FOUNDATION OF SUSTAINABLE NUCLEAR POWER

REPORT COMPILED BY THE FOUNDATION

TRUNG LE, JAMES MCROBERTS, CRAIG MACOMBER, ALAN LOH, YIN-SHIUAN (JESSICA)

THE FOUNDATION

University of Washington
Seattle, WA 98195

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Ms. Diana Munoz
Sieg 431D
University of Washington
Seattle, WA 98195

Dear Ms. Diana Munoz,

In the following proposal, we will present a new approach to solving the need for clean energy. The research and analysis focus on a type of nuclear fission power plant, the Molten Salt Reactor, which is an uncommon but promising alternative energy source. Our research will focus on designing, building and improving the Molten Salt Reactor, as well as, explaining to readers that Molten Salt Reactor is not a threat to our environment, but instead, will have a positive effect on global warming.

Global warming is currently one of the most significant issues in today's world and attracts attention internationally. Humans consume a vast amount of electricity each year, with most of the electricity generated by Fossil Fuel Reactors. These reactors introduce significant amounts of greenhouse gases into the atmosphere. Some measures have been implemented to stop the greenhouse effect including the use of carbon credits and the development of renewable energy sources to take the place of Fossil Fuel power plants. However, these measures are not enough; greenhouse gas emissions continue to rise every year.

This proposal will introduce the Molten Salt Reactor, which is a safe and environmentally friendly power source that will decrease the greenhouse gas emissions from power sources each year. Homeowners who live around these reactors can expect complete safety from radiation since the nuclear waste will decay in a much shorter time.

Thank you for your time and consideration as you review our proposal. Please feel free to contact us for any questions, comments, or concerns,

Sincerely,

THE FOUNDATION
thefoundation@foundation.com

TABLE OF CONTENTS

CONTENTS

LIST OF ILLUSTRATIONS

Figures

Tables

EXECUTIVE SUMMARY

Developing a sustainable, environmentally friendly energy source has always been an issue for the past 20 years. With consistently high demand for fossil fuel, especially in developing countries like China, the recent rebound in soaring coal and oil consumption has led to increases in prices and carbon dioxide emissions. As a result, it has become all the more imperative to find a reliable alternative energy source. While nuclear power has been available for a period of time, public concerns and technical issues still exist, discouraging countries across the globe from adopting the energy source. In response, we will be addressing the main issues of risk analysis, cost reduction, and waste disposal for our project.

One of the chief public concerns, especially with the recent Fukushima incident in Japan, is safety. The issue with the nuclear plants in Fukushima is that the disaster, along with a number of lesser events in the past, was very much preventable. Signs of danger, however, were often ignored or outright covered up in fear of getting shut down or to cut costs in upgrades and reinforcements. As part of our team's plan in developing and promoting nuclear energy, a key point we will focus on is the analysis of possible dangers that our developing plants may pose on the public, and to address any safety concerns the public may have. This will be an ongoing process that will continue after the development and completion of the initial plant.

Another major obstacle in the development of nuclear power as a viable energy source is the inhibiting cost of just building and maintaining a plant. In the past, companies have wasted billions of dollars on unfinished plants in 1980s, and scrapped a number of reactors due to their high operating cost in 1990s. Our research on a more efficient design, the molten salt nuclear reactor, will focus on addressing these economic issues, and by standardizing our designs, will reduce costs in the construction process.

Most important of all, while nuclear plants may have the benefit of little to no toxic emissions, a common concern is the disposal of nuclear waste. With current technology, the by-products of nuclear plants are considered dangerous for close to a million years, posing constant risk of contamination to nearby water systems. With the aforementioned molten salt reactors, however, the system allows for waste to be constantly reprocessed as fuel to the reactors. Not only does this increase the energy efficiency of the fuel, the final resulting waste product will only need to be contained for a shorter period of time before safely disposed of.

While alternatives like hydro and solar power exists, they can only be offered to areas that can provide the appropriate natural resource. Our goal is to promote the adoption of nuclear energy as not only an environmentally friendly source of power, but also a sustainable source as well. Research and development will be committed to back up the claim, as molten salt reactors have the potential to not only alleviate the world of its energy crisis, but also resolve the lingering issue of operating cost and waste disposal of nuclear plants. Safety, however, will always be our number one priority, and we will be sure to address every possible sign of danger that shows up.

INTRODUCTION

PROBLEM/PURPOSE

Power is an essential utility of modern society. As a response to this most sought after need, countries and companies around the world have established ways to generate electricity through different kinds of power plants. This is commonly accomplished by weighing among the available sources then choosing the cheapest. Environmental impact is also taken into consideration if technology and cost association permit. Unfortunately, these constraints often make unsustainable energy the best short term economic decision in many cases. One of the most popular types of power source is coal due to its cost efficient design a widely available resources. However, coal plants are the main contributors to greenhouse gas emission and abundant waste into the atmosphere. A typical (500 megawatt) coal plant can produce up to 1.4 million tons of coal each year, and currently there are about 600 coal plants in the US running on a daily basic (Coal vs. Wind, 2012). As the Earth condition is degrading over the years, this issue needs to be addressed to eliminate the problem.

BACKGROUND

Carbon dioxide is a major component of greenhouse gas emission. Burning fossil fuels such as oil, coal, and natural gas in combustion reaction results in high production of carbon dioxide. Fossil fuels are the primary resources used to generate electricity (El-Sharkawi, 2009), and the world mostly relies on burning fossil fuels to support the electricity consumption. Therefore, world's carbon dioxide emission is increasing rapidly.

There are other, non-nuclear, popular renewable energy sources, such as wind power, solar power and hydro power. These are great alternatives, but they are restricted in many ways by available resources of the local areas, hence are not a universal solution for green power. Also, these renewable energies require a more advanced infrastructure to implement, which is not currently in existence in most countries around the world. Coal, on the other, can be found almost anywhere on Earth. The US has coal existence in 48 different states. Therefore, coal plant presents itself as a cheap alternative, easy to implement and distribute infrastructure than renewable energies.

PROPOSED PROJECT/SCOPE

We propose a way to lower the cost of energy generation: nuclear fission. Our approach is to create a foundation dedicated to international development and sharing of technology related to a selected nuclear reactor design: the molten salt reactor. With the world's largest producer of CO_2 emissions, China, ("Pbl Netherlands environmental,") starting work on a similar project and showing interests in international cooperation, now is a great time to start up our foundation. Our foundation would accept, verify, and unify research from all over the globe. With sufficient funding, we will hire experts in the field, and together with exciting designers, develop a nuclear reactor design free from national secrets and restrictive regulations. This would establish an open source design standards that others can use to implement on nuclear reactor operations. When many of these reactors are built, they will be similar or identical which means only one maintenance and monitoring procedure needs to be designed. A good international standard, even though difficult to spread and become accepted, will make our reactors even cheaper, more attractive and safer to operate than previously possible. With our foundation providing internationally accepted procedures and safety standards, the public fears regarding nuclear should be decreased, and we expect widespread acceptance and use of the design. Based on the timeline for China's project, we expect this could be done in as little as 10 years if sufficient funding and international cooperation is available. It will take longer than this for our reactors to displace a significant fraction of fossil fuel based power plants, but after 10 years, we expect to start making a real difference. Our foundation alone will not solve the entire problem but it would place the foundation step to get us headed in the right direction.

TECHNICAL INFORMATION

Our foundation's goal is to lower the cost of nuclear reactor power generation under the assumption that these lowered costs will allow nuclear power to displace other more harmful forms of power generation. Before outlining how we will lower the costs, we will present a brief justification for this assumption.

Currently, nuclear power is in use. France gets 78% of its power from nuclear, followed by 6 other countries, including the US, which get 15-60% of their power from nuclear; this shows that its costs are competitive with the alternatives, otherwise no one would be building nuclear reactors ("Iaea press releases," 20 J). If these costs can be lowered, nuclear power will become even more competitive and be selected in more situations. The result will be increased use of nuclear power throughout the world.

What holding back nuclear power are not simply its economic costs. There are also social and environmental costs. Nuclear reactors can have some negative impact on the local environment, and people have fears about this, both justified, and irrational. These factors can be counted as 'costs' against using nuclear power. Lowering these should help the same way lowering economic costs help. To lower these costs, we will develop, test, and make freely available a design of a Molten Salt Reactor. Along with the design, we will develop and publish complete operating and monitoring procedures.

Before delving into the details, here is an outline of exactly what a Molten Salt Reactor is, how it works, and some important differences between it and other reactor designs.

THE MOLTEN SALT REACTOR

The Molten Salt Reactor, or MSR, is a nuclear reactor design where the traditional water coolant is replaced with a molten salt mixture. This allows the reactor to operate at higher temperatures for greater efficiency while maintaining low and safe pressures. Rather than injecting fuel rods, the fuel is dissolved in the salt mixture.

MSR reactors are in use. The first was operated in the 1960s, and several have been built since then. We are not trying to develop a better reactor technology: this has been done by many separate groups, companies, and nations. The designs have never been shared openly and internationally for free use. We simply wish to gather what we can, and develop what is missing, to produce a freely available design for a cheap and safe MSR. Currently China is the world's largest emitter of CO_2 ("Pbl Netherlands environmental") and therefore they play an important role. They are starting a major project to develop and adopt MSRs, and they have expressed an interest in international cooperation ("Nuclear power in," 2011). This makes now an idea time to start this project focused on MSRs, and develop the international cooperation they are looking for.

LOWERING ENVIRONMENTAL COSTS

Nuclear power has several potential environmental costs. The most feared is generally the large scale release of radioactive material into the atmosphere, as in the case of Chernobyl. This issue has been sufficiently addressed through containment vessels, and non-flammable moderators ("Safety of nuclear," 2011). For a MSR, the fuel is already liquid and mixed with the coolant, and is not under high pressure. This removes any dangers related to not being able to remove or cool the fuel and its radioactive byproducts in an emergency such as a meltdown. If a MSR needs to be shutdown, the fuel, and the radioactive waste products, along with all the coolant, can simply be allowed to flow out of the bottom of the reactor into a cooling area ("Energy from thorium,"). This makes the worst case situation a leak, but with the reactor operating at low pressures, such leaks should be easy to prevent, and minimal in scale if they occur at all. This alone makes Molten Salt Reactors much safer than the already quite safe more common designs.

The other major environmental cost of nuclear power is the nuclear waste. With the common fuel rod based reactors, this waste is initially in the form of used fuel rods. They have to be removed and replaced with new rods when they are used up, and are filled with a wide mix of fission byproducts. With a MSR, the fuel is dissolved in the coolant, and can be added continuously. The waste products can be chemically separated while the coolant is being circulated, and removed for processing. Many of the waste products, especially the more dangerous and difficult to properly store and dispose of ones, can be easily re-injected into the salt mixture, and further reacted in the reactor core. Since these waste products are dangerous because of their radioactivity, they still have some energy left that can be extracted by the reactor and can be converted into different waste products. After sufficient processing, the waste can be reduced to compounds that only need short term storage before being safe to dispose of (Gat & Dodds, 1993).

The third, and much less discussed environmental issue related to nuclear power is acquiring fuel. MSR reactors can be designed to run on Thorium 232, which can be mined easily ("Thorium," 2011). They can also consume uranium (the most commonly used nuclear reactor fuel) and even plutonium as used in nuclear weapons. Nuclear fuels have very high energy densities: “one pound of uranium can supply the same energy as 3 million pounds of coal” (Asaravala, 2011). With such high energy densities, it is clear that even rather expensive methods can be applied to acquire the fuel, and as the volumes of fuel needed is much less than coal, it is even an improvement environmentally over coal mining if the fuel is mined. The amounts of fuel available for easy mining is vast, generally expected to last several thousand years at least, however if needed, it can even be extracted from sea water ("Supply of uranium," 2011).

As shown there, the MSR design has very low environmental costs. Making a good MSR design available, as our foundation plans, would lower the environmental costs of nuclear power.

LOWERING SOCIAL COSTS

One of the main reasons nuclear power is not more popular is because people dislike it. No one wants to build and support nuclear power under such public opposition. Our plan deals with this in two steps.

First, we remove any legitimate fears. Some of the environmental fears were legitimate, but few of them apply to our MSR design. By developing and heavily reviewing our design within our international foundation, we should be able to minimize and accurately determine the real environmental threats. Given that there are several MSR reactors in operation, all of them have been in lease research usage since the 60s, and none of them have ever had a significant environmental issue ("Safety of nuclear," 2011), We expect to produce a very safe design.

One particular fear that MSR reactors can address is nuclear proliferation. It is easy to design and operate an MSR that is incapable of producing anything useful as far as manufacturing nuclear weapons (Engel, Rhoades, Grimes & Dearing, 1979). This means that there is no need to fear allowing nations to use nuclear power that will lead to them developing nuclear weapons.

The second step is to convince the public that our safety analysis is actually correct. Since we are making only one reactor design, all the reactors derived from our project will be identical. The design and operating procedures only need to be verified once. All the relevant details can be presented to the public, with reviews from the international community, and communities can trust that their reactor, when built, will be just as safe as other nuclear reactors that many experts have considered safe. To convince the public that the operating procedures and maintenance at their reactors are safe, we will also publish said procedures. In addition we can provide an auditing service for those who desire to have their reactors and procedures checked to make sure they meet our heavily reviewed standards.

Together these should drastically reduce the public concerns about nuclear reactors, and thus lower the social costs of building and using them.

LOWERING ECONOMIC COSTS

As addressed above, we have plans for lowering the social and environmental costs. This removes the non- economic reasons to avoid nuclear power. Some of these also lower economic costs. The reduced waste storage is cheaper for example:

Our main cost saving come from three areas: removal of design costs, lowered construction costs, and lowered operating costs for the amount of power produced.

The design costs are removed by the fact that we will pay for one design in advance, and let everyone use it for free. Designing reactors is expensive, especially when including all of the safety analysis.

We will lower operating costs in several ways. First, MSR reactors are more efficient, so you get more energy from the fuel consumed which leads to lower fuel costs. They can also run on more unique fuel types: we will design our reactor to run on the fuel which turns out to be most cost effective during our development and design phases. We will also lower the cost of safety reviews, maintenance, and general operating procedures by providing a single, well reviewed and refined, policy for these tasks. We will also provide third party auditors and inspectors which, because all our reactors are identical, will be very familiar with the design and procedures and have an easy, and thus quick and cheap, time inspecting the reactors thoroughly.

We will lower the construction costs by investing extra in the design to minimize them. Since we are operating on a design once, build many strategy, this is beneficial. Also, there will most likely be many parts that can be produced more cheaply in bulk, and then sold to the companies building the reactors, either by our foundation or third parties.

Together, all these factors will significantly lower the cost of nuclear power. It is not currently apparent how large this difference will be, but considering most of our costs are expected to be design costs, which would have to be done for reactors anyway, the savings we provide to the nuclear power industry should exceed our funding after only a few reactors are build. Given that reactors are being built and developed currently, we expect this to happen pretty quickly. Most importantly for us, these lower costs should increase the production of nuclear power plants as new plants are added, displacing coal and other power plants as they wear out. This also lowers the cost associated with shutting down harmful power plans, making other international organizations working on global warming jobs easier and more economically practical.

STATEMENT OF WORK

The work proposed in our project is centered on designing, building, and showcasing a sustainable MSR nuclear reactor demo. This is a challenging task, and six overlapping phases need to occur to complete said task.

Throughout the entire span of the project, we will be collecting funding. During the initial setup/problem evaluation phase, years 1-2, funding will be directed toward setting up our foundation, researching MSR nuclear reactors and public opinion on nuclear power, and sorting out any potential legal issues we may face. The focus of the MSR research will be on the cost effectiveness, sustainability, and safety of these reactors. The research will also include getting in contact with all the groups that are actively working on relevant nuclear projects, and asking for their cooperation.

The design phase of the MSR demo spans 4 years during years 3-6. We will hire a sufficient staff to design a reactor based on our research from the initial evaluation phase, and finish said design.

The analysis phase, during years 4-7, overlaps with the design phase and will be used to verify that the design is cost effective, sustainable, and safe throughout development. An exhaustive final check will be administered once the design is finished.

Once the reactor design is finished and verified by the analysis phase, we will build a demo reactor using the design. This demo phase lasts a minimum of 4 years and is currently set for years 7-11 in our project timeline. The demo phase could last longer than 4 years if sufficient funding is lacking since building the demo nuclear reactor will cost the most amount of money throughout our project.

Overlapping with these later phases, will be the international marketing and monitoring phase. As soon as the design phase starts producing beneficial results, we will start looking for parties interested in building reactors from our design. This will be followed by starting maintenance and monitoring program to safely and efficiently assist outside parties to use our design and/or demo reactor.

Our timeline was created by basing our sequence and duration of tasks off of previous and future nuclear power programs throughout the world. Specifically, we looked at China's nuclear power program and we found that from construction start to operation date of a nuclear power plant was about 5 years ("Nuclear power in," 2011). So based on this data and our plan to collaborate with other nuclear programs like China's, we created our estimated 11 year timeline.

PROJECT TIMELINE

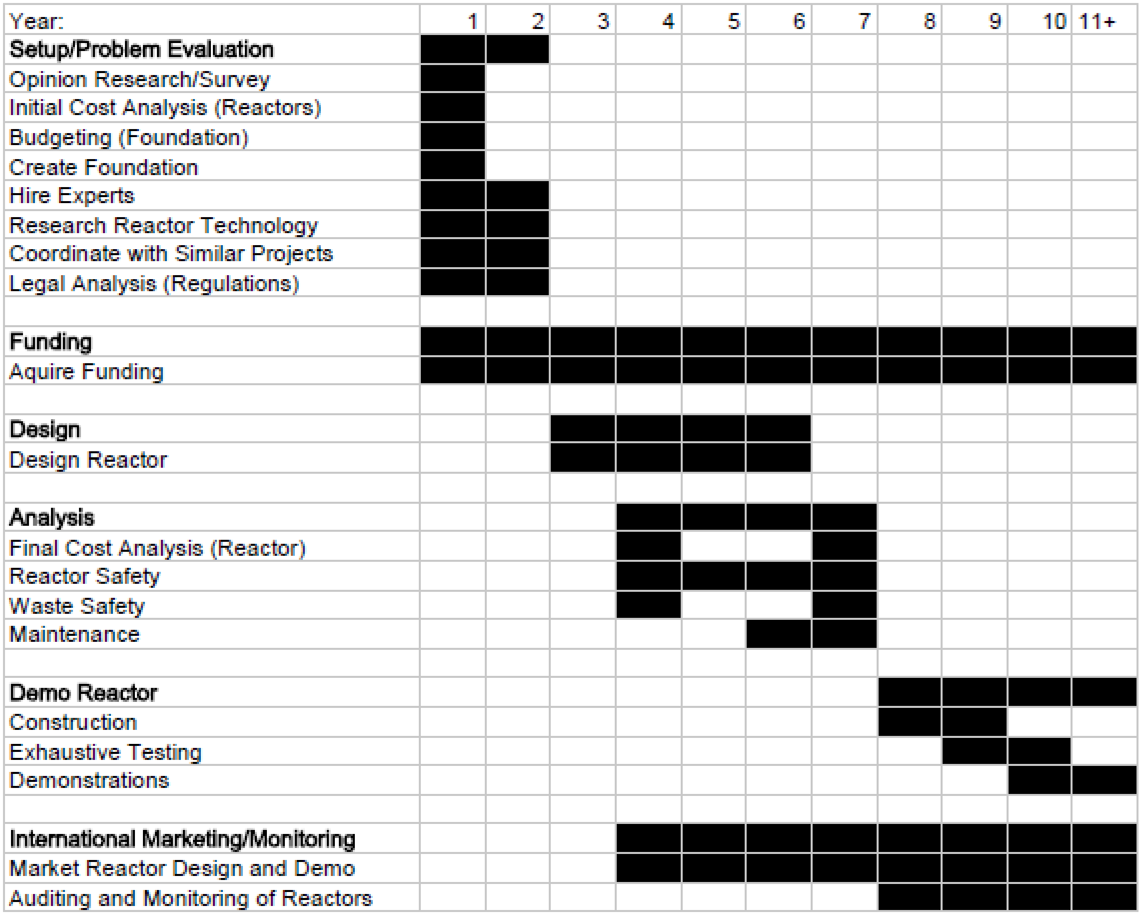

FIGURE 1: GANTT CHART ILLUSTRATING PROJECT TIMELINE OVER THE NEXT 11+ YEARS.

PERSONAL INFORMATION

James McRoberts is a senior in the Electrical Engineering department at the University of Washington. He is focusing on control systems and design and is also interested in embedded systems. James will bring insight into the feedback system of the MSR power source and a strong desire to create sustainable power sources throughout the world.

Craig Macomber is a senior in the Computer Science and Engineering department at the University of Washington. His focus is on software engineering.

Trung Le is a senior in the Electrical Engineering department the University of Washington. His focus is in embedded systems and is a valuable assess to the control team for automation. His ambition aligns with the team, which is to make popular a new sustainable energy source that is clean, efficient, and cheap is design and operation.

Yin-Shiuan (Jessica) Chen is a junior in the Electrical Engineering department at the University of Washington. She is focusing on digital signal processing and is interested in software engineering. She aspires to create sustainable power sources and develop lower budget and more efficient power plants.

Alan Loh is a junior in the Computer Science and Engineering department at the University of Washington. His focus is on computer engineering, particularly the hardware aspect.

COST INFORMATION

The key reason why this project is cost effective is that the MSR will pay for itself in power once it is up and running. The unknown element is how large of a loan will be needed to build the initial demo reactor. Further research is required to get reasonable monetary figures for how much the initial demo reactor will cost to build. However, initial costs of the problem evaluation phase are outlined below.

As a non-profit organization, an important aspect of our funding will be based upon gathering volunteers and other foundations to help fund our MSR research and demo costs. If these first steps are achieved successfully, then that would leave a small amount of costs for publishing and reviewing all of the research, hiring a committee of nuclear engineers to oversee the process, and hiring an expert to lead our public opinion campaign to improve the image of nuclear power.

Hiring a 5 member publishing and reviewing team for the research working 10 hours a week for 2 weeks at $15 an hour will cost $1500. Next, hiring a committee of 3 nuclear engineers for consulting will cost $720 per consultation. Each member of the committee will work 8 hours a day at a rate of $30 per hour. We expect to consult with the committee once a month for the first 6 months, so the total cost of the committee is $4320. If we are unable to find a public opinion representative voluntarily, we will hire a full time public opinion expert for the first 3 months to quickly bolster public opinion on nuclear power. The cost of this expert will be $18 per hour, working 15 hours per week, and working for 12 weeks for a total cost of $3240. This brings the total cost, assuming minimal volunteer and other outside help, to be $9060. Table 1 below is the requirement costs for completing the evaluation phase of our project.

TABLE 1: COST BREAKDOWN OF PHASE 1

Cost for Completing Phase 1: Problem Evaluation	Required Item
$1,500	Publishing and Reviewing Team
$4,320	Nuclear Engineering Committee
$3,240	Public Opinion Expert
$9,060	Phase 1 Total Costs

The design and demo reactor phases will cost a significant amount of money that needs to be researched during the evaluation phase. A sample of the electricity costs in euro cents per kilowatt-hour is given in the Figure 2 below. The figure illustrates a study in Finland in 2003 that provides quantitative results regarding the initially high price of constructing a nuclear reactor (seen in purple) compared to constructing other power sources. The initial design and construction cost for a nuclear power plant is 1.38 Euro cents/kWh compared to 0.76 Euro cents/kWh for a coal power plant ("Economics of Nuclear Power," 2011). Nuclear power is about double the price to initially construct, but significantly cheaper in the later phases. This is seen in the cheaper O&M (operations and maintenance) and fuel costs.

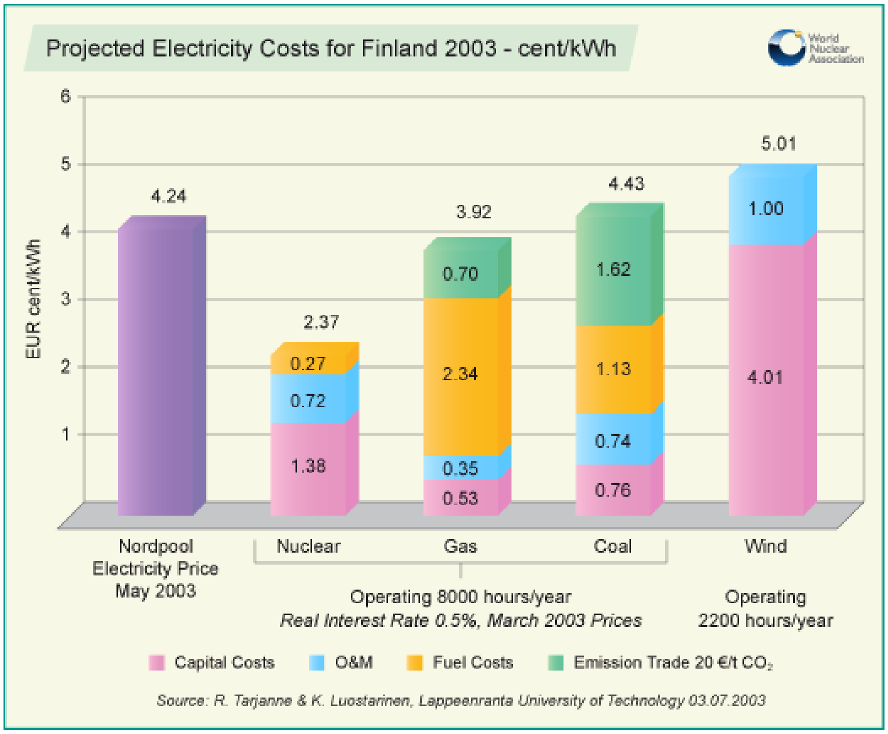

FIGURE 2: ELECTRICITY COSTS FOR NUCLEAR POWER PLANTS COMPARED TO OTHER POWER SOURCES (“ECONOMICS OF NUCLEAR POWER,” 2011).

The high initial costs of constructing a MSR nuclear power plant is similar to the data presented in Figure 2 above. However, the gathering of public support and the attention of other groups interested in funding a nuclear power project will provide the needed grants and funding for completing our project. Once the public sees the demo reactor, public opinion on nuclear power will improve. The support for the system will grow, leading to more funding opportunities, more return on investments, and cheaper construction costs of MSR reactors.

CONCLUSION

Cost, nuclear waste, and safety concerns have often discouraged companies from developing and investing into nuclear fission. Nuclear fission is a sustainable energy source, and these issues can be addressed with the molten salt reactor design. Thus, we have outlined a plan for exploring the potential of this particular nuclear reactor design.

With adequate funding and support, our team seeks to work with multiple countries and companies in researching and expanding upon the molten salt reactor design. By hiring experts and researchers to develop a safer, more cost effective design, we will be able to improve reactor's capabilities in reusing nuclear waste more efficiently, and develop stricter safety standards. At the same time, public concerns and misconceptions will be answered through safety and cost analysis throughout the development and construction phase, developing public support of the use of nuclear energy.

Our initial goal is the construction of a molten salt reactor power plant to showcase the advantages of the design to the world. With enough international interest, we plan on making the reactor designs and operating procedures available for no additional cost. By doing so, we expect to significantly lower the costs in building and operating nuclear reactors for countries across the globe. Not only will this open up a more environmentally friendly alternative when other clean sources of power are not available, it will assist in the global move to more sustainable power generation. Ultimately, our goal is not just the guarantee of safety to the public and reduction of reliance on the limited supply of fossil fuels, but to also increase the efficiency of power generation, thus possibly allow the public to pay even less for their power than before.

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