008). Why is brazil enriching uranium? *Energy Policy, 36*(7), 2573. doi:DOI: 10.1016/j.enpol.2008.02.033

long lasting system of production after the oil crisis of the 1970's (1974)[28]. This small group was under the control of the executive branch and the President of France, at the time, President Valery Giscard d'Estaing. The team was in close contact with the electrical company and the nuclear industry, which enabled all decision making to occur at the top rungs of the government. The policy team determined that to reduce the control of energy nuclear must have a dominant role in their energy production:

> On the whole the results of the policy followed after the first oil shock have been substantial. A highly centralized decision making process ensured the coordination of actions engaged on all fronts. Imports were diversified: more gas and coal and less oil. Domestic production increased mainly thanks to nuclear energy, this huge investment effort being expected to bear all its fruit at the end of the 1980s[29].

That national investment led to a nation run by nearly 80% uranium and plutonium using light water and breeder reactors with a program to recycle spent fuel to maximize the use of the uranium. This highly centralized system was able to not only push through the changes necessary to construct this system but to ensure that the population abided by the government's policies. In 1976 localities were allowed to protest the placement of nuclear reactors but in reality these rules did not present a threat to the implementation of the national plan. With such a

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[28] Fagnani, J., & Moatti, J. (1984). The politics of french nuclear development. *Journal of Policy Analysis and Management, 3*(2), pp. 265. Retrieved from http://www.jstor.org/stable/3323937

[29] de Carmoy, G. (1982). The new french energy policy. *Energy Policy, 10*(3), 182. doi:DOI: 10.1016/0301-4215(82)90097-0

heavy investment and the policy makers' support for their program it is highly unlikely that this system would change at the whim of the public. It is the strength of the national leadership that allows this nuclear energy system to continue.

Economic Characteristics

The primary purpose of the energy group's focus was on restricting the costs and fluctuations of the market by making nuclear energy the main component of energy production. The high potency of uranium allowed the French system to maximize energy independence (France imports coal and oil in large quantities) and in the process are protected from the hazards of importing other fuels:

> France still imports half of its consumption of primary energy, against nearly the three quarters before the nuclear program[30].

The program operates at 80% nuclear still using the uranium and recycling the fuel which will become more costly in comparison to other energy sources into the future. The system still provides energy independence but the cost of not establishing thorium to continue the use of the current infrastructure will make energy far more costly. The alternative of removing nuclear energy as a power source is also unthinkable, as the alternatives would return the nation to a dependence on other countries and a loss from the lack of use from their existing energy infrastructure.

[30] Meritet, S. (2007). French perspectives in the emerging european union energy policy. *Energy Policy, 35*(10), 4768. doi:DOI: 10.1016/j.enpol.2007.04.010

Societal Organization

Unlike the other countries under comparison the French seem unique in the fact that there is no evidence that the population is demonstrating a public enthusiasm with nuclear technology. Every other nation has shown that the general population has placed effort into supporting the development of this technology to some degree. The source of policy generation is restricted within the government and the needs of the economy. This is evident through the decision dictated from policy makers under a time of crisis and France has been operating off of the proposed policy ever since. The sheer magnitude of energy production coming from nuclear seems to be the holding factor that keeps the French accepting its presence:

> As stated above, France derives over 79.1% of its electricity from nuclear energy, so one could reasonably expect that economic growth enhances nuclear energy consumption in the country[31].

If they were to change their energy infrastructure the domestic consequences would be severe enough to warrant an easier ability for national leaders to control dissent against its current policies. The citizens of France appear to have left the decision to utilize nuclear power to the policy makers and remained fairly content with the outcome with no sign of organized approval. This is also a sign of the French government's ability to control the debate on nuclear energy.

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[31] Yoo, S., & Ku, S. (2009). Causal relationship between nuclear energy consumption and economic growth: A multi-country analysis. *Energy Policy, 37*(5), 1912. doi:DOI: 10.1016/j.enpol.2009.01.012

Japan

Government Centralization

The Japanese held not only a strong central government with policy making concentrated within a few elite government ministries to rely on but a political economic support as well. After World War II, Japan was being rebuilt by the United States both in terms of general aid and in preferential trade. The national focus on long-term economic success also bolstered the ability to pay for American technology at less than market value. In the instance of nuclear technology it was acceptable to the American government to allow the Japanese access to its nuclear energy production technology:

> In March 1966 the government and both sides of the nuclear industry adopted the planning target of building 30-40000 MWe of light water nuclear plant by 1985. The nuclear plant suppliers purchased the necessary design and know-how licenses from the US industry, to enable them to build light water nuclear plants after importing the first of each design from the Americans[32].

Nuclear energy was in large part a measure of the Japanese reconstruction effort aided by the United States. This provided them with domestic and international encouragement in nuclear production. The national political structure allowed for the economic and social functions of the Japanese society to be unified in reconstruction and a long-term plan for economic prosperity, which included nuclear power. This power is currently being tested by the disaster in the Fukushima Daiichi nuclear facility after the earthquake and tsunami

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[32] Surrey, J. (1974). Japan's uncertain energy prospects: The problem of import dependence. *Energy Policy, 2*(3), 213. doi:DOI: 10.1016/0301-4215(74)90047-0

caused damage to the plant. The impacts of this event are testing the relationship of between the government and the people, which may in turn cause change the dynamics of the government's ability to control energy policy.

Economic Characteristics

Japan is a nation that is burdened by a lack of national resources. This has caused the countries economy to specialize in final product goods. The importation of resources also is a burden for energy production:

> As a country with a poor resource base, Japan views nuclear power as a major pillar in its longer-term energy strategy which is designed to reduce dependence on imported oil by developing alternative energy resources[33].

Much like with France, Japan uses nuclear energy to provide a more secure energy supply for its economy. The system of recycling nuclear waste to get the best use of the material is also established as a process to reduce importation. This problem has had negative historical impacts including the occupation of China during World War II and the decision to combat the United States rather than lose their economic system completely. Thorium is a beneficial next step that could easily and cheaply be imported and with the energy provided and the large supply the cost would not increase much even with an increased demand by other nuclear countries.

The Ministry of Economy, Trade, and Industry (METI) has the authority to make policy supporting nuclear power and has remained Japan's key economic

[33] Hayden Lesbirel, S. (1990). Implementing nuclear energy policy in japan top-down and bottom-up perspectives. *Energy Policy*, *18*(3), 267. doi:DOI: 10.1016/0301-4215(90)90218-S

driving force. This agency, along with the private sector, has established the nuclear recycling system used to ensure energy independence is maximized and that energy prices can remain low:

> Key governmental agencies and industry together embarked on a path to ‘‘close’’ the nuclear fuel cycle through reprocessing and recycling the used nuclear fuel from the light water reactors (LWR). In closing the fuel cycle, Japan, a nation poor in natural resources, hoped to develop an energy infrastructure free from dependency on foreign sources[34].

It is the connection between the national economic structures that allows for such multifaceted systems to become operational and continue to be operated in the private sector. This is perhaps the reason that the centralized control is now yielding to the protests of the population that had invested so much in nuclear despite industry like fishing opposing it from the early stages. The economic agencies, primarily under MITI (now as of 2000 METI), that have supported nuclear power as an industry appear to have been overly passive regarding issues such as safety that could impede nuclear power production. While this has certainly nurtured the growth of the industry it fails to control it in other aspects. The result is the potential for failure and as a result opposition in other stakeholders.

[34] Pickett, S. E. (2002). Japan's nuclear energy policy: From firm commitment to difficult dilemma addressing growing stocks of plutonium, program delays, domestic opposition and international pressure. *Energy Policy, 30*(15), 1337-1355. doi:DOI: 10.1016/S0301-4215(02)00028-9

Societal Organization

Japan has always been considered in modern times a very centralized society. This has the ability to engage in large transformational change that is not only accepted by the economic community but on a social level as well:

> A singular commitment to industrial expansion by the people, businessmen and the government (the idea of 'Japan Incorporated'), and a hardworking, disciplined and increasingly skilled labour force[35].

The combination of the three aspects working together (at least to the extent of accomplishing tasks) served a fairly similar purpose with the French falling in line with the policy recommendations to go nuclear in their own country. This was not as single minded as one would expect. During the 1960's the lack of industrial safety measures towards the environment were of great concern to industries that required a healthy environment to sustain their business. Nuclear reactors seemed little different with concerns of the waste and proximity to locations that fisherman frequented. This concern may not have manifested itself immediately and affected the construction and until recently operation of nuclear reactor systems, however with this new disaster it has sparked the terror of Hiroshima and Nagasaki with the protests of business and environmentalists. The consequence is the Prime Minister's public position that nuclear must be decreased. This disaster, although not finished in its effects on nuclear policy, does demonstrate the potential effects on policy based on these three factors and what

[35] Surrey, J. (1974). Japan's uncertain energy prospects: The problem of import dependence. *Energy Policy, 2*(3), 204. doi:DOI: 10.1016/0301-4215(74)90047-0

must be done to ensure that long-term policy is sustainable not just economically but in the hearts and minds of the public.

This change in policy is understandable given the more recent change in behavior by the Japanese government that has allowed the public more power in the nuclear energy debate[36]. The government conceded some authority to local organizations when power plant issues in the 1990's occurred too frequently and without redress. The result was a diminished capacity to use the technocrats in the bureaucracy as an authority, which allowed these public groups an opening to push their agenda through.

The United States

Government Centralization

The United States has set the precedent for being undecided regarding energy policy. The Nuclear Regulatory Commission is the succeeding organization to the AEC, or Atomic Energy Commission, formed by the Atomic Energy Act in 1946[37]. The Atomic Energy Act of 1954 allowed for commercial access to nuclear energy and placed the AEC in charge of safety and hazards as well as the promotion of the technology. The agency was transformed into the NRC in 1974 with the Energy Reorganization Act after industry complaints regarding excessive safety measures from regulations flooded congress. The new agency was to center its attention on broader issues of safety. Radiation and reactor safety along with waste management are among the primary purposes of the agency. Licensing of new plants and renewal of older facilities are another primary function more closely related to the AEC's mission to promote the

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[36] http://www.rice.edu/energy/publications/docs/JES_NuclearEnergyPolicyPublicOpinion.pdf

[37] http://www.nrc.gov/about-nrc/history.html

industry. The ERDA, or Energy Research and Development Administration, was formed at the same time as the AEC and was charged with nuclear weapons testing and related activities. In October of 1977, the ERDA became the DOE, or Department of Energy, and took over other agencies energy research tasks and became more focused on alternative energy sources. In 2000 the NNSA, or the National Nuclear Security Administration, with the purpose of combating nuclear weapons and handles the US stockpile of nuclear weapons[38]. The research branch of the nuclear agencies first was solely within the jurisdiction of the weapons researchers and only in 1977 during the period of anti-breeder reactor sentiment within the government is the agency transformed into an energy research agency. When the agency is created it avoids nuclear research to focus on other energy possibilities instead. A sub-agency is created in 2000 to ensure our safety through maintaining our weapons and preventing others from gaining access to them. Nuclear research is not conducted out of its own department anymore and when it did it was on the basis of military technology rather than energy advances. Because of the way the agency was established nuclear energy not only competes with other energy options but it starts with less emphasis than others. Regarding energy in general the US continues to allow more local and regional groups dictate outcomes of all manner of energy policy remain decentralized as a result:

> First, the institutional structure of utility rate setting in the US is fragmented and decentralized[39].

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[38] http://www.nv.doe.gov/about/default.aspx

[39] Arnold, P. J., & Cheng, R. H. (2000). The economic consequences of regulatory accounting in the nuclear power industry: Market reaction to plant abandonments. *Journal of Accounting and Public Policy, 19*(2), 164. doi:DOI: 10.1016/S0278-4254(00)00009-0

The same holds true for much of energy production development as well. Nuclear in particular has been an important source of government emphasis into energy research and for self-serving reasons. Nuclear technology made its scientific origins through producing energy from fissionable materials. The military have had several uses for fissionable energy, which took the form of two primary outcomes. The first outcome of government stock in nuclear research being the atomic bomb and led the United States away from thorium as the key fissionable element and toward uranium 235 due to the ability to be weaponized and more importantly for light water reactors, plutonium, a powerful element that can be weaponized, is produced as a part of the fission process. The second outcome is the use of light water reactors in submarines. The benefit that certain government programs received from nuclear research spilled out into the commercial sector in part propelling it and in another unfortunate that this was in a direction away from other forms of nuclear power such as from thorium. For commercial expansion into Europe the Euratom agreement of 1958 was agreed to but placed the United States light water reactors as the primary model despite a potentially better European graphite design[40]. These agreements combined with the economic advantage of working from a known product (light water from military use) made the previously used technology more marketable as a commercial design. As support for these programs faded do to social opposition (ranging from local protests over power facility placement

[40] Cowan, R. (1990). Nuclear power reactors: A study in technological lock-in. *The Journal of Economic History, 50*(3), pp. 541-567. Retrieved from http://www.jstor.org/stable/2122817

to the later national opposition by evidence of 70-80% polling for a complete freeze on nuclear energy expansion[41]) so did the commercial applications of these technologies.

The current post-Fukushima Daiichi disaster political environment shows the same anti nuclear tendencies that occurred before which represents both a burden and a benefit to thorium policy. With Germany's response to eliminate its nuclear power completely other countries, in this instance China, did not respond by defending the old technology or by abandoning it but by resetting its goals to incorporate the thorium fuel based technology that had been abandoned. This provides not only the demonstration to the United States that it is possible to continue to promote nuclear technology if it is based on thorium but the opportunity to act as a rival to place in competition with:

> If China's dash for thorium power succeeds, it will vastly alter the global energy landscape and may avert a calamitous conflict over resources as Asia's industrial revolutions clash head-on with the West's entrenched consumption.
>
> China's Academy of Sciences said it had chosen a "thorium-based molten salt reactor system". The liquid fuel idea was pioneered by US physicists at Oak Ridge National Lab in the 1960s, but the US has long since

[41] Meyer, D. S. (1993). Institutionalizing dissent: The united states structure of political opportunity and the end of the nuclear freeze movement. *Sociological Forum, 8*(2), pp. 158. Retrieved from http://www.jstor.org/stable/684633

dropped the ball. Further evidence of Barack `Obama's "Sputnik moment", you could say[42].

There can be no greater political rallying cry to wield than China meeting its energy needs with American technology. The outcomes of this race are not simply a manner of meeting Americans economic needs or changing social perception of a volatile issue but of centralizing American decision making power at the federal level to allow the economics and the social interests to fall in line which, given the current political climate, is inconceivable. Without the national support thorium has to compete with industries such as coal that has a solid footing in the energy industry and has already begun to attack nuclear after the disaster to stay on top. The national leadership is necessary to guide the public toward envisioning thorium as more than just a solution to its needs but a need in of itself.

Economic Characteristics

Nuclear power as an economic solution to power costs and increasing demand has previously not met as profitable a margin as its competitors. This did not prevent the French or Japanese from adopting nuclear power because of the lack of home grown options while Americans have options for energy production in coal burning. In his paper "Nuclear power: Understanding the economic risks and uncertainties" Kessides puts forth a cost benefit analysis of using nuclear

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[42] http://www.telegraph.co.uk/finance/comment/ambroseevans_pritchard/8393984/Safe-nuclear-does-exist-and-China-is-leading-the-way-with-thorium.html

power against other forms of energy production. In it he describes the reduction of green house gases (which should also include the damage to property and health from more local emission dangers) as well as the removal of price variations in fuel costs. The reason the United States does not engage in further nuclear energy production was under the assumption that the country was already over producing energy. The number of power plants that were scheduled for construction decreased during the 1970's prior to Three Mile Island because of low demand during the recession[43]. The market did not favor continued nuclear expansion despite previous evidence of demand.

Societal Organization

Nuclear energy did share a unique social connection in America. While other countries were dreaming of nuclear technology so as to join the ranks of the elite countries the United States was enjoying the success of developing nuclear technology first and employing it to achieve greatness internationally. While the devastation caused by the nuclear bomb created a negative reaction in Japan in the US it was heralded as the tool to end the war. The relationship at first between the weapon and the domestic utility was a positive attribute. This allowed for the spread of nuclear technology from military hardware to peaceful energy production:

> Everywhere except in Canada, military issues were the first to be considered-in France and the United Kingdom weapons-grade fissionable material was in demand; in the United States naval propulsion was

[43] Surrey, J., & Huggett, C. (1976). Opposition to nuclear power : A review of international experience. *Energy Policy, 4*(4), 286-307. doi:DOI: 10.1016/0301-4215(76)90023-9

> the main application. When these demands had been relieved or were no longer so pressing, civilian power emerged as the main consideration, and the important characteristics of reactors became cost and safety[44].

Transferring the technology from one section of society, which had established much of the nation's global prominence, and distributing it to assist with all elements of life has allowed nuclear technology a great push forward. In other words, the government had successfully promoted nuclear technology as a symbol of American strength and success (as a by product of supplying national security). With the American public supporting nuclear technology it made it easier to transfer weapons into energy technology. This would not last however. The decline of public support came in the late 1960's and early 70's from the downsides including waste, cost, and the potential of being a victim of the technology as opposed to being its sole wielder changed the perspective of its use[45]. The Three Mile Island disaster on March 28th 1979 in Harrisburg, Pennsylvania cemented the fears over safety when human error from poorly trained operators and a technical malfunction involving the coolant system resulted in a meltdown and the release of contaminated water into the river (by order of the NRC) and radioactive particles into the air[46]. Despite the reports that followed stating that cancer would not be caused by the contamination the incident further vindicated anti-nuclear sentiment and protests

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[44] Cowan, R. (1990). Nuclear power reactors: A study in technological lock-in. *The Journal of Economic History, 50*(3), pp. 541-567. Retrieved from http://www.jstor.org/stable/2122817

[45] Surrey, J., & Huggett, C. (1976). Opposition to nuclear power : A review of international experience. *Energy Policy, 4*(4), 286-307. doi:DOI: 10.1016/0301-4215(76)90023-9

[46] Luther J. Carter "Political Fallout from Three Mile Island", *Science*, 204, April 13, 1979, p. 154.

increased. The situation had been complicated further by the release of the movie "The China Syndrome" portraying a nuclear meltdown due to a similar problem with human error and technical malfunctions that was released 12 days prior. Jane Fonda the lead actress led protests against nuclear technology after the disaster.

> Nuclear energy has maintained its status as a symbol but has been transformed: The concept of nuclear power as a symbol of centralized and large-scale bureaucracies, distant from consumer control, is common to much opposition to technological change[47].

Nuclear energy by becoming something to oppose has not been brought against the norm but instead fulfilled expectations. By keeping the decision making process among elites whether they are engineers and scientists, politicians and policy makers, or the members of the industry it is a natural outcome for affected groups to oppose policies. Given the already paranoid nature of preventing information for defense purposes and denying more access to the civilian sector through the moratorium on breeder reactors in 1980 attacking this particular technology cannot be seen as an unexpected consequence.

National Comparison and Conclusions

The ability for a government to influence technological development has been a necessity for the nuclear industry. While Brazil was able to easily control the research and manufacture of nuclear facilities through the power of the dictatorship, other counties had to rely on the other factors to justify the creation of pro-nuclear policy. India and Japan were similar in the manner that they would appeal to the population by

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[47] Bickerstaffe, J., & Pearce, D. (1980). Can there be a consensus on nuclear power? *Social Studies of Science, 10*(3), pp. 312. Retrieved from http://www.jstor.org/stable/284583

emphasizing the need to support nuclear technology as a means of national prestige, Japan utilized the Japan Inc. model in order to restructure and compete economically after World War II and India with the push to become a global power in part by energy independence and also through the mastery of the "exotic technologies". France pushed through nuclear energy in response to the energy crisis of the 1970's. While India and Japan both also have used economic means to justify nuclear technology both have been showing strain (particularly Japan) after the Fukushima disaster while France remains resilient enough to criticize Germany for planning to discontinue all nuclear activities. It appears that because the government centralization depends upon the legitimacy through either economic or social support that depending on which is more emphasized as the reason for nuclear technology becomes the crux for nuclear industry's support. The United States has the capacity to use certain populations to promote thorium such as the environmentalists who want greener energy and industry that may want regulation change so they are not charged to dispose of the material. American economy could use thorium to support a diverse and long-term energy infrastructure to promote energy independence and decrease uncertainty. Another consistent method for promoting nuclear technology is competition between rival countries. Brazil's rivalry with Argentina produced a buildup of nuclear technology research in both weapons and energy form. The rivalry has decreased with the change in government but instead of a complete dismissal the insistence on nuclear disarmament has brought both countries together diplomatically and the technological focus has reverted to energy production. India and Pakistan also share a rivalry, which in this case has led to the production of nuclear weapons. The United States has the potential to be rivals with China although restricted more to the energy for economic growth than weapons creation.

The economic situation of a country has a profound effect on the type of energy is chosen as the primary power source. Brazil and India may be importing resources but they both are drawn toward using their own large supplies of thorium and, in the case of Brazil, uranium. This possibility is also open for the United States which also possesses large quantities of the material. Japan and France both lacked energy sources of their own and were drawn to the more cost stable option of nuclear power. Japan uses nuclear as a primary source to diversify its energy options whereas France chose to avoid the fluctuations it experienced in the oil crisis and use overwhelming nuclear power. Brazil has maintained other power options and so despite the nuclear research and need for power has used the natural resources to use primarily hydroelectric power with a diverse set of options to explore beyond what can be achieved with the natural terrain. The United States has the potential to use its natural thorium reserves to sate its energy consumption but it has to accept it as an option and realize the costs inherent to its current energy strategy. While France reacted dramatically to the energy crisis Americans fail to react to increases in energy prices and tolerate other costs in the form of negative externalities. Americans appear to act as if the demand for energy of the current system is inelastic. This appears to make it difficult to acknowledge the economic need to shift to alternative options. The United States has better options in thorium based fuel to reduce costs and improve national energy independence but unlike other countries it remains dependent on importing and more environmentally costly choices.

The public has a strong influence over how policy is formed in most political systems. Brazil had a strong public support over nuclear research while rivaling the Argentineans. That support carried on and transformed into energy research and the need to act safely with their countries' nuclear push even when the dictatorship fell which demonstrates that the support survives even without commands from the top of the government. India and Japan both connected to nuclear technology through the rallying of the nation to improve their economic conditions and establish respect internationally. India had a strong nuclear development plan that was side tracked by nuclear weapons ambitions and as a result lost the international support they needed for energy development and failed to meet the milestones set in the beginning of the program. Recent international aid and trade are helping to bring back the old goals despite some opposition to uranium-based technology. Japan never had support for weapons and failed to monitor and improve the nuclear industry that it had created. With the Fukushima disaster the public support vanished. France acted to prevent its policy makers from removing all diversity from their energy portfolio but did not act in favor of it either. To the French nuclear energy was a solution to a problem and did not represent anything greater to the public. The United States has had support for the nuclear development but let it go in response to the realities attached to the brand of nuclear technology that they had attached themselves to. It is possible that thorium which was dismissed while uranium based nuclear technology was popular could represent an icon of dissent from the old system but it takes leadership to empower such symbols.

Path dependence is the primary driver behind these countries' nuclear technology outcomes. In each instance previous policy choices have set the precedent for energy policy in the future. India originally planned to use thorium and this was in favor with the public and the economic future of the nation and was supported by the government in a way they could continue to control. Despite changes to the plan from nuclear weapon ambitions and opposition on the basis of safety, the old plan is returning to fruition. The centralized control of a long plan with support from both resource bases allowed the possibility of nuclear energy from thorium to remain possible. Brazil had an investment of resources and history that allowed for the option for use in the economic arena to become open. The symbolism of nuclear technology as a national strength, a weapon during the dictatorship and an energy source in the hands of the democratic government, allows for thorium to be used in an energy production context now that the economy will need it to provide growth in supply and necessary locations to bring Brazil to prosperity. France made a choice to move toward a society run on nuclear power to avoid the restrictions of relying on foreign suppliers of energy. The result of the policy change and massive investment is a nation that despite a lack of enthusiasm from its public has chosen to keep all of its nuclear facilities open despite the political repercussions in neighboring Germany. Japan based its nuclear plan as a part of the national strategy for economic success. Although nuclear energy was an important section of the energy production assortment it in of itself was not immune to public scrutiny after the disaster. The result is a proposed reduction as a percentage of energy creation by the Prime Minister. While nuclear energy is to be cut to allow other sources deemed safer to replace it, nuclear energy at the moment will continue in Japan. The United States has a history with nuclear technology that has aided the development of the technology but has also alienated the public from accepting it when the social perception changed. As the nation that pioneered the atomic bomb and was the only nation to use it on another, its creation has provided a lot of reverence for it. The commercial use was a side project from the continuing military applications. Initially this was appreciated. Over time the consequences that were not considered including the waste or the potential of being a victim to the technology either through foreign attack or domestic disaster took over. The policy decision to cease research into the effective use of thorium as a nuclear fuel in the 1960's and the choice to not produce breeder reactors in the 1970's for fear of terrorists using the plutonium made the role of nuclear technology clear in US policy. Currently, very few reactors are being planned for production and those are to replace the old designs from the 1960's that were to be decommissioned. The role of nuclear technology had been defined through policy decisions and prevented the possibility of using the technology in a way contrary to perception. The policy decisions that are made have shaped the outcomes of nuclear technology regardless of national system. This requires policy makers to act in the forefront of any attempt to create nuclear energy policy.

The United States has the possibility of creating the same factors that propelled these other five nation states into undertaking the incorporation of thorium based nuclear energy production. Due to recent events and past history it requires a great deal of leadership to use what once hindered the adoption of this technology with what current challenges that Americans now face to reach the same conclusion as other nuclear countries.

The United States currently lacks a forum of national leadership that will allow for centralized control of energy that would be required for nuclear technology to become dominant. National focus on nuclear energy was primarily centered on weapons technology first (the main use of the light water reactor was for submarines). In this way it was not only encouraging nuclear research and at the same moment discouraging thorium research. This policy choice demonstrated an example of path dependence toward uranium-based nuclear reactors that would continue to inhibit the ability to change policy direction back towards thorium. As national momentum was moved from the natural escalation from uranium in light water reactors to the production of plutonium through fast breeder reactors it did not reconnect with thorium but dismissed nuclear as a whole. Nuclear technology research moved from being a competitive action to an object of scorn with the need to deny the technology to other countries and organizations. While the competition can be rekindled with the rush to meet the national need for energy with China who is not only a political, military, and economic contender but intends to win using American made technology. While this action has the capacity to accomplish the feat of brining the national attention on thorium based energy production it will not happen on its own. Countries such as India, France, and Japan established long term plans to create and maintain the system of research, production, and local support needed to not only establish but to maintain this energy production system to avoid having it removed from centralized control.

The United States faces challenges about the status of energy production in its future. The first is the more widely accepted need for increased energy production to meet demand. The second, which is more politically restrictive due to business needs, pertains to the waste output from the electricity generation. This can take the form of local air pollution or the nonlocal effects of climate change, which has been suggested, should have an economic penalty inflicted upon the producers that in turn would affect the efficiency of that power source. Given the intermingling of these different concerns it has become quite difficult to establish a solution. Nuclear in the case of Japan and especially France have allowed for energy independence to a degree that these countries could not afford otherwise. The closed system of light water and breeder reactors puts France on a better economic footing to provide energy to its economy and non-industrial demand. The United States could use thorium under the same economic plan for the sake of solving its energy needs, environmental concerns, and energy independence. However without the involvement of leadership to connect this solution to these problems at the national level as Japan and France did with their policy makers the United States will either continue without a plan or lose out to another that has leadership but backing a less efficient energy solution.

The amount of connection between ordinary Americans and the possibilities of nuclear energy, let alone the sparse knowledge of thorium, has eroded. Previously, before the 1950's, the United States promoted nuclear energy as an enduring symbol of national ability to be not only militarily and economically dominant, but technologically superior. With the fear of that technology's military capacity dominating during the Cold War and the increased worries over environmental hazards, reactor mishaps, and terrorism threats the social support of the use and research of all nuclear technology for the most part disappeared from the public eye. This response against negative aspects of nuclear has been overturned and used in the continuation of nuclear programs and the push toward thorium energy programs. Brazil had nuclear programs that served a similar competitive purpose with Argentina as it did with the US and the USSR. When the dictatorship collapsed the civilian government did not destroy the previous works in nuclear engineering but propelled it toward the peaceful thorium technology that was desired by the people. The history of uranium and plutonium based technologies are not the obstacle that Americans must overcome to meet this goal but the hurdle to be used to that end. Americans can quite be receptive to the agreement with their concerns for non-weapon, environmentally friendly, and economically palatable thorium reactors if it is presented in a manner that responds to their needs, is open to the science and process, and has an element of leadership from a national policy making entity.

It is possible for the United States of America to adopt thorium as an alternative nuclear fuel. However, currently the factors that are required for this process to be accomplished are not in place. The key piece to meeting these requirements is the leadership to utilize the current social needs and economic situations that are present in America today. If that component were at hand it would be quite plausible that the United States could be using thorium based nuclear fuel to solve its energy needs.

Limitations

The limitations of this study are based on the uncertainty in judging the present variables associated with nuclear power endorsement. Given the March 11, 2011 earthquake and tsunami in Japan and the nuclear plant issues has the potential to either persuade countries against nuclear power or further present the opportunity to remove the current toxic fuel in exchange for the less destructive thorium. Given this uncertainty the conclusions that can be made are rather limited by the effective application of the thorium fuel cycle toward the public and the policy makers who are held accountable to them.