Reducing the Barriers to Fusion Electric Power

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Abstract

A potential solution to some of the current problems faced by the U. S. Magnetic Fusion community is presented. It can be implemented with little or no increase in the present funding level and it could promote a more positive attitude toward what is, in its ultimate application to electricity generation, a very long and costly research program. The proposed solution is to devote a significant fraction of the current program to developing, and marketing, near term commercial products from low Q devices. It is anticipated that such a research and development program is in fact less expensive than the pursuit of very large and complex toroidal power plants based on the DT cycle. A few examples of near term commercial products are discussed and a plan presented that could ultimately lead to economical and environmentally attractive fusion power plants.

1. Introduction

The U. S. fusion program is currently facing growing barriers to the development of fusion electric power. These barriers are being formed on many different fronts and before the topic of alternate pathways to fusion can be addressed, we must understand the nature of the challenge that is being placed before us. Let us first address what appear to be the main arguments against what many scientists and engineers have spent 10, 20, or in some cases, even 30 years trying to do, and that is to develop an attractive fusion electric power plant.

2. Barriers To Fusion Electric Power in the U. S.

There appear to be at least 7 major sources of our current problems and these are summarized in Figure 1. The subsequent remarks pertain largely to the U. S. and its magnetic confinement program.

First, and the most obvious, is that there is currently no perceived need for a major new source of electricity in the U. S. This topic has been addressed quite well by other authors in this conference(1-3), and can be summarized by the strong movement towards smaller, natural gas based high efficiency turbine power plants. This trend is expected to last for at least the next 1-2 decades, during which time all other forms of electricity producing systems (coal, oil, fission, and renewables) will face similar competition.

The second barrier is also obvious and that is the precipitous drop in federal funding for magnet fusion research (Figure 2). As the funding continues to plummet from its peak in 1980, which was ≈4 times the 1997 level in real dollars, there is less and less money available to generate new ideas and to build larger devices to test the viability of those concepts which do show promise. The reasons for this drop in support must be seriously analyzed and it is the thesis of this paper that they are not only connected to the first barrier but also to the remaining 5 barriers.

- **No Perceived Need for Major New Source of Electricity Production**
- **Major Drop in Federal Funding**
- **Current Fusion Power Plant Concepts Require Very Large Prototypes**
- **Fusion Community Does Not Have an Economical Power Plant Concept**
- **Fusion Community Has Not Integrated Well With Electric Utilities**
- **Very Little Private Industry Money Invested**
- **No Obvious Near Term Commercial Applications From Fusion Research**

Figure 1. Current barriers to fusion electric power in the United States.

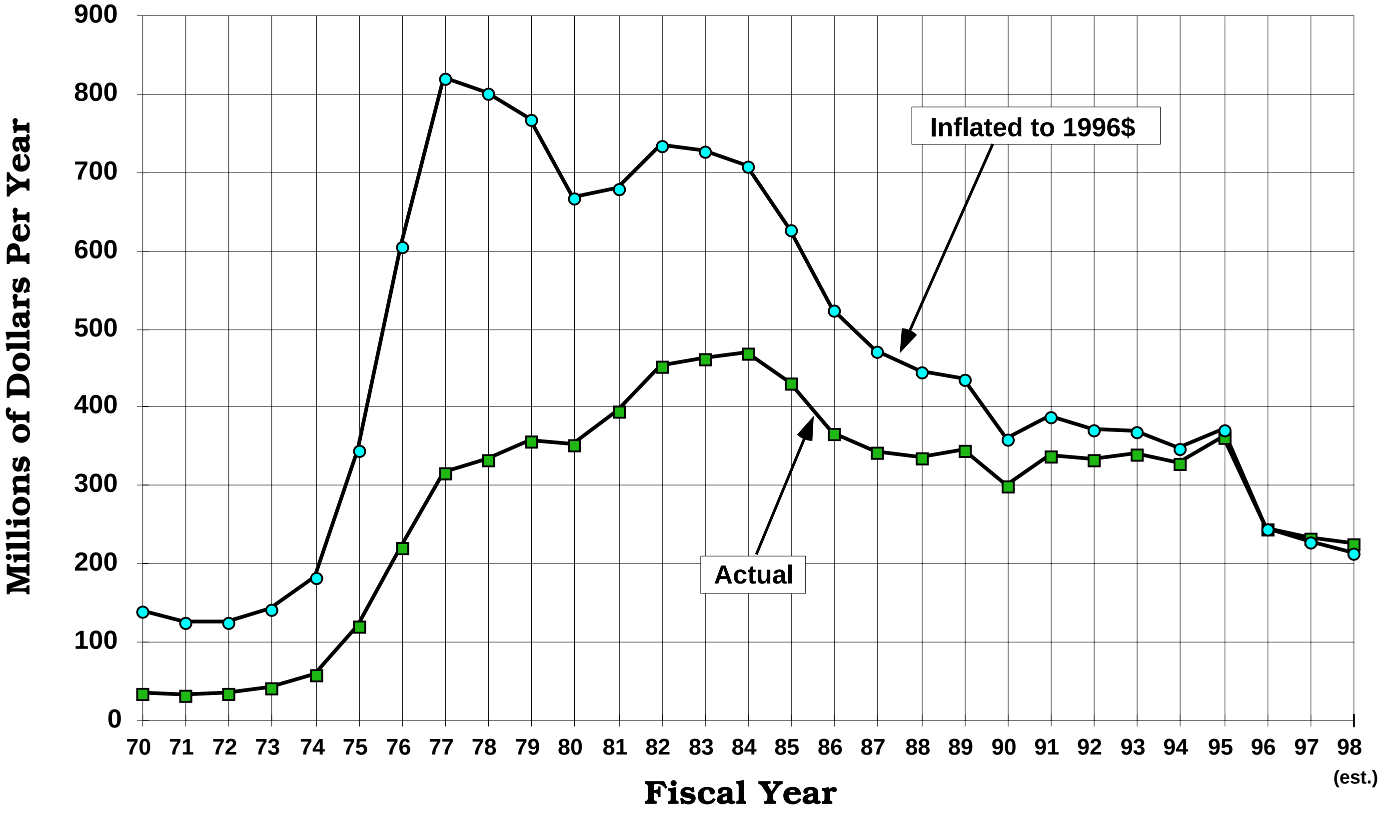

Figure 2. The DOE magnetic fusion budget has dropped to its lowest level in 22 years.

The third barrier stems from the fact that current fusion power plant concepts require very large prototypes. In today's economic and legislative climate, the U. S. fusion program seems to be completely out of step with what is going on around it. At 10 billion dollars for the next step in the program, we have priced ourselves out of the "game". That number needs to be reduced by a factor of ≈100, or to around 100 $M for a prototypical power facility. It is certainly evident that even when the next step is as low as 1 billion dollars, the current mood in Federal funding agencies is not conducive to funding proposals of that magnitude. Examples of this attitude include the CIT, BPX, and TPX designs.

The 4th barrier is certainly controversial in the fusion community, but a strong case could be made for the statement that we no longer have an economical power plant concept. This may seem to be an odd statement from the authors who have, for most of their career, been deeply immersed in the fusion reactor design community. However, after leading or participating in over 40 fusion power plant designs in the past 27 years, we have reluctantly come to the conclusion that the complexity, large size, radioactivity, and radiation damage problems associated with what has been placed on the table before the government, the utilities, and the public results in a electricity production plant that is too unreliable, and too costly to compete even with the renewables.

The 5th barrier is one that the fusion community brought on itself and is fortunately fixable. Namely, the fusion community has not integrated well with the electric utilities. Other papers at this conference and from previous publications(1,4,5) have hinted at the problem but the fact is that most utilities consider fusion in a "fundamental science" mode at best. It is hard to identify any utility in the U. S. that has fusion in their 10 year plan or even their 20 year plan. However, most utilities have included wind, solar, and other renewable schemes. This needs to change if the fusion community is to be taken seriously outside of its own technical circles.

The 6th barrier stems from the fact that very little private industry money has been invested in fusion research. What is meant here specifically pertains to the area of energy applications and not the hardware developed for current experiments. It appears that the industrial participants of the fusion program are quite willing to act as "Job Shops" (even though they will certainly deny that in public) but one sees very little "Skunk Works" type of activity such as that which was so successful in the aerospace community.

The 7th, and final barrier, one that is expanded upon in the remainder of this paper, is that there appear to be no obvious near term commercial applications coming from fusion research. Here the important distinction must be made between spin-offs, which can and do occur under the current program(6-11) versus real applications from fusion products that come from a fusing plasma. Some earlier considerations of this topic were reported in 1996 (12). The point here is that until the public sees some tangible, and positive, results from the fusion program, it will always have difficulty selling itself as an energy program.

After outlining the barriers to be overcome, how has the U. S. fusion community approached these problems in the past?

3. Traditional Approach to Developing the Long Term Potential of Fusion Energy

A very simplified version of our traditional "energy driven" approach to moving from where we have been in the past to a future commercial fusion power plant is shown in the upper half of Figure 3. For the most part, the long range plan (for the past 40 years) has been to provide an inexhaustible source of electrical energy from fusion. We have rolled forward from plasma physics concepts, which predict how to confine or initiate a fusing plasma, and then built an ever larger series of devices to test out the associated plasma theory and plasma technology. Next, we have traditionally proposed to build a series of facilities with Q>1 (Q=[energy released]/[energy input]) to solve the technology problems associated with neutrons, breeding, handling high heat fluxes, etc. Once those nuclear technology problems are solved and sufficient confidence has been accumulated, it was then proposed to build a demonstration reactor on the way to a commercial power plant.

Unfortunately, we have learned that the approach outlined above is an untenable path both in the cost and the time it will take before the public sees some return on its investment. We have found that it is simply not acceptable to talk about 50 year development scenarios costing 10's of billions of dollars without giving some early tangible benefits to the public. Thus, the current fusion program in the United States, has stalled and is in danger of being removed from the list of potential solutions for our long range energy supply.

4. An Alternate Approach to Fusion's Long Range Potential

One way to attack this dilemma is shown in the bottom half of Figure 3. This would involve a parallel approach which, up front, made a substantial effort to identify products, with detailed business plans, that could be produced from fusing plasmas in Q<<1 devices. These devices would not necessarily be the current configurations based on tokamaks, lasers, or ion beams. In this approach, one would have to allow for considerable paradigm shifts in past thinking and the fusion program must not be constrained to keeping one or another laboratory in business locked to the traditional approach of the past. What is being suggested is not a typical 2 year, 1 million dollar study by a few scientists and engineers. This approach, if it is to be effective, must involve a substantial number of the current researchers and program resources (perhaps as much as half) for several years followed by 5 to 10 "tiger teams" to pursue the most promising ideas. Not all of the approaches will be successful, but some will and the element of urgency coupled with competition, bolstered by hard headed business plans, should attract the attention of industry and the public. In parallel, the rest of the program could be oriented toward electricity production using the information developed by the low Q devices or by developing low cost, low power level, more traditional concepts.

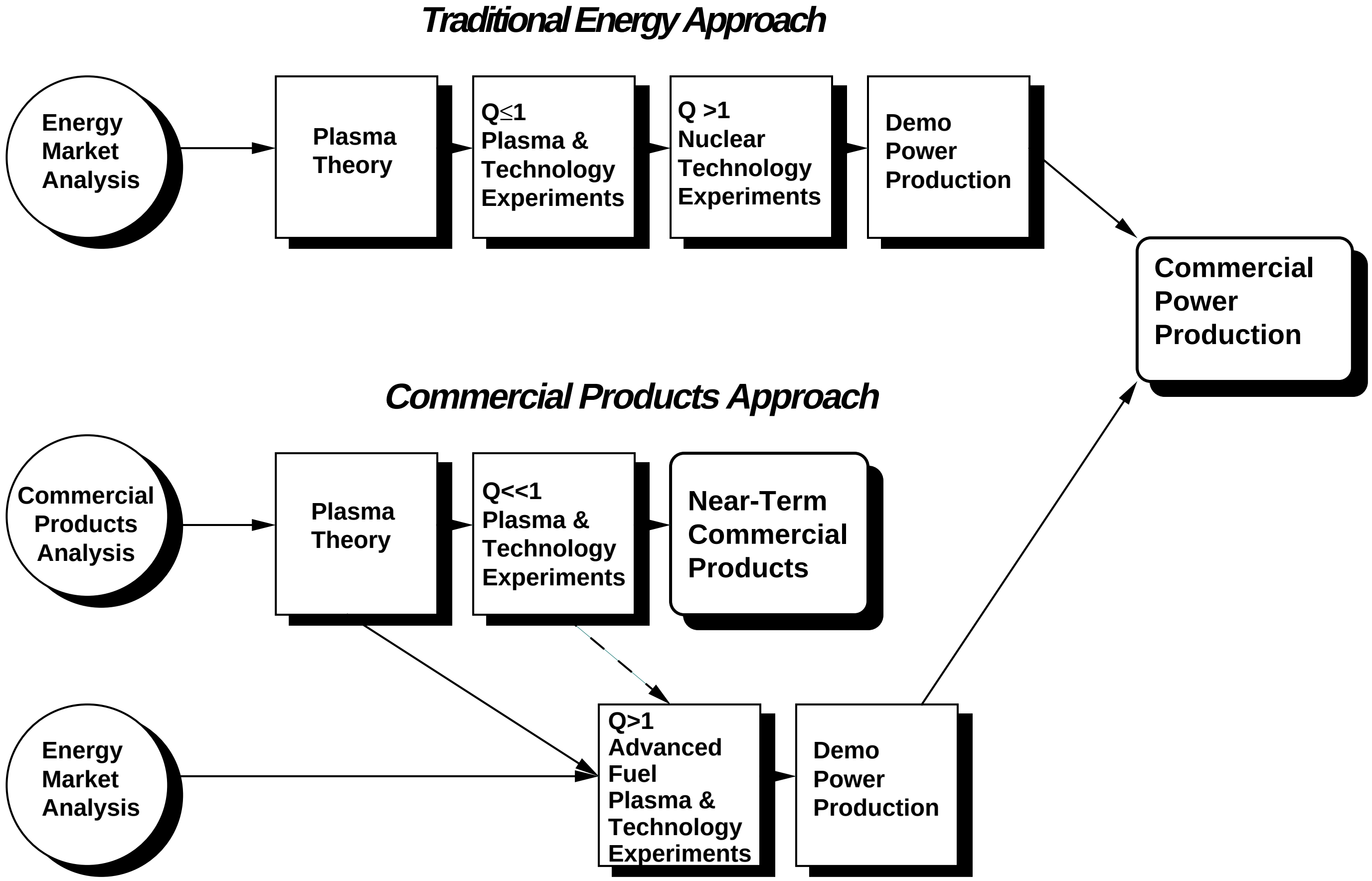

Figure 3. How do we get there from here?

For this approach to work assumes that we have something unique to sell.

4.1. What Does the Fusion Community Have to Sell That is Unique?

There are at least 5 important products that come from fusing plasmas. These are:

High Energy Neutrons
Thermal Neutrons
High Energy Protons
Electromagnetic Radiation
High Energy Electrons

There is a wide variety of particles, energies, and production rates available from the most promising fusion fuel cycles. The relationship between the energies and production rates per watt of fusion power for neutrons, protons, and alpha particles is shown in Figure 4. Except for the alpha particles from the $p^{11}B$ reaction, most of the production rates vary from 3 to 10 x 10^{11} particles/s per watt of fusion power and the particle energies vary from 1 to 15 MeV. One of the important uses for these energetic particles is for the transmutation of specific isotopes to less dangerous atoms and to isotopes that can be used to benefit society. Neutrons of all energies and protons with energies > 5 MeV are of particular importance for such transmutation reactions.

It is important to relate the number of particles produced/s in Figure 4 to the Q of the device. For example, the rates in Figure 3 correspond to Q x 10^{11} particles/s per W of input electrical power. If $Q = 10^{-3}$, the values would correspond to 10^{11} particles per kW of input electrical power. Granted that low Q devices can produce useful nuclear particles, to what use can we put these particles?

4.2. Near Term Applications of Fusing Plasmas

Figure 5 shows the wide range of possibilities that have already been identified at the University of Wisconsin during the past few years. These applications range from production of radioisotopes for medical and tracer uses to the use of ionizing radiation to deactivate chemical/biological weapons. In between these extremes, there are other beneficial uses such as the detection of contraband (explosives, drugs, etc.), alteration of materials properties such as surface modifications for mechanical and electronic applications, and generating pulsed images of large components in the field (welds, examination for cracks, etc.).

The difference between the list in this paper and that from another paper in this conference(11) is that the applications here are specifically aimed at low Q devices. That is, the authors of this paper have not considered desalinization, fissile fuel production, etc., because these latter applications generally require large, high Q devices which will undoubtedly require decades of development. It is felt that low Q devices can have a more immediate effect on the marketplace and while none of the individual near term applications will have the economic impact of generating electricity, providing desalinated water, or even large scale destruction of fission reactor wastes, the immediacy of their impact can have the effect of insuring support for the longer range fusion program. A more extensive list of the near term applications can be found in a previous publication(12) and only 2 of the ideas will be highlighted in the rest of this article.

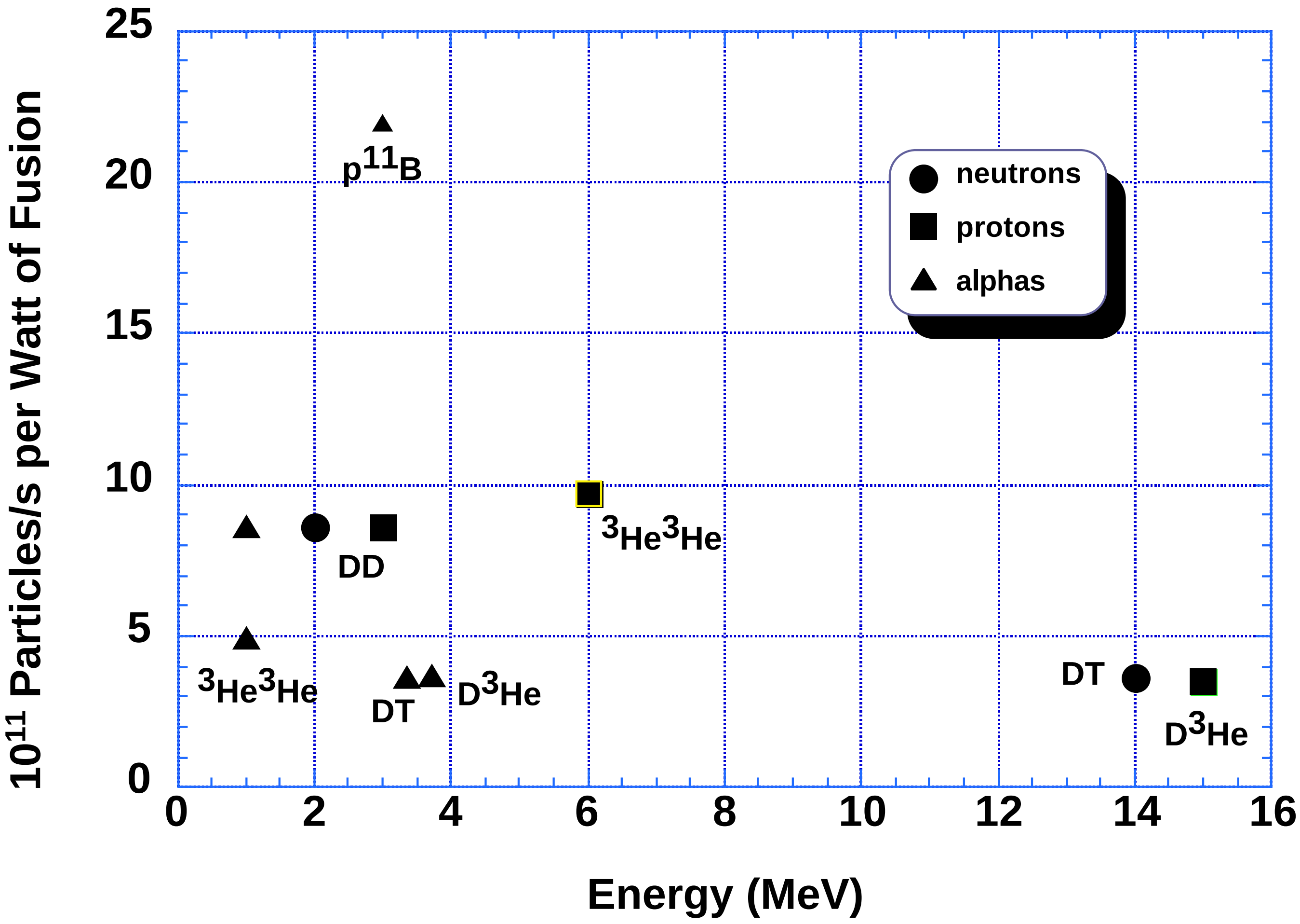

Figure 4. Fusion fuels can produce large numbers of highly energetic particles for commercial applications.

4.2.1. Destruction of Particularly Long Lived Radioisotopes

It is well known that the ≈15 MeV protons from the D^3He reaction can induce significant (p, n) reactions in materials. This can be particularly important if one has very long lived isotopes which one would like to "destroy". This destruction really involves the transmutation of the long-lived isotope into one which has a much shorter (e.g., <30 days) half-life or even converted directly to a stable isotope. Since it takes ≈ 10 half-lives to effectively reduce the activity of an isotope to an innocuous level, then in 1 year the long lived radioisotopes would be "deactivated". Examples of which isotopes one might irradiate with 15 MeV protons are given in Figure 6.

The target isotopes are on the right and the products of the (p,n) reaction are on the left. Remember, if the half life of a particular isotope is less than 10 hours, then in ≈10 half lives (≈4 days) the activity of the isotope is reduced by a factor of ≈1,000. In a year (1000 half lives) the activity is reduced by a factor of 1,000,000,000 over the original amount. Since it is reasonable to think about storing radioisotopes for a year, anything with a half life of <10 hours will be essentially gone and converted to a stable isotope in less than a year. In that way, one can show that a low cost, high energy proton particle flux could essentially destroy extremely long lived isotopes and present another option to deep geological waste burial facilities.

4.2.2 Mobile PET Generator

One of the most popular isotopes used in positron emission tomography (PET) is ^{18}F. It is used for a large number of diagnostic scans and is particularly good for brain scans. However, because of its ≈2 hr half life, and the exposure received after the test, its current use is not permitted in pregnant women and children. On the other hand, if a much shorter half life material were available, the residual dose following the diagnostic procedure would be less. One isotope that fills this requirement is ^{15}O (half life ≈ 2 min). The problem with this isotope is that its half life is so short that it is impossible to manufacture at a location very far from the actual location where it will be used. A small, (1 watt) D^3He source could produce ≈ 1 Ci of ^{15}O from a (p, n) reaction with ^{15}N and it could be used in close proximity to a patient because of the limited shielding required by this fusion reaction. In this case, even a $Q = 10^{-3}$ source would require a power supply of only 1 kW. It could literally be a "coffee cart" source of radiation that we need to compete with larger cyclotrons which are, of course, not mobile.

So how does all this fit together?

	Neutrons	Protons	Electrons	γ or X-rays
Radioisotopes	✔	✔		
Detection of Contraband	✔			
Radiotherapy	✔			
Alteration of Properties in Materials	✔	✔	✔	✔
Destruction of Radioactive Waste	✔	✔		
Food/Equipment Sterilization			✔	✔
Pulsed Imaging	✔	✔	✔	✔
Processing Municipal, Industrial & Medical Wastes		✔	✔	✔
Deactivating Chemical/Biological Weapons		✔	✔	✔

Figure 5. Near term applications of reaction products from Q<1 fusion devices.

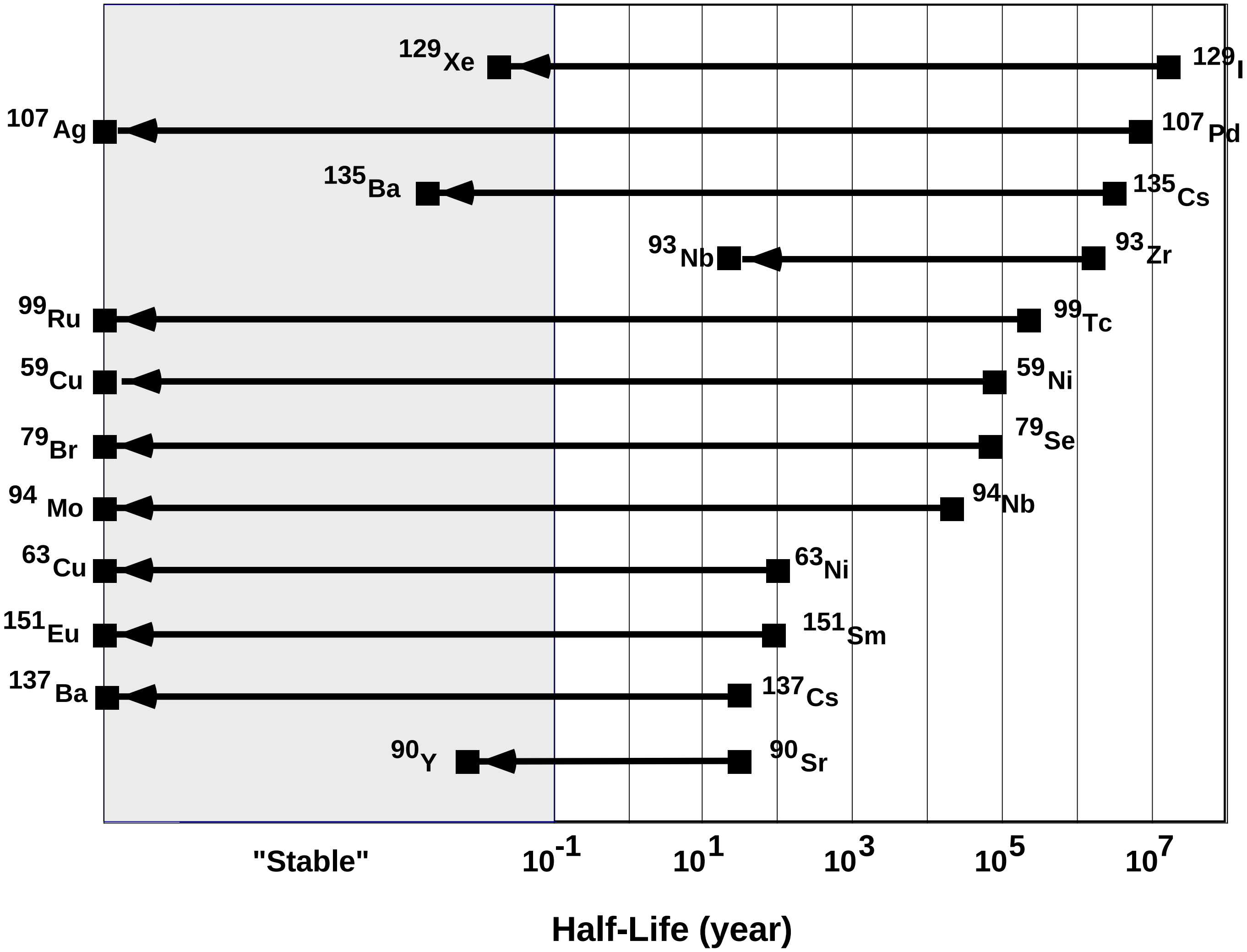

Figure 6. Protons from the D^3He reaction can be used to "burn up" long lived nuclear waste.

5. Conclusions

A summary of how the proposed scenario fits in the long range vision of fusion is shown in Figure 7. The end point is the same as our current program, that is, electric power plants that could supply a significant fraction of the U. S., if not the world's needs. However, the starting point is quite different. The adjustment is necessary because of the lack of pressure for new sources of electricity, the current emphasis on balancing the national budget, and the reductions in the national fusion budget. The initial focus is on near term products for civilian and military applications with $Q<1$ plasma conditions. Once products that the public can use and identify with fusion in a positive way are demonstrated, the fusion community would be ready for the 2nd phase. This would involve taking those concepts that show promise in Phase 1 to the $Q>1$ stage but short of the large scale power plants that we have been working on for the past 25 years. A few examples of Phase 2 activity might be small power sources for remote locations, space power or propulsion, or destruction of toxic wastes.

Finally, the community should be in a position to narrow down to one or two of the concepts and fuel cycles that show the economy of scale in phase 2. Such concepts must have the robustness needed to compete with fission and renewable sources in the middle of the 21st century.

While this is one vision of the future, and there certainly is room for others, it is believed that if we continue on our present path, we will find ourselves with a much smaller fusion program than we now have. We must acknowledge, and break down, the 7 barriers now before us and be willing to explore new, innovative approaches to developing our ultimate dream of clean, safe, and economical fusion power plants.

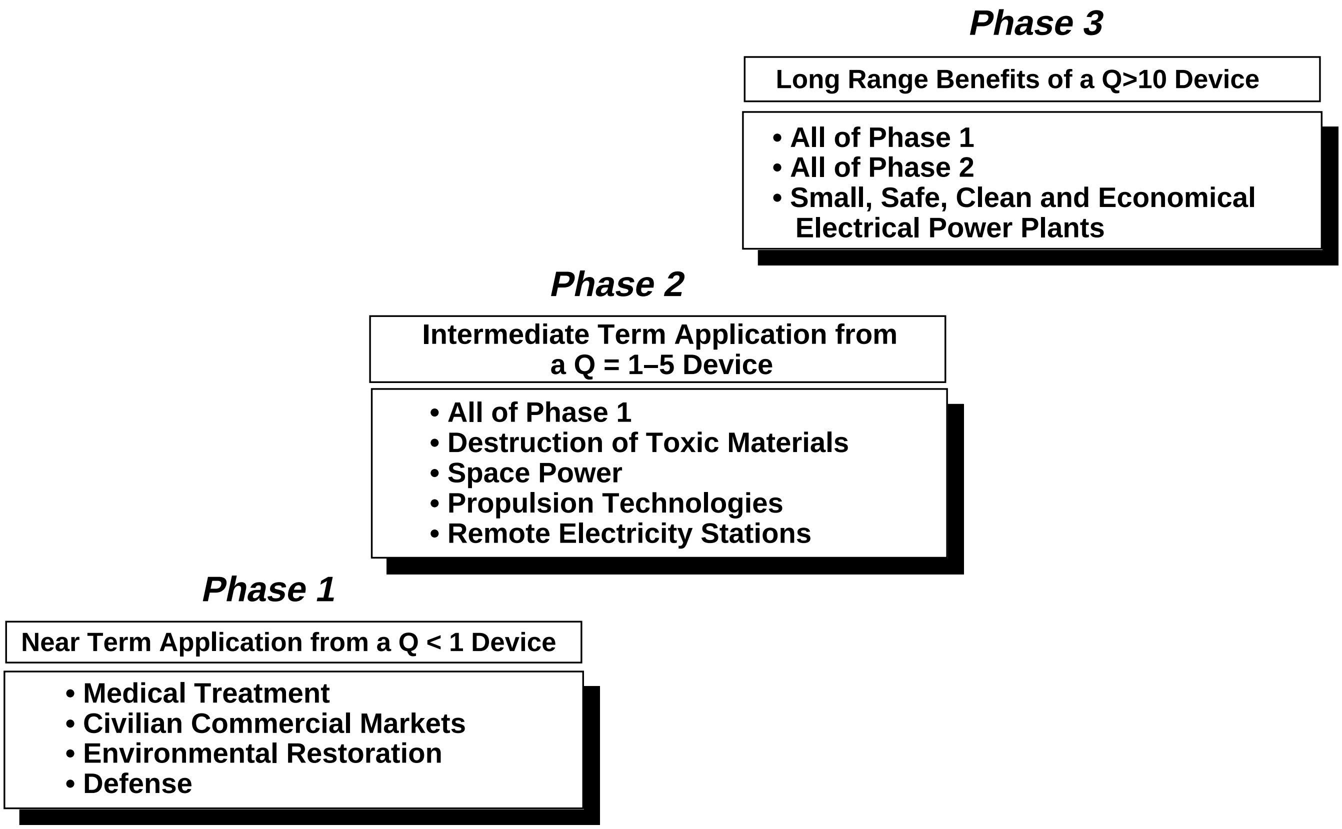

Figure 7. The development of the IEC fusion concept can lead to near term as well as long-range benefits for U. S. business.

Acknowledgment

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