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Essential Criteria for Fusion Power Plants

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Fusion energy holds enormous promise as a future energy source because of a number of intrinsic benefits:

i. Economic attractiveness: fusion fuel sources are abundant and fusion reactions are powerful which implies that fusion power production will become economically attractive in the long term with inclusion of externalities;
ii. Intrinsic safety: fusion plants are intrinsically safe because there is no potential for a runaway reaction. The closed T fuel cycle implies no radioactive materials need to be transported, and the presence of fertile material, such as U-238 or Th-232, exposed to 14 MeV neutrons would be easily detected, leading to low risk of proliferation;
iii. Low environmental impact: only low-level radioactive waste and almost all materials are recyclable [1].

The essential criteria required for a fusion power plant to realize the promise of fusion energy are presented in Table 1. These criteria must be satisfied by fusion power plants in order to be acceptable to utilities, industries, and the public. Numerous power plant studies conducted since the early 1970s (such as the UWMAK [2], STARFIRE [3], and ARIES [4] series) focused on the attractive characteristics of 10th-of-a-kind power plants for a mature commercial market based on accepted and/or desired advanced physics and technologies. More recent studies [4-7] have been based on close interaction between fusion researchers, electric utilities and industries that have interest in constructing and operating future fusion facilities. The criteria of Table 1 provide key insights on the strategic directions that the U.S. fusion program should pursue in order to continue developing attractive and economically competitive power plants that provide substantial electric power with minimal environmental impact.

Because most of the studies being referenced [2–7] were conducted more than twenty years ago, it is important to consider new developments in the electricity-generation market over the past few decades. For instance, the electricity market is moving beyond the debate between base-load versus intermittent, and will need new, properly sized, economical load followers [8]. Because this market is a moving target and will likely continue to be so over the next several decades, it is worth periodically revisiting the criteria for an attractive fusion power plant based on evolving market requirements. Furthermore, there are fundamental differences between the U.S. and global markets that will likely persist for the next several decades; these differences should also be recognized.

Table 1. Essential Criteria for Attractive Fusion Power Plants

- Economically competitive compared to other sources of electric energy
- Stable electric power production with load-following capacity
- Steady state operation with high system availability and well-controlled transients
- Tritium self-sufficiency with closed fuel cycle
- Reduced-activation, radiation-resistant structural and functional materials to extend safe service lifetime and reduce cost and radwaste stream
- Reliability, availability, maintainability, and inspectability for all components
- Easy to license by regulatory agencies
- Intrinsic safety, minimal environmental impact, and wide public acceptance
    - No need for evacuation plan even during severe accident
    - No local or global environmental impacts
    - Minimal occupational exposure to radiation/toxicity
    - Routine emissions and tritium leakage below allowable levels
    - Inclusion of proliferation safeguards by design
- Integral radwaste management and decommissioning plan
    - Minimize radioactive waste by design, recycling, and clearance (release of allowed materials)
    - No high-level waste; only Class C low-level waste or better.

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