Washington Internships for Students of Engineering

# Management of Used Nuclear Fuel and High Level Waste:
## Is GNEP the Answer?

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## About the WISE Program

The Washington Internships for Students of Engineering (WISE) Program, is designed to help engineering students understand the interface between science and technology and public policy as well as provide opportunities to understand how they can be involved in that process. The program was begun in 1980, and each year students from all across the nation are chosen and sponsored by varying professional societies related to engineering.  The students are given the task of selecting a public policy issue, and addressing that issue through writing a policy paper on that topic.  During the process of the 9 week program, they are able to interact with those who are actually involved in making the public policy decisions and learn how those are made.  They are given the opportunity to see who they can track down, interview, bump into, make connection with, or whatever other creative methods they could imagine to get the information and opinions they were looking for. For more information see: http://www.wise-intern.org/index.html

## Acknowledgements

Personally, as a student studying Nuclear Engineering I have a great interest in that field and obviously the policies that guide the decisions that are made there. The opportunity to spend a summer in Washington was appealing to me, if not slightly intimidating as well. However, I was quickly amazed at the doors that were opened and the willingness to share and teach that was expressed by almost all of those I encountered. The opportunities to sit across the table from NRC commissioners, Chief Nuclear Officers of Utilities, Vice Presidents of Companies, Directors of Large Government organizations, members of the House and the Senate and their staffs, and ask questions about policies as well as the other decisions that were made was an excellent experience. It would be inappropriate to speak of the experience without saying thanks to all the people at NEI who were so invaluable in providing expertise, suggestions, contacts, and not to mention food and juice. Professors from ISU were invaluable in helping to understand and grasp the concepts. Many thanks are owed to ANS for sponsoring me in this program and making it possible, especially for the use of Dr. Alan Levin who was a wonderful resource and person to bounce ideas off of. Thanks to the rest of the WISE society sponsors and their respective representatives who always kept us informed as to the more social aspects of DC and providing numerous opportunities to interact with new people. Thanks to Dr. Jackson for his never ending optimism and questioning mind. My fellow WISE "Policy Associates" for whom I have the greatest of respect. And lastly, to all who have provided such helpful information, I have left most names out because the list would be too long and it would only be one more hit on Google for the many great things that you all do.

## Executive Summary

With the world moving into an ever increasing need for energy independence, many people at home and abroad are looking to the power of the atom to create opportunities for new electricity production and development.  The current system of the atomic fuel cycle in the United States provides for a once through fuel cycle with all the used fuel being stored first on site with the eventual goal of a repository. The objective of the new Global Nuclear Energy Partnership (GNEP) is for an international partnership between advanced nuclear power nations to develop and implement closed fuel cycles as well as sharing their technology with others developing nations in exchange for compliance to weapons issues.

Under the GNEP program it is proposed that fuel will be used in the reactor then reprocessed and refabricated into new fuel and then used again, thereby reducing the quantity of material that would need to go into a nuclear waste repository. There are currently several options available for fuel cycles which include:

a) Continuation of the current system of a once-through fuel cycle and dispose the UNF and HLW in dry cask storage and eventually a repository.

b) Implementation of  fuel reprocessing that would allow for the remaining Plutonium (Pu) and $^{235}$Uranium  (U) to be removed from the UNF and placed back in the system to be used in the fabrication of new fuel assemblies using a mixed U/Pu fuel known as mixed oxide fuel (MOX).

c)  Use of advanced reprocessing methods to separate out components then use transmutation to convert troublesome isotopes.

1) Transmutation using reactors

2) Transmutation using accelerators

Each of these has their specific benefits and challenges. However policies must be enacted to allow for the development and use of the technologies in an appropriate manner.

The options must be evaluated on the criteria of effects on national security, long term safety and waste forms, economic feasibility, and finally long term sustainability of the program and plan. Does the GNEP program fulfill these requirements better than other options is a question that must be evaluated?

The GNEP program lacks sufficient program definition and explanation in order to allow for the accurate evaluation of criteria. In its broadest sense the program defines solutions to the issues that are at hand and need to be resolved; however it lacks the detail to properly demonstrate the paths to those solutions. It is recommended that the program go forward with a push first on defining objectives and a roadmap to them and second to demonstrating and fulfilling those goals in a timely and efficient manner, thereby demonstrating the ability of the Department of Energy to follow through on schedule without overwhelming budget deficits. If the GNEP program does not continue, some policy must be enacted in order to continue research on a closed fuel cycle, as well as engage others internationally to maintain continuity on this important issue.

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## 1.0 Introduction

Each year the citizens of the United States pay billions of dollars to support the defense of our country and to maintain its independence. Many citizens feel safe at the consideration of a strong military and a broad base of usually supportive allies. However, in recent years a subversive threat is becoming more and more obvious. It is apparent that the US has become addicted to foreign oil and has been forced to be involved in Middle Eastern politics in an attempt to protect our interests and way of life. In recent years, there has been a renewed interest in the decades old call to lessen this dependence and to make steps towards energy independence in the US. With the increasing concern over climate change coupled with what is estimated to be large growth in the energy needs for the country over the next several decades, nuclear power is emerging from the back corner of the room where it had been pushed after accidents such as at Three Mile Island and Chernobyl. With the days of the Cold War gone, and the memories of duck and cover drills in case of nuclear war, fading from the minds of the public, not to mention the impressive, but not unexpected absence of nuclear related accidents, there is increasing realization that commercial nuclear power generation has operated safely and successfully for almost 30 years since Three Mile Island. The ability of nuclear power to provide a large base load that does not emit $CO_2$, that is economically competitive and stable, and that can produce consistent baseload power is motivating the discussion and change of opinions that are driving what is being called “The Nuclear Renaissance.” However, on the eve of what may become an era of large nuclear growth, there are also issues that must be resolved and questions answered, not only to fully assess the situation, but also because the ability to define policies that answer the hard questions is the only solution to the issues that can either drive or discourage this supposed rapid escalation of nuclear power.

One of these issues is what appears to be the never ending question of what to do with the nuclear waste that is generated. This question has been debated and discussed over the several decades, decisions have been made, policies have been formed, but as of yet none have been put into place nor completely implemented. Most recently there has been a renewed push to close the fuel cycle. Numerous programs and goals have been implemented to do so, the most current of which is the Global Nuclear Energy Partnership (GNEP).

The GNEP concept is broad in its scope of both international and domestic policies to further the use of nuclear power to help solve the issues of energy independence as well as attempting to reduce the national security risks as well. Domestically, within the framework of the Global Nuclear Energy Partnership (GNEP), options and technologies have been suggested in an approach to close the fuel cycle and dispose nuclear waste. The Department of Energy (DOE) has created a roadmap and is researching and developing technologies to achieve its desired end of a defined path for the permanent management of Used Nuclear Fuel (UNF) and High Level Radioactive Waste (HLW). Opinions and reactions to GNEP are varied, not only to the policy implications, but also the technology path. The technologies and strategy currently proposed in GNEP involve the reprocessing of UNF from light water reactors (LWR) and then refabrication into fast reactor fuel containing the actinides which could then be fissioned in a fast reactor. However, the question remains, is GNEP the answer to the UNF and HLW issue?

Whatever solution is chosen, it will involve certain risks and benefits and trade offs from other available options. The merits of each path to resolve the issue is what causes the debate about which course should be selected, and what policies should be enacted. The course to be taken must be decided upon not only based upon the scientific facts, but also based upon the values and interests of the parties involved, which is eventually the American people, now and in the future.

# 2.0 Background Information

## *2.1 Nuclear Fuel*

The first nuclear reactor to generate a usable amount of electric power in the United States and in the world was EBR-I at the National Reactor Testing Station (NRTS) in Idaho.[1] EBR-I first went critical on December 20, 1951, and over the course of the following 56 year time span numerous nuclear reactors have been constructed and used to supply electricity to the grid. Of these constructed nuclear reactors, 104 are still operating today. All of the U.S. operating reactors are what are known as light water reactors (LWR) for their use of ordinary water as a coolant and a moderator to slow down the neutrons in the reactor. The nuclear fuel that has been used in the commercial reactors in the United States for the last several decades is composed initially of uranium dioxide ($UO_2$). Naturally occurring uranium is 99.28% $^{238}$U and .72% $^{235}$U. For the standard LWR currently operating in the US, the percentage of $^{235}$U normally must be increased to between 3 -5%. This process is known as enrichment and the amount of enrichment needed, depends heavily on the type and configuration of the reactor. As the $^{235}$U in the reactor fissions to produce energy, some of the $^{238}$U atoms absorb a neutron and then subsequently undergo radioactive decay that result in the formation of $^{239}$Pu. Similar to $^{235}$U the isotope $^{239}$Pu is fissile and can also undergo fission which releases heat that then is used to produce power. Once this nuclear fuel has been used in the reactor and almost all of the $^{235}$U has been consumed by fission, the fuel is then classified as UNF. The UNF contains approximately 94% $^{238}$U, 1% $^{239}$Pu, 4% fission products, 1% $^{235}$U and minor actinides. This UNF however, still contains more than 95% of the potential fission energy that was initially contained in the fuel. This energy is primarily stored in the $^{238}$U atoms that could be converted to $^{239}$Pu by absorbing a neutron and subsequently undergoing radioactive decay.

Each of the components of the UNF has its own issues to be resolved. The fission products tend to have relatively short half-lives on the orders of decades, causing them to be the dominant factor for both heat and radiotoxicity over the short term up to the first several hundred years. However, several isotopes generated as fission products do exist that have extremely long half lives and can be difficult to manage. The actinides consist of all of the elements that have an atomic number greater than that of Actinium. Those with an atomic number greater than 92 are also often called the transuranics (TRU). The actinides other than uranium and plutonium are often called the minor actinides, due to their much smaller presence in spent fuel. These minor actinides are the dominant factor to the levels of heat and radiotoxicity in the fuel in the long term, after the fission products have decayed away. These are the components that cause concerns over the UNF for tens to hundreds of thousands of years.

For the last 40+ years of energy production, this spent fuel has been classified as HLW and has been stored on site at the power plants, awaiting eventual permanent disposal. Currently the U.S. inventory of UNF is 56,000 metric tons of heavy metal (MTHM) of commercial fuel with approximately 2100 MTHM generated each year.[2] The Department of Energy and the Department of Defense also posses approximately 7000 MTHM of UNF and HWL as a result of reactor experiments and the weapons program, that is slated to be deposited into the Yucca Mountain project. The location of these wastes can be seen in the figure below.

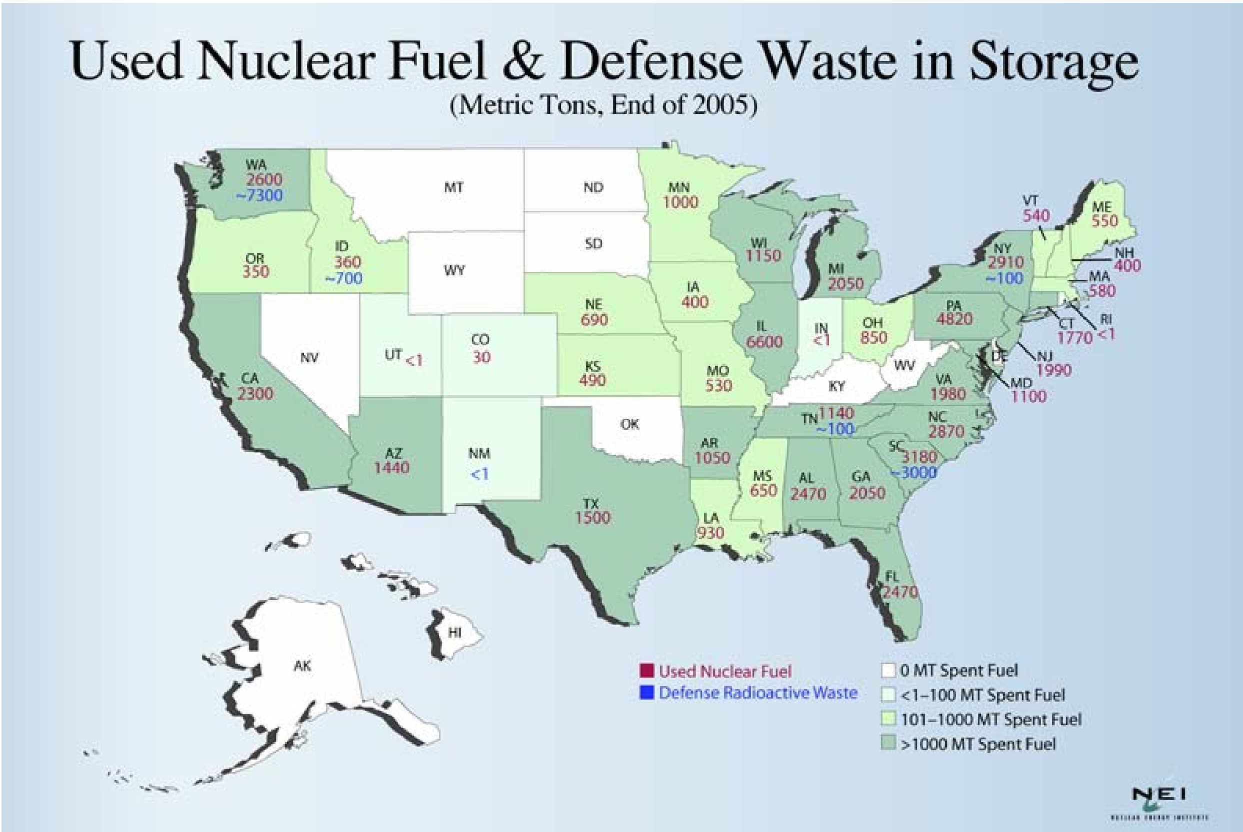


**Figure 1:** Storage of UNF and HLW by State[3]

There are many suggested or contemplated possible options for what can be done to most effectively manage the UNF and HLW. The options currently being presented are:

a) Continue the current system of a once-through fuel cycle and dispose the UNF and HLW in dry cask storage and eventually a repository.

b) Implement fuel reprocessing that would allow for the remaining Plutonium (Pu) and $^{235}$Uranium (U) to be removed from the UNF and placed back in the system to be used in the fabrication of new fuel assemblies using a mixed U/Pu fuel known as mixed oxide fuel (MOX).

c) Use advanced reprocessing methods to separate out components then use transmutation to convert troublesome isotopes.

1) Transmutation using reactors

2) Transmutation using accelerators

## *2.2 Direct Disposal*

The Nuclear Waste Policy Act (NWPA) of 1982 and further amendments established the Federal government's responsibility for the long term disposal of commercial UNF, and instructed the DOE to begin site characterization studies for a location to construct a permanent geologic repository for UNF and HLW. The original act was amended in 1987, directing the DOE to go forward on the siting and licensing procedures exclusively for a site at Yucca Mountain, Nevada. The original target date for the transfer of UNF from reactor sites to the Yucca Mountain Project was 1998. Currently Yucca Mountain is undergoing preparations to submit a construction and operating license application by June 2008, leading to construction with an expected opening time of 2017. This timetable is using the most optimistic of scenarios.

The current storage limit as mandated by the legislation for the proposed repository at Yucca Mountain is 70,000 MTHM. However studies done by outside agencies show that the actual repository capacity is much greater than this imposed legislative limit. Numerous Yucca Mountain project studies show varying reports of actual capacity depending on the criteria used in the study. The study done by the Electric Power Research Institute (EPRI) gives figures varying from 260,000 to 570,000 MTHM depending upon the disposal methods used.[4] Thus, if the current capacity as mandated by legislation is not adjusted, the Yucca Mountain project will have UNF waiting that will more than fill it, before it is even opened. However, increased legislated capacities would allow for many more decades worth of fuel to be stored in the repository. Greater capacities can cause a sense of security with the present situation and a reduction in the feeling of urgency because the increased capacity would allow for more time until another alternative must be considered. Also, it would affect the economic benefits that are used in the arguing of other options due to calculated savings from the cost of not constructing a second repository.

These capacities however are only accurate if UNF goes directly to the mountain without any separations activities. Any activities to separate individual components would require consideration of other issues such as heat loading and radiation doses at the limits of the repository at times long into the future. All of these concerns would necessitate policy changes from congress, and consideration of regulatory concerns from the Nuclear Regulatory Commission (NRC). These would either need to be included in the license application, or would require later modifications to the licensing process if the application had already been approved.

## *2.3 Reprocessing*

Reprocessing involves the separation of reusable UNF components from those that are considered waste and the subsequent reuse of the useful components in the fabrication of new fuel. The practice of commercial reprocessing grew out of the weapons-development program, in the U.S. and elsewhere. It was first undertaken as a commercial enterprise in the U.S. in the 1970's at the Nuclear Fuel Services plant in West Valley, New York. That plant was undergoing modifications in 1977 when the Carter ban on reprocessing came about and was never restarted due to unfavorable economic competitiveness of reprocessing uranium versus mining and enrichment. However, since that time the US policy on reprocessing could perhaps be best described in relation to the game "Red light, Green light." The relation is that in remarks on nuclear policy given by President Carter in 1977 all reprocessing was indefinitely deferred.[5] Later, in 1981 President Reagan lifted the Carter ban on reprocessing, once again giving a green light for reprocessing.[6] The Clinton Administration reaffirmed the policy of a once through fuel cycle and a red light, once again, was given on reprocessing.[7] Currently there is a green light under the Bush Administration. As can be caused with the childhood game, each switch causes setbacks and delays that can cripple technology development. Currently there are several proposed methods for reprocessing available or in the process of research and development, but currently no operating commercial facilities in the U.S.

There are two different process options for reprocessing. The first is aqueous reprocessing that involves processes such as PUREX and its more proliferation derivatives such as UREX, COEX etcetera. The PUREX process is currently used to separate the components of oxide fuels, although it could be used for metal fuels as well. It is the process that was initially created to generate a plutonium stream that could be used in the weapons program. The aqueous processes involve the dissolution of the fuel in a solvent and results in the separation of the uranium, the plutonium and the other components of the fuel in varying streams depending on the process. Currently numerous countries participate in various forms of the PUREX process including the United Kingdom, France and Japan. The fear in regards the PUREX process is the risk of proliferation, due to the pure stream of separated plutonium. The streams of all aqueous processes involve highly radiotoxic components that must be managed using hot cells and other monitoring techniques.

The UREX process, as well as the other derivatives is very similar in theory to the PUREX process in that they are aqueous processes that are designed to separate the components of the fuel. However, unlike the PUREX process, these other processes are designed to keep the plutonium in an impure stream that makes it more proliferation resistant. They are yet to be demonstrated on a large scale.

The pyroprocess was invented at Argonne National Laboratory and is a reprocessing method that was used at the Idaho National Engineering Laboratory (INEL) for the EBR-II reactor. It involves the separation of fuels through an electrorefining process and was developed for the use of metal fuel; however work is being done to prove its feasibility in oxide fuels as well. All work to reprocess in this process must be done in a hot cell due to the radiotoxicity of the fuel during the process. This can be seen as an inherent safety feature to deter anyone from attempting to remove any part of the UNF during the separations process. This technology was demonstrated with the fuel reprocessing and refabrication at EBR-II, and supporters claim that it could be done much more economically feasibly than current operating reprocessing methods.

## 2.4 Transmutation

The principle of transmutation involves converting the undesirable isotopes into other isotopes that are either stable or are more convenient to deal with. Principally, by causing the fission of the long half lived minor actinides, thus generating fission products that have much shorter half lives. Also among the fission products are two that cause trouble due to their solubility and that they have long decay half lives, particularly these are $^{99}Tc$ and $^{137}I$. It is considered that these also could be transmuted to make the final end product more convenient to deal with. There are various concepts that have been considered for transmutation of waste. These options involve transmutation through the use of fast reactors, and accelerator driven systems. Each of these options would require some sort of reprocessing to allow for suitable fuel production.

### 2.4.1 Fast Reactors

A fast reactor is a nuclear reactor that operates on high energy or 'fast' neutrons, which are neutrons that are not moderated to slower speeds and have energies in the keV to MeV range. The concept of fast reactors was initially presented during the years after World War II when it was conceived that fast reactors could be used as 'breeder' reactors by creating more nuclear fuel than they consumed. This was a motivating factor for fast reactor development when the world resources of uranium were assumed to be small, an assumption that has proved to be incorrect in recent decades. The concept gave many the idea of an infinite energy source, and work was done to design and build fast reactors. The Integral Fast Reactor (IFR) concept as developed by ANL-W involved a complete and closed fuel cycle from mining to disposal. The fast reactor was to be used to sustain itself with fuel requiring only small amounts of natural uranium to be added to the system and expelling only relatively small amounts of HLW. Once sufficient burn up had occurred, the fuel would be removed from the reactor and re-processed using the a process called the pyroprocess. The plutonium, uranium, and actinides would then be reused to fabricate new fuel, while the fission products would be prepared for disposal as high level waste.

Much of this technology was gained and proven in a Sodium Cooled Fast Reactor named EBR-II at the INEL that began operations in 1964. The choice of sodium coolant was made because sodium is relatively unreactive with neutrons and would allow for good cooling capabilities with minimal neutron loss. However, there was great controversy over the possibility of a fast reactor that could breed fuel and increase the world inventory of plutonium which caused for the discontinuation of the IFR program and the decommissioning and disassembling of EBR-II. In his 1993 State of the Union Address, President Clinton announced that nuclear power research and development would be eliminated.[8] The program continued to be funded for the next few years, but only for the decommissioning of the reactor, which occurred over the next several years. It is important to note, that the Japanese government had provided $40 million of the development of the EBR-II project and had committed another $60 million before the announcement to shut down was given. This canceled partnership with the Japanese left a bad international impression on the ability of the US to retain a steady partnership for nuclear R&D.

### *2.4.2 Accelerator driven Systems*

Another technology that has been discussed and researched is the process of accelerator driven transmutation of waste. In this process a sub-critical mass of fuel including the actinides and other fission products are assembled together. A particle accelerator is then excited and aimed at a target that releases spallation neutrons as a result of the interaction with the accelerator. These neutrons that are generally in the fast spectrum then serve as an extra source of neutrons that will allow the chain reaction to be sustained as long as the accelerator continues to excite a source of neutrons from the target. It has also been proposed that electricity could be generated using the process heat given off as a result of fissions in the system.[9] Research for this project was through the Advanced Transmutation of Waste (ATW) from the DOE beginning in 1991 and continuing up through the end of FY2007. However, the DOE has currently abandoned efforts in this research due to the high costs of the facilities and the low potential for commercialization as compared to a fast reactor.[10]

## 2.5 Global Nuclear Energy Partnership (GNEP)

The GNEP program was presented by President Bush in 2006. The focus of the partnership is aimed at a global partnership for the advancement of nuclear power safely and securely, with a domestic research and development component to employ advanced technologies in closing the fuel cycle. It is designed as a program to decrease proliferation risk by creating fuel supplier states and fuel user states. The diagram below shows a general overview of the GNEP International process.[11]

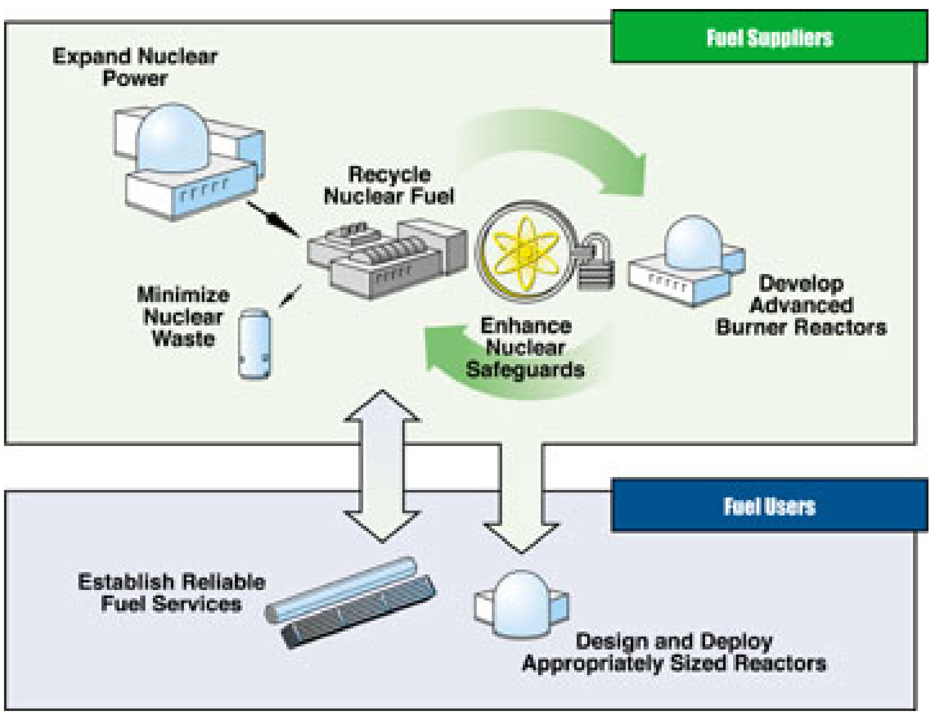


**Figure 1:** GNEP International Program

Under the GNEP program the fuel supplier states would develop technologies that allow for a complete proliferation resistant fuel cycle that includes reprocessing and transmutation of fuel. Also, advanced reactor designs would be developed to allow for versatile use depending upon needs. Under the partnership, the fuel supplier states would share reactor technology and create a reliable source of fuel for the fuel user states. In return, the fuel user states would agree to not engage in enrichment, reprocessing or other sensitive fuel cycle operations. The countries known as fuel suppliers would be responsible for the manufacture and delivery of the fuel to the reactor and would then assume responsibility for it once it is removed from the reactor. The concept of the GNEP program has evolved since its announcement in 2006. The initial roll-out of GNEP included a large component of the push for the International community to work together to create a forum for cooperation. While an interesting concept to many, it was met with many questions, not the least of which is the need to prove domestically that the US can do what it is asking the rest of the world to achieve. The GNEP program has more recently evolved to where the main focus is to achieve and demonstrate a closed fuel cycle. To establish this proposal, there are two main principles that GNEP seeks to addresses in regards to closing the fuel cycle.[12]

- Develop, demonstrate, and deploy advanced technologies for recycling spent nuclear fuel that do not separate plutonium, with the goal over time of ceasing separation of plutonium and eventually eliminating excess stocks of civilian plutonium and drawing down existing stocks of civilian spent fuel. Such advanced fuel cycle technologies would substantially reduce nuclear waste, simplify its disposition, and help to ensure the need for only one geologic repository in the United States through the end of this century.
- Develop, demonstrate, and deploy advanced reactors that consume transuranic elements from recycled used fuel.

The current fuel cycle plan involves the reprocessing of LWR fuel to separate the fission products from the U, Pu, and actinides. All but the fission products would then be fabricated into fast reactor fuel which will then be placed into a fast reactor where it can continue to be reprocessed with the intent that as many of the actinides will be transmuted as is possible.

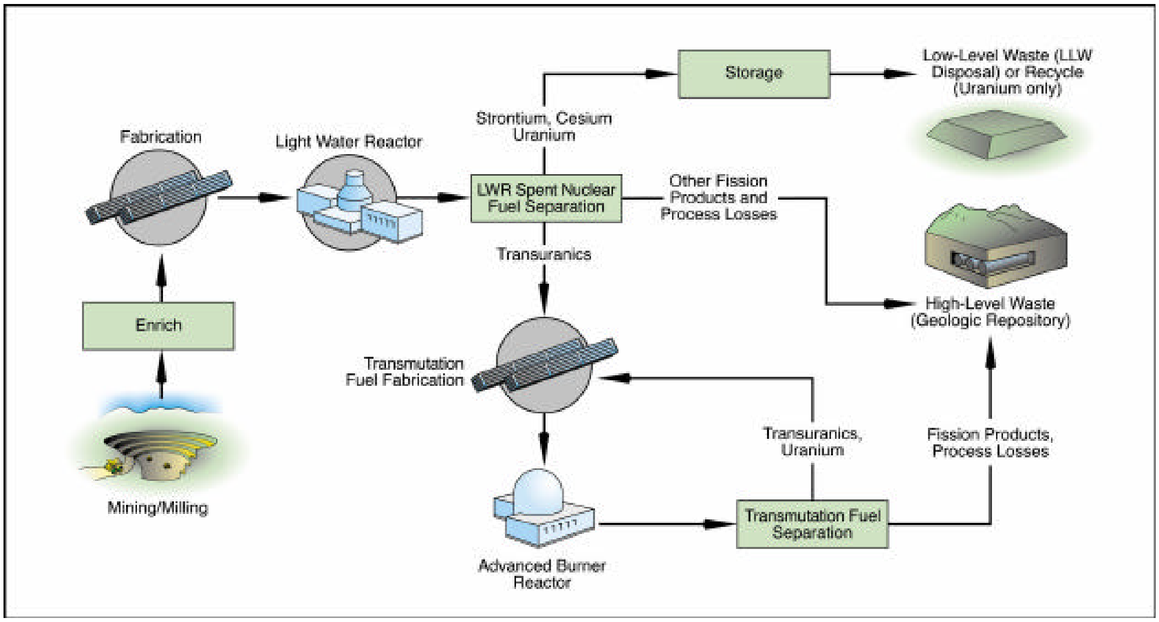


**Figure 2:** Proposed GNEP fuel cycle program. [13]

However, the exact path to these goals has yet to be determined. Currently the DOE is seeking to construct three multi-billion dollar facilities to move forward with the necessary research for the program to move forward. These include an Advanced Fuel Cycle Facility (AFCF), Combined Fuel Treatment Center (CFTC), and Advanced Burner Reactor (ABR), also known as the Advanced Recycling Reactor (ARR). The plan is to pursue design and demonstration in a parallel fashion such that the technologies to operate the facilities will be mature once construction of the facilities is complete. The GNEP plan calls for the CFTC and the ABR to be Industry Led public/private partnerships, while the AFCF would be a DOE Lab-Led Project. GNEP is still in the early development stages where much is still dependent on sufficient Congressional support in order to get the requisite funding. The success of the program is largely dependent on consistent funding and support from the congress as well as industry. The DOE is currently undergoing development of the program and probing attitudes and support for the concepts. A recommendation to the Secretary of Energy from is expected to be made by June of 2008 as to whether or not GNEP should move forward based upon the support from industry and the technology development roadmap. There are several groups that have weighed in may affect the progress of GNEP and demonstrate the value and credibility of the program:

**Congressional Support-** The GNEP program experienced serious budget cuts from the administration budget demonstrating a lack of conviction in both the House and the Senate as to the ability of the DOE to accomplish any project on schedule and on budget.
**Nuclear Vendors –** Numerous Statements of Interest proposals were submitted to the DOE in regards to GNEP facilities and are currently under evaluation. The Vendors would love to build something, however strong DOE financial support would be required.
**Public -** Criticism that the program is vague and undefined, while extremely ambitious and asking for deployment of technology that is yet to be proven.

If a decision is made to carry the program forward it will still require continuity of support and funding through various administration changes as well as congressional classes in order to develop into maturity and allow for the completion of the stated objectives.

## 3.0 Analysis of Policy Issues

Throughout the Nuclear Age there has been much controversy over what to do with UNF and HLW, but it has always been assumed that the Federal government should be responsible for eventual disposal of said materials. This was confirmed through the NWPA and the creation of the Nuclear Waste Fund (NWF) and the subsequent mill/kWh charged to all electricity generated by nuclear power. Now, the government has yet to enact a consistent policy for the disposal of fuel. The industry has not taken a waste management lead, because frankly it is a problem that the Federal Government has taken on and they ought to be responsible for it. There are a few values issues that become quickly intertwined when evaluating policy for nuclear waste and spent nuclear fuel disposal. Questions that involve personal values and corporate interests carry great weight in the policy debate. To find an effective solution, answers must be agreed upon for questions such as: How long can we postpone a permanent solution, or should we begin building new plants without a functioning end of the cycle solution? Will the problems that we have today be easily solved by tomorrow's technology? This also conflicts with the question of whether or not the American people are taking responsibility for their actions, or are they enjoying the pleasures of today at the expense of tomorrow's world? What price is too high to pay now to ensure that the best alternatives have been found to manage our resources and protect the future? Where is the balance between fiscal management and taking responsibility to how current actions affect current and future world conditions? A balance must be struck to these issues before a reasonable answer will ever be found. Each group that is involved will have its own competing interests, and a final solution must be mutually beneficial to all parties involved by finding a correct balance or compromise between the values and interests of all affected parties. The values and issues involved in the disposal of nuclear waste are complex and involved. Principally they are:

1) Protection and minimization of all possible areas where any nuclear material could be used to threaten the National Security of the United States or any of its citizens.
2) Long term stability and ability to contain nuclear material for the health and safety of future generations.
3) Economic use of technologies so as to not penalize the American people while corporations reap profits.
4) Long term sustainability of plans that would allow for energy security and stability.

## *3.1 Proliferation Concerns*

Currently all commercial sites undergo a security design process where the NRC gives specific threat risks that must be secured. These design based threat (DBT) initiatives indicate the security threats for which a security plan must be designed and prepared. Without studies having been done, it is difficult to know what the risks are, but there are some accepted risks of each proposal. Reprocessing provides for a concern about the proliferation of weapons or other radioactive material, especially plutonium. The GNEP reprocessing research is designed to minimize this threat. The GNEP goal is that these objectives can be attained and a combination of safe processes and designed security can provide a safe and secure solution to closing the fuel cycle. However, a proven technology that satisfies the GNEP criteria has yet to be deployed on a commercial scale. The principle of a burner reactor would allow for this generated plutonium to be consumed.

Currently numerous nations perform activities involving harnessing the atom for its power. Many others are in the process or looking to develop such capabilities. As these in some instances unstable nations develop nuclear programs the security threat of proliferated materials increases, either from a dirty bomb or an actual weapon of mass destruction. The GNEP vision is that when not physically in the reactor, the fuel will be overseen by a nation that possesses a more advanced nuclear technology, and is sufficiently stable to provide adequate security. However, the questions as to who will make the decisions of who qualifies to participate in this international agreement and who will enforce the violation of it, remain to be answered. These would need to be addressed by an international coalition that in order to be stable could establish policies and procedures that would create an atmosphere of trust and confidence between each of the nations in the coalition, but also with the remaining nations that might look to become fuel user states. In order for this international coalition to be trusted in its desire to share technology, the nations would need to demonstrate that they believe in the technology that they are offering. Nobody wants to buy from a salesman that doesn’t even use his own products.

### *3.2 Waste Forms and resulting Radiotoxicity and Storage Needs*

One concern is the composition of the resulting waste forms from each of the fuel cycle options. Each of the final storage options has as the final step, some time of long term storage. The ideal situation from a disposal situation would be to reduce radiotoxicity and volume as well as keeping the heat output to manageable levels. The Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD/NEA) undertook a study to analyze the effects of several different fuel cycles.[14] Some of that work was done as a comparison of quantities of required feed products and waste materials for the generation of one terawatt hour of electricity (TWh). The data for specific proposed fuel cycles was compiled in a task force report issued by the Nuclear Energy Institute (NEI). [15] Five separate fuel cycles were considered and evaluated for their use of materials and relative waste products. The considered fuel cycles were:

1) **Open Cycle:** Uranium oxide (UOX) fuel burned once in LWR then directly disposed as HLW.
2) **PUREX:** UOX fuel burned in LWR, Pu recycled into MOX fuel using PUREX process, for one time use in LWR. Spent MOX fuel directly disposed w/HLW.
3) **UREX:** UOX fuel burned in LWR, Pu and Np recycled into MOX fuel for one use in LWR. Spent MOX direct disposed w/HLW.
4) **GNEP UREX:** UOX fuel burned in LWR and reprocessing using UREX process to convert to FR fuel then pyroprocessing to recycle FR fuel.
5) **GNEP PUREX +:** UOX fuel burned in LWR, Advanced PUREX used to produce MOX & Am targets as FR fuel, as well as reprocess FR fuel.

One of the first considerations for these cycles was the relative amounts of material that would be needed to generate equivalent electricity.

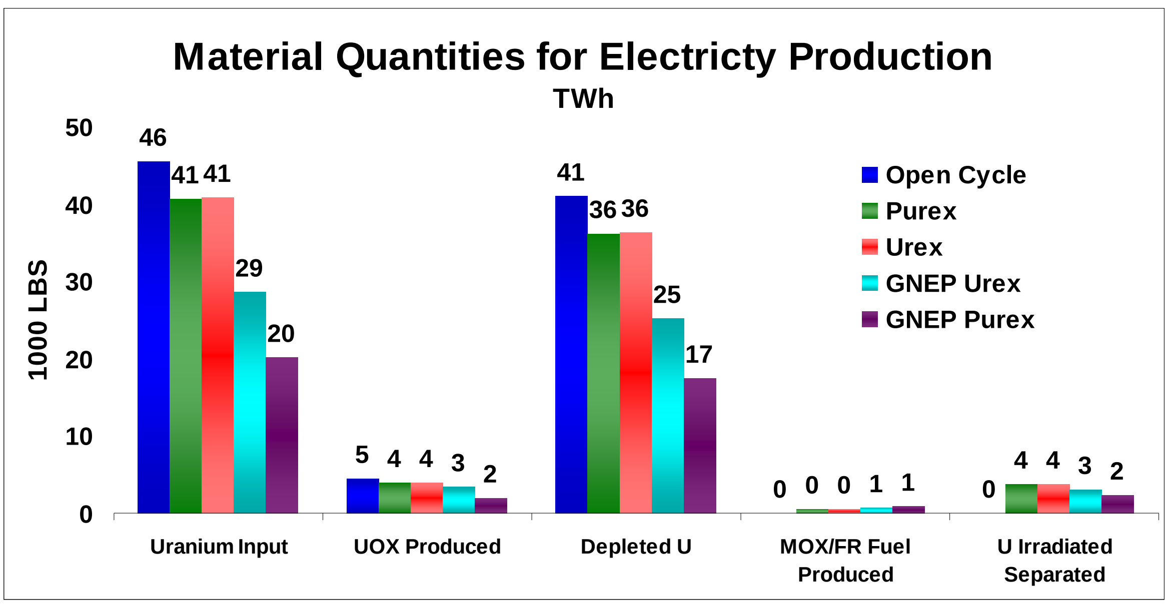


**Figure 3:** Demonstrates the relative amounts of materials used and produced through the considered fuel cycles.

This graph demonstrates that the GNEP proposed processes involving fast reactors would require fewer raw materials and leave smaller left over quantities in the process. This is because the advanced processes actually extract more of the original energy content of the material as it is repeatedly run through the system.

Another factor is related to the amount of left over uranium and plutonium as well as the generated fission products.

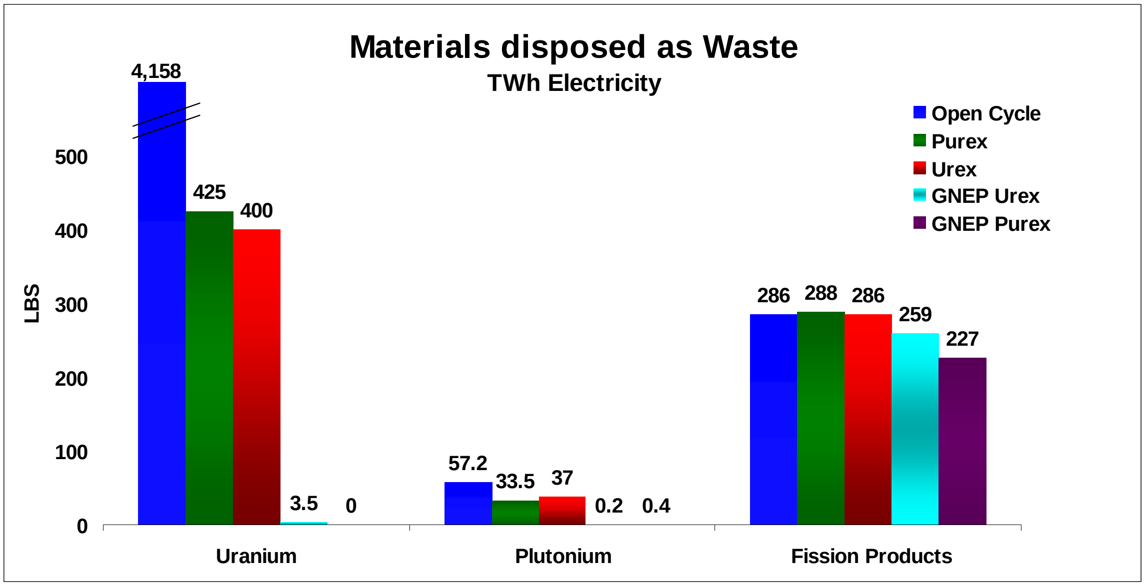


**Figure 4:** Remaining quantities classified as waste under each given scenario.

It can be seen that using the transmutation program as suggested by GNEP the uranium is almost completely consumed as is the plutonium. The quantity of fission products is similar in all scenarios, because approximately the same number of fissions must occur to release a given quantity of energy.

The long term difficulty of dealing with UNF and HLW comes as a result of the presence of the actinides which have long half-lives and control the heat loading and radiotoxicity levels in the long term. A comparison of the quantities of the minor actinides can be seen below.

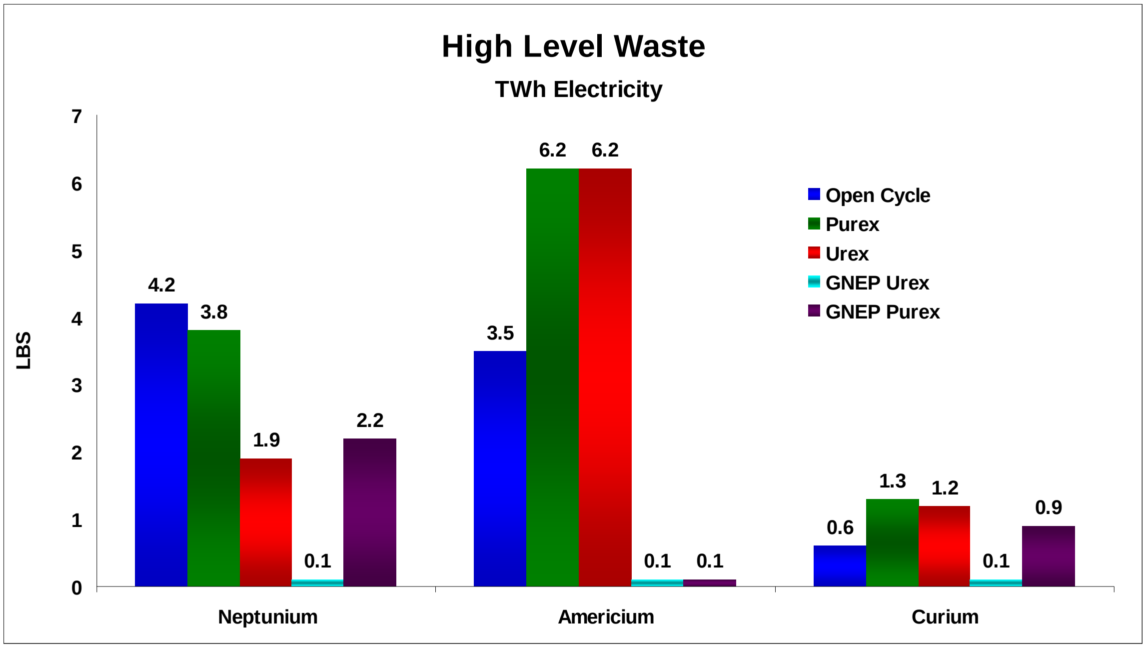


**Figure 5:** Comparison of the relative quantities of minor actinides to be disposed of by Fuel Cycle.

The GNEP program of integrated UREX/pyroprocessing to transmutation dramatically reduces the amount of actinides for final waste disposal. Other options can have the effect of allowing for increased production of some as a trade off for consumption of others.

Another consideration when quantifying residual waste is the physical volume that it occupies. The volume is one of the least critical factors, because the heat and radiotoxicity require spacing greater than the volume barriers, but is still something that can be measured and quantified to demonstrate the actual amount of material that is considered the waste stream.

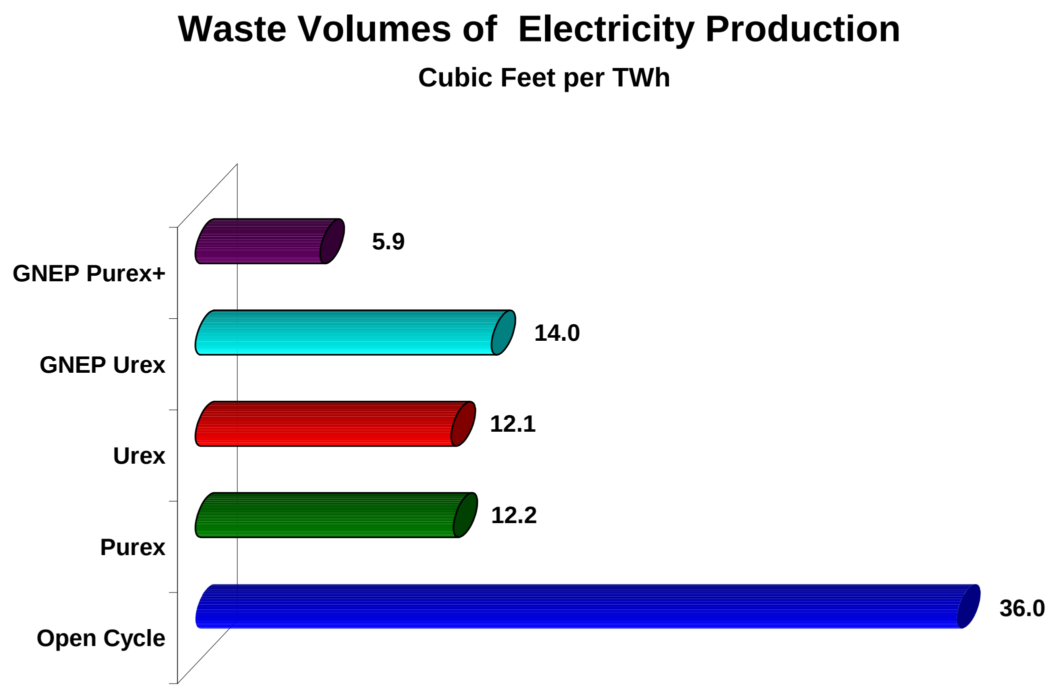


**Figure 6:** Volume of various HLW that would need to be disposed of in a geologic repository.

It is important to note that these numbers are data estimates and although the technologies have been proven, the transmutation has yet to be demonstrated on a commercial scale. In an evaluation only of the conservation of materials and final waste forms and volumes, the GNEP process of reprocessing and then reuse in a transmutation set up is an obvious choice. The merits of which reprocessing system to use would depend on other factors, not the least of which would be the design for the FR.

## *3.3 Cost Comparisons*

A requirement for any sustainable solution is that either it will be commercially viable, or the government will have to take responsibility for continued project management, and be subject to possible budget cuts and constraints each year due to congressional support or lack thereof. The favorable economic conditions must be caused by either the process itself, or aided by government intervention by some type of subsidy. Since a closed fuel cycle has not been employed commercially in the US, actual cost data is difficult to obtain for much of what is proposed. Much of this is because the facilities would be new buildings operating with processes that have not yet been fully deployed. It is important however to consider that at times the selected option may not be the most economically feasible, due to the fact that there are other considerations that can be factored in that motivate the choice of a more expensive alternative that offers certain benefits.

### 3.3.1 Once through Disposal

For the route of direct disposal, the actual costs to construct a repository are unknown. However all current options considered other than long term dry cask storage, will require a geologic repository for final disposal of something. Therefore the only costs that are to be associated with direct disposal are the incurred costs of increasing the repository capacity, either by constructing a second repository, or expanding the capacity of the first. The DOE estimates of the cost of the Yucca Mountain project to be approximately $57.6 Billion.[16] This estimate covers the entire system life cycle cost and includes construction, transportation, operation, and other expenses. Critics of the once through system claim that this number is far too low. It is the most current estimate published, however it does not include all the political costs that have and will be required to get a repository running. A second repository constructed using the lessons learned in the first, is estimated to cost less, however the question remains as to how much less and that implies that the first is constructed.

### 3.3.2 Reprocessing

Numerous studies have been done with reports issued about the economics of reprocessing. Each report involves varying factors which have different economic impacts. In a report issued in June of 2007 the Keystone Center notes that the cost of fuel from reprocessing would be $0.034/kWh while that of a once through cycle would be $0.014. [17] The costs and economics of reprocessing have been a controversial subject for years and many claims have been made as to the feasibility to it. Each study seems to have varying assumptions and claims that make their point look more favorable, however none as shown reprocessing to be reprocessing to be economically competitive without factoring in some sort of a ‘benefit factor’. These ‘benefit factors’ tend to be some sort of other savings such as the cost savings that would be associated by delaying the need for a second repository, or other intangible benefits. These ‘benefit factors’ are very important to consider when evaluating options, however they are very difficult to quantify because they in some way or another represent some intangible benefit to which it is difficult to assign a value.

### 3.3.3 Advanced Reprocessing and Fast Reactors

It is difficult to estimate the costs to implement fuel reprocessing and fast reactors as has been suggested under the GNEP program, because commercial size facilities have never been constructed. It has been estimated that each of the three proposed GNEP facilities would be several billions of dollars. However, the technology is yet to be economically proven on a commercial scale. It is projected that capital costs of construction would be greater for electricity produced through a FR facility. However, supporters of the pyroprocess argue that it has the ability to lower operating costs, thereby making the process a more economically competitive option.

### 3.3.4 The ATW program

Although a commercial size accelerator driven transmutation system has never been built, the DOE created a cost estimate for the entire program when it was presented to Congress. It has been argued that much of this cost could be recovered by the sale of electricity. The estimated costs of the full program can be seen below.

**Table 7.1. Total Deployment-Driven System Life-Cycle Costs by System Phase and System Element (Billions of Undiscounted 1999 Dollars)**

| Element | R&D | Demonstration | Implementation | | | Total[a] |
|---|---|---|---|---|---|---|
| | | | Capital | Operating | D&D | |
| Accelerators | 0.17 | 3.0 | 11.0 | 44.0 | 0.6 | 59.0 |
| Transmuters | 1.0 | 2.0 | 30.0 | 49.0 | 3.0 | 86.0 |
| Separations | 0.5 | 2.0 | 9.0 | 41.0 | 1.0 | 53.0 |
| ATW Fuel Fabrication | 0.0 | 0.6 | 2.0 | 41.0 | 0.2 | 44.0 |
| Site Support | 0.0 | 1.0 | 1.0 | 31.0 | 0.1 | 33.0 |
| Retrieval/ Transportation/Disposal | 0.0 | 0.1 | 0.0 | 4.0 | 0.0 | 4.0 |
| Integration | 0.07 | 1.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| Subtotals | 2.0 | 9.0 | 54.0 | 210.0 | 5.0 | 279.0 |

[a]Totals may not be the exact sum of the columns due to rounding.

**Table 2:** Estimated Life Cycle Costs of Accelerator Driven Transmutation System[18]

The funding for this project has been allowed to expire. It appears that this ADT has not made the cut to pass onto the next level. One of the reasons for this cut is that the electricity proposed to be generated through an ADT Reactor would not be constant, and as such it is difficult to justify the sale of generated power as a credit.[19] Without the sale of power to offset the cost, the expenses outweigh the benefits by too much to justify the research.

## *3.4 Long Term Sustainability and Outlook*

For any fuel cycle closure and waste disposal solution to work it must be sustainable. Any solution will require the dedicated investment of resources for a long term in order to actually make the solution work. This is not a 'quick fix problem' the US has spent 50+ years causing this problem, which will not be solved in one congressional session. The once through fuel cycle with a permanent geologic repository is an option that makes sense now, because it is the most economically feasible option when it comes to making power. However, it leaves UNF that is an environmental concern for tens of thousands of years, and although it is unknown what the condition of man in such time will be, is that an ethical solution when there are other technologies available.

Reprocessing and refabrication into fuel that is placed back into a reactor is a method to extract more energy from the same amount of uranium and decrease the physical volume of UNF and HLW that must be placed into a repository, but does not do anything to address the long term radiotoxicity and heat issues of the fuel generated by the presence of the actinides and some of the fission products.

Advanced reprocessing and transmutation leads to the ability to minimize the amount of HLW while maximizing the energy that is obtained from the raw materials. All of the technologies might not be known at the moment; however the limiting factor for long term sustainability is the current inability to compete economically.

Criticism has been leveled against the government and claims have been made that private industry is the only group capable to address the issue if a solution is to be found. However, research for long term UNF management will not be initiated by private industry unless there is some sort of financial incentive to drive that research. The responsibility for technology development for and the creation of a long term UNF and HLW management program does not lie with industry, but was given to the government through the NWPA of 1982.  The DOE has, through that act, and subsequent contracts, the obligation to manage all commercial UNF and HLW in exchange for the payments made to the NWF. If there was financial motivation to invest and develop these technologies, it would quickly be done, however it must be remembered that industry provides a service and receives money, while government receives money and provides a service. Therefore any solution in which the industry is to get involved out of necessity must be financially beneficial in order for them to stay in business.

# 4.0 Conclusions

The issues that surround the debate about what should be done with UNF and HLW are complex and involve numerous parties that all suggest solutions that are technically feasible. The final solution to the question as to what should be done to deal with UNF and HLW will most likely involve a variety of these various options as they are most beneficial to all. The technologies and policies to complete a commercialized fuel cycle are yet to be fully developed. There is a need to begin work on the technology to close the fuel cycle, because development will take time and even though possible deployment may be decades away, it will come. Without factoring in the difficulty to quantify benefits of repository savings due to reprocessing, it is not a commercially viable option and should not be enacted just for the sake of doing it until there is a need. Advanced reprocessing and transmutation of waste offers the greatest benefits to the minimization of the radiotoxicity of wastes as well as long term repository performance and should be continually funded and pursued in the research and development stages. Policies should be established in a consistent matter to allow for the development and implementation of a variety of solutions.

This leads to the question, is GNEP the answer? Possibly, domestically, the GNEP program addresses the issues that are required for the US to have a closed fuel cycle. This may not be the only way to accomplish this objective, but it is using technology that has been proven as the base for further development. It is the development of these technologies that will allow for more efficient use of the resources available, minimize the effects of waste products while maximizing the ability to deal with them and allow the US to stay a leader to other nations in not only technology but also responsible policy for the management of this important resource.

# 5.0 Recommendations

There are several actions and recommendations that should be taken to ensure progress for this issue.

*The world seems committed to increasing its reliance on nuclear power. This creates the imperative for some sort of global partnership or agreements on how to best address the issues that will come. If not GNEP then something else will be needed.

*The US needs to work towards a closed fuel cycle, both to minimize HLW for disposal, but also as an example to the rest of the world for responsible behavior.

*The US must maintain a sustained development scenario for the issue of UNF and HLW management. A program must be maintained and consistently adapted to current technology. Funding cuts or arbitrary politics can cause years of delay for technological development. If not GNEP, then something else must replace it.

*The GNEP program should continue forward at a deliberate but steady pace, seeking to demonstrate the technical feasibility of transmutation as well as seeking ways to make it as cost effective as possible. The updated roadmap should clearly explain the research and development steps needed and the path to achieve them.

*In preparation for the June 2008 decision on GNEP, a believable and achievable timetable even if not completely optimistic should be created such that Congressional support and funding can continue as the DOE continues to demonstrate a clear path forward and a reasonable achievement of program goals.

*Considerations ought to be made as to how thinking out of the box about the economics of a closed fuel cycle would most benefit the commercialization of technologies to minimize wastes, as well as the most effective ways to engage industry to help achieve a common goal.

Enacting these recommendations will ensure that the US may obtain a steady and consistent fuel cycle policy along with the development of a final solution to waste management. This achievement will benefit both the citizens of the United States and the rest of the world as threats of nuclear dangers decrease and energy and technology increase.

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[1] Stacy, Susan M. Proving the Principle: a history of the Idaho National Engineering and Environmental Laboratory. Jason Associates Corporation 2000. DOE/ID-10799.

[2] MTHM refers to the mass of the initial heavy metal (actinide) components in the fuel. It is commonly used in the nuclear industry as a measure of the amount of material in the fuel that is either fissile or fissionable. These numbers generally refer to the mass of the fuel originally placed into the reactor. This is a term used in the nuclear industry and is more commonly used to reference amounts of uranium than and actual mass.

[3] Diagram Courtesy of Nuclear Energy Institute (NEI)

[4] Program on Technology Innovation: Room at the Mountain. Electric Power Research Institute Tech Update May 2006.

[5] Carter, Jimmy. Nuclear Power Policy Remarks and a Question-and-Answer Session With Reporters on Decisions Following a Review of U.S. Policy. April 7th, 1977
http://www.presidency.ucsb.edu/ws/index.php?pid=7315&st=nuclear&st1=reprocessing

[6] Reagan, Ronald Statement Announcing a Series of Policy Initiatives on Nuclear Energy October 8th, 1981.
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[7] Clinton, William J. Message to the Senate Returning Without Approval Legislation on Nuclear Waste Policy. April 25th, 2000
http://www.presidency.ucsb.edu/ws/index.php?pid=58410&st=reprocessing&st1=yucca

[8] Clinton, William J. State of the Union Address February 17, 1993. http://www.presidency.ucsb.edu/ws/index.php?pid=47232

[9] A Roadmap for Developing Accelerator Transmutation of Waste (ATW) Technology. DOE Report to Congress. October 1999.

[10] Per conversation with Buzz Savage on June 26, 2007.

[11] GNEP International Process, DOE http://www.gnep.energy.gov/gnepProgram.html

[12] GNEP strategic plan Department of Energy (GNEP -167312)

[13] "Spent Nuclear Fuel Recycling Program Plan" DOE Report to Congress. May 2006 http://www.gnep.energy.gov/pdfs/UNFRecyclingProgramPlanMay2006.pdf*

[14]Advanced Nuclear Fuel Cycles and Radioactive Waste Management NEA-OECD, NEA No. 5990, 2006.

[15] NEI Fuel Cycle Task Force Report June 2006.

[16] "Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program" Department of Energy May 2001. DOE/RW-0533. http://www.ocrwm.doe.gov/about/pm/pdf/tslccr1.pdf

[17] Nuclear Power Joint Fact-Finding, The Keystone Center July 2007.

[18] A Roadmap for Developing Accelerator Transmutation of Waste (ATW) Technology, DOE Report to Congress October 1999 http://sciencepolicy.colorado.edu/about_us/archives/projects/gccs/2002/jvc/pdf-docs/doe_rw-0519.pdf

[19] Discussion with Buzz Savage (Director of GNEP Fuel Cycles) at DOE, June 26, 2007.