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# Socio-economic Aspects of Fusion

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**Abstract.** Fusion power systems, if developed and deployed, would have many attractive features including power production not dependant on weather or solar conditions, flexible siting, and minimal carbon dioxide production. In this paper we quantify the benefit of these features. In addition, fusion deployment scenarios are developed for the last half of this century and these scenarios are analyzed for resource requirements and waste production.

## 1. Introduction

There is an increasing recognition that issues related to energy supply are becoming a significant factor in reducing economic growth. This problem is fueled in part by the growing energy needs of developing countries such as China and India. There is also a recognition that energy supply problems begin to manifest themselves not when fossil energy production reaches a peak, but rather at an earlier time, when demand begins to exceed supply. The economic difficulty derives from the direct impact of high fuel prices along with the indirect impact of balance of payment shortfall. In addition to the economic impact of fossil fuel supply issues, there is recognition of the detrimental environmental impact of fossil fuel usage.

Fusion energy has the potential of alleviating both the economic and environmental impacts of present fossil fuel constraints, albeit on a time scale in the more distant future. The features of fusion that have the potential for both economic and environmental benefit are the following:

- Reliable power production that is not subject to weather conditions
- Capability of siting at desired locations within a distribution system minimizing the need for long distance transmission
- Minimal carbon dioxide production for reduction in global warming

In this paper we will quantify important aspects of these features. It should be noted that cost of electricity will be an important factor in the market share of the deployment of a technology. Clearly, a goal of fusion is to develop a reactor with a competitive cost.

The national power system will certainly include a combination of power sources optimized to meet regional constraints and requirements. The potential role of fusion in this mix will be derived from the features outlined above. In this paper, we will quantify important aspects of these features in the context of deployment in the Northeast region of the United States.

## 2. Deployment Options

The phases leading to potential fusion based power production are: development, prototyping, initial deployment, and market penetration. There is a valuable historical record of technology development and deployment from which to draw insight into deployment trajectories for fusion. Over the last several centuries there is a recorded history of the deployment of transportation and energy technologies among others. After development and prototyping, these technologies enter an initial deployment phase characterized by a significant second derivative in production. This is followed by a phase with relatively constant ramp rate, and then a phase leading to and including saturation. In addition, the more recent history of fission reactor deployment has important parallels to future fusion reactor deployment from which to draw insights to the possible deployment of fusion power.

The historic trajectories for technology deployment have a surprisingly similar shape and timescale to saturation. The shape of these trajectories has been parameterized in the form of an analytic fit named a "logis curve". For these curves, the time scales for initial deployment (period of high positive second derivative) and market penetration (roughly linear ramp) are surprisingly similar.

For example, the linear ramp periods fall in the range of 25 to 50 years. The evolution of fission deployment was similar in character to other technologies, with a market share in the 10-20% range in many countries. In France and the Province of Ontario Canada, the market share was considerably larger. In these two regions the fission power production reached saturation in 20-30 years after significant market penetration.

Drawing on this historical data and the projections for the development of fusion, we have postulated a world deployment scenario for fusion. (*See Figure 1*).

For the purpose of developing this scenario, we have assumed a Demonstration Reactor is operational by 2040. The figure shows the non-carbon dioxide-emitting power required to meet a reasonable power production goal, while keeping the carbon dioxide in the atmosphere below 750 ppm. Thus, how fusion power production could contribute to the non-carbon dioxide power production is illustrated.

This scenario has a relatively high second derivative during early fusion market penetration, and a generous period of linear rise toward saturation. The levels of market penetration proposed *(see Figure 2)* will require fusion contributions to energy sectors beyond electricity production. This could be accomplished through hydrogen production.

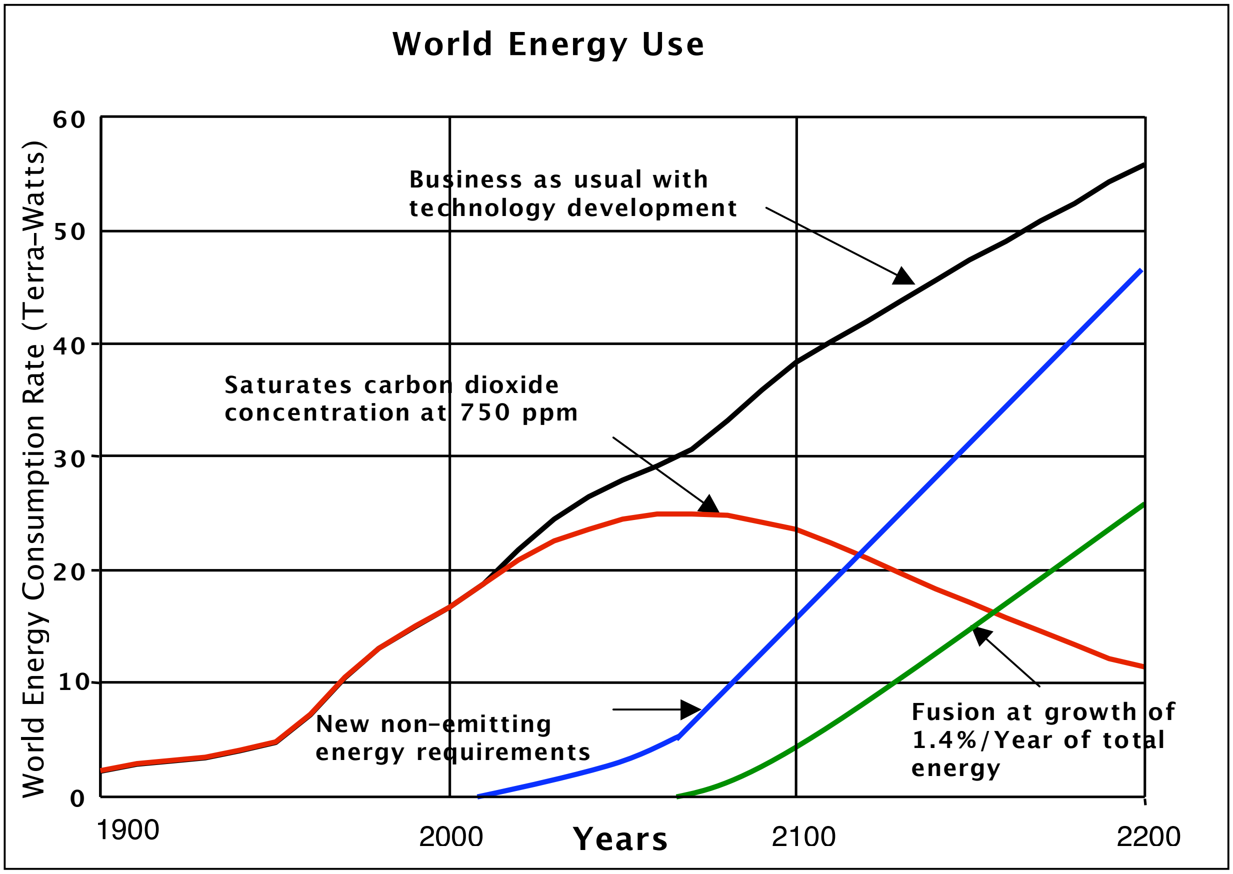



*Figure 1*

## 3. Siting

A major attraction of fusion power reactors is flexibility in siting. A fusion reactor does not require special weather conditions such as high sun exposure or high and steady wind exposure. Hopefully safety considerations will not be an impediment to site selection. If this is true, fusion reactors should be deployable near or within distribution systems and not requiring long distance transmission. Long distance transmission will be a cost, and possibly, a feasibility issue.

Using the North East coast as an example of the limitations of renewable energy sources Figure 2 shows the wind resources as a function of distance (west) from this region. This data is for Class 3 wind conditions and both moderate and severe siting restrictions. Each square kilometer can typically provide about one megawatt of electric power. The North East region is projected to consume roughly 0.15-0.2 TW in the 2050 time frame. We see that it would be necessary to draw from the Midwest region to provide a large fraction of East Coast power from wind resources. This is certainly not optimum and likely not feasible. A much better choice would be to use the wind resources near their origin and avoid long distance transmission, and provide significant amounts of power for the East Coast from fusion.

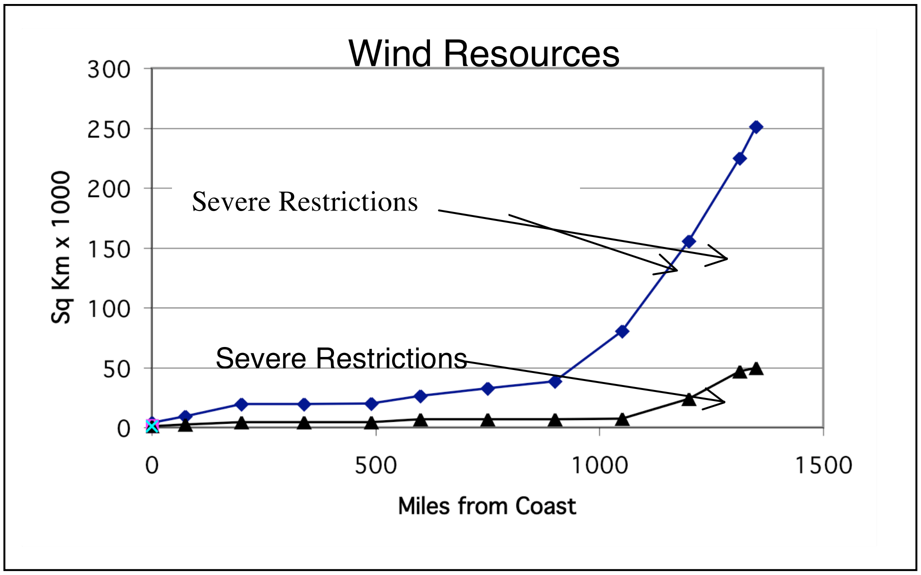



*Figure 2*

**4.** Reliable Base Load Capability

Advanced societies require a high probability that their power needs will be reliably met. This requires enough reserve within a distribution system, or transmission from a reliable source, to offset scheduled and unscheduled outages for power sources. The reserve within a distribution system can in general be high fuel cost—low capital cost power generation, or energy storage. The only energy storage that can be implemented in the foreseeable future, at reasonable cost and flexibility for siting, is compressed air storage.

The unscheduled outages place the greatest demands on the system due to the inability to schedule these outages during low demand periods. The value of a power source will depend on its availability. The availability is defined as the operating time divided by the scheduled operating time. Not only because of the impact of availability on capacity factor, but more importantly, the need to purchase reserve power systems to cover outages. This reserve power will be most needed when base load power is not available during periods of peak demand. This fact is captured by the statement, “the primary value of investing in a power source is to meet peak demand.” Therefore, we should measure power sources against their ability to meet peak demand. This ability to meet peak demand is a probability issue. The value of a power plant will not only depend on its availability, but also on the size of the plant relative to the overall size of the distribution system supplied by the plant.

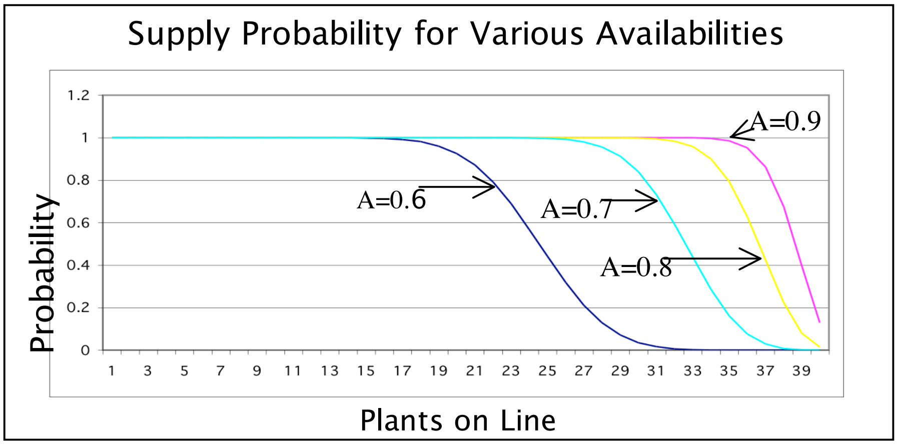


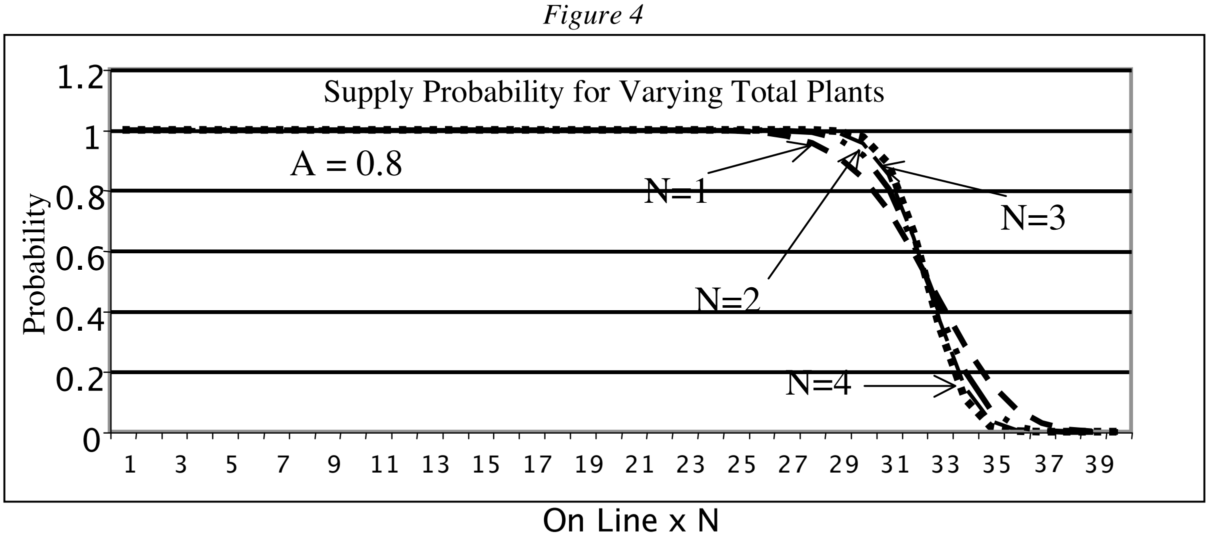

*Figure 3*

To illustrate the impact of availability on the probability that a given number of fusion plants will be on line, we have examined a simple power distribution system with forty identical plants. Here we show the probability for four assumed availabilities. *(see Figure 3).*

For a given probability of plants being on-line, higher availability results in a greater power level from a fixed number of plants. Conversely, to meet a given demand level at lower availability requires more plants. Higher availability plants have more value to the utility.

To illustrate the impact of the number of identical plants on this same probability at fixed availability we show in figure 4 the probability for N x forty plants for four values of N. These same curves illustrate the probability of plants being on-line as a function of plant size relative to the total capacity of the distribution system, i.e. plant size relatives to total capacity is proportional to 1/N. The value of plants for varying size as defined above is shown in figure 5, where the value of a plant is defined as the number of plants, operating at perfect availability, required to meet peak demand divided by the number of plants, operating at the prescribed availability, required to meet peak demand with the required probability. The probability requirement for this case was 0.95.

*Figure 4*



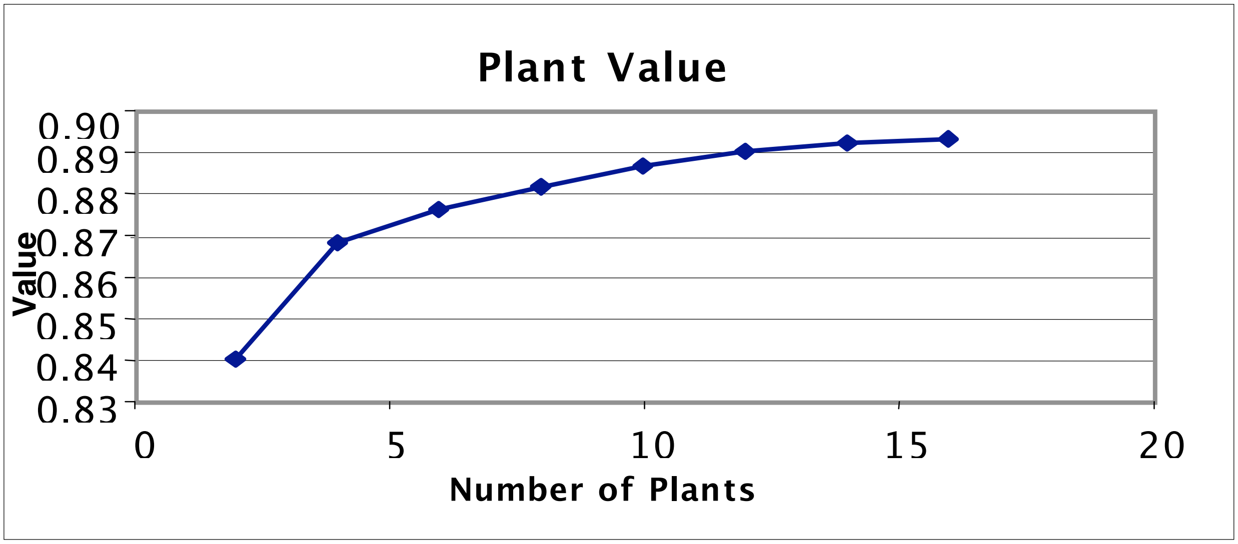



*Figure 5*

It is of interest to contrast the value of fusion plants with the value of a renewable such as wind. The value of a wind power source will be a function of the fraction of power being produced by the wind source (on average) relative to the overall size of the distribution system. Again we examine an isolated system made up of a number fusion power plants combined with a wind power source. The value of the wind power (as defined above), as a function of the fraction of the distribution system, is shown in figure 6.

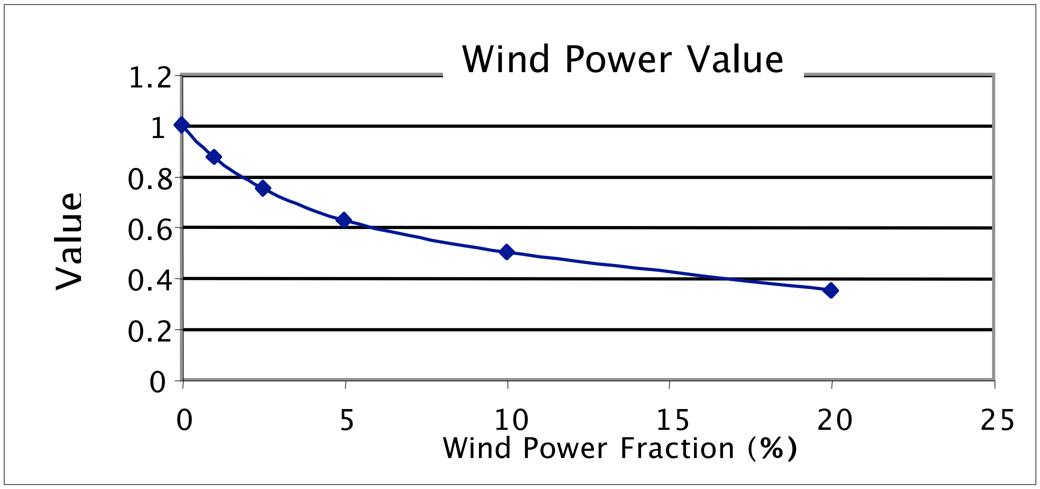



*Figure 6*

It is interesting to note that when wind is a small fraction of the system, its statistical variation is not important and its value is the same as a high availability plant. However, a significant economic penalty ensues as the wind fraction increases. This suggests a hybrid solution with modest fractions of wind power, where it is economically competitive, combined with environmentally attractive fusion reactors.

## 5. Impact on Carbon Dioxide of Fusion Deployment

Since the deployment of fusion is not imminent, the issue arises of whether it can have a useful impact on reducing the levels of carbon dioxide in the atmosphere. To address this issue, we have implemented a code for modeling carbon dioxide in the atmosphere. The mathematical basis for the code is the integration of a Kernel times the prescribed emissions to determine the concentration in the atmosphere [1]. The Kernel is generated from a best fit to the results from complex atmospheric models. The Kernel is basically the response to a delta function emission. This approach can be a simple but powerful tool by using a best fit to averages between models produced as part of the Intergovernmental Panel on Climate Control (IPCC) effort [2].

The atmospheric carbon dioxide modeling code discussed above has been used to assess the possible impact of fusion power deployment on atmospheric carbon dioxide. The fusion deployment scenario discussed in section 2 was used assuming the fusion power replaced an equal amount of fossil fuel power production. The result is shown in figure 7**.** Since fusion power is deployed only near the end of this century, and since carbon dioxide reservoirs in the environment produce a time lag between emissions and atmospheric response, significant impact of fusion on atmospheric carbon dioxide is delayed until the early part of the next century. However, fusion could be a major contributor to total stabilization of carbon dioxide in the atmosphere.

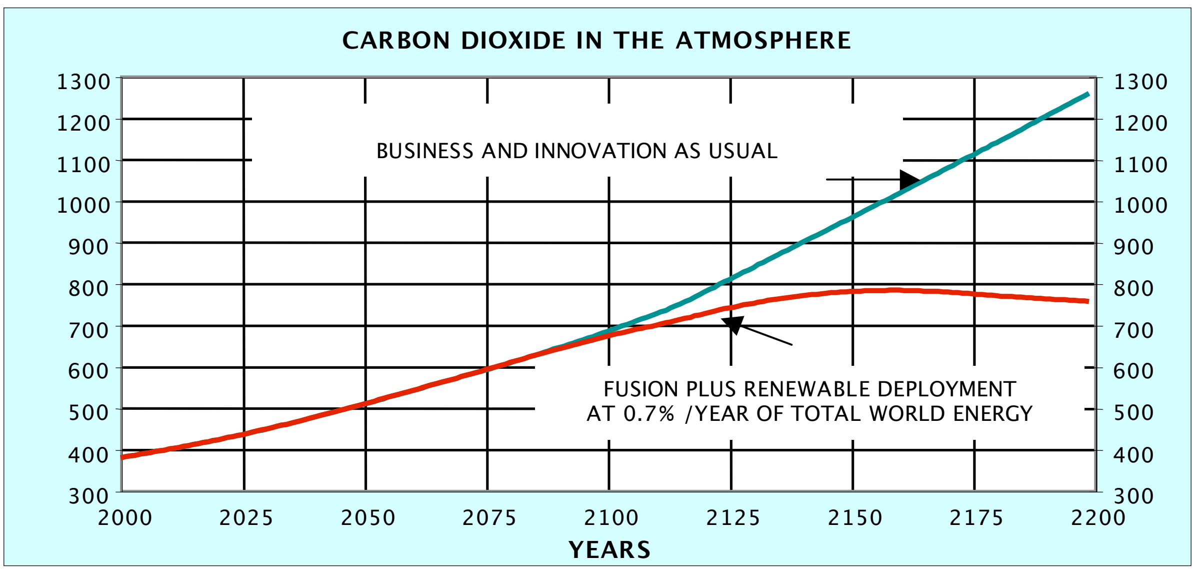



*Figure 7*

## 6. Special Issues for Fusion

The deployment scenarios for fusion discussed in this paper envision a significant ramp-up of the power produced by fusion reactors during the latter half of this century. Along with the beneficial aspects of this deployment, there are several issues that will need attention. The two most important issues are the resources necessary to produce these plants, and the activated waste produced during operation and decommissioning. The resources necessary for constructing the reactors has been assessed based on the materials envisioned for the ARIES reactors. The conclusion is that increased world production will probably be needed for specialized elements such as vanadium. However, the required production should be well within a feasible range, and should not be limited by total reserves. The goal of fusion development is to deploy power reactors, which generate only low level, activated waste. If this goal is realized, the waste produced in the U.S. by deploying fusion reactors, as shown in figure 1, would require, by the end of this century, the burial of a volume of low level waste comparable to the present available licensed U.S. capacity. On this basis, we conclude that the activated waste produced by deploying fusion reactors should be a manageable problem.

## 7. Conclusions

The future deployment of fusion power plants would have many attractive features. Included in these are flexibility in siting the power plants, predictability of power production, and reduction of carbon dioxide emissions. It is recognized that a significant development effort will be required before a prototype reactor can be constructed. In addition, the deployment of fusion power plants will require material resources and the disposal of activated waste. Both of these issues should be manageable. If this deployment can be realized, it would have a significant impact on carbon dioxide in the atmosphere early in the next century.

## Acknowledgements

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