The Path to Market for Compact Modular Fusion Power Cores[1]

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To take any new energy technology to market, we have to first consider what the market will demand around the time that the technology matures; and then: which organizations will be in the mix to develop the technology. Typically new energy technologies are incubated in government science programs, then advanced towards the market place by the private sector when there is a clear sense of near-term returns (<10 years). The path to market is discussed in the following sections: Market, Path, and Compact Fusion Systems.

US Electricity Market

> *"Electricity demand (including retail sales and direct use) growth has slowed in each decade since the 1950s, from a 9.8-percent annual rate of growth from 1949 to 1959 to only 0.7 percent per year in the first decade of the 21st century."* EIA Annual Outlook June 2012

Due to the slowing of the growth in demand for new electricity generation, and general all-round slowing of economic growth in the US, there is interest in lower-power (100-400MW) distributed power generation. These units can be added to existing facilities when and where needed, or phased in over a period of time, thereby reducing capital risk to the power company. Replacement of existing fleet is also considered desire-able.

Path to Market

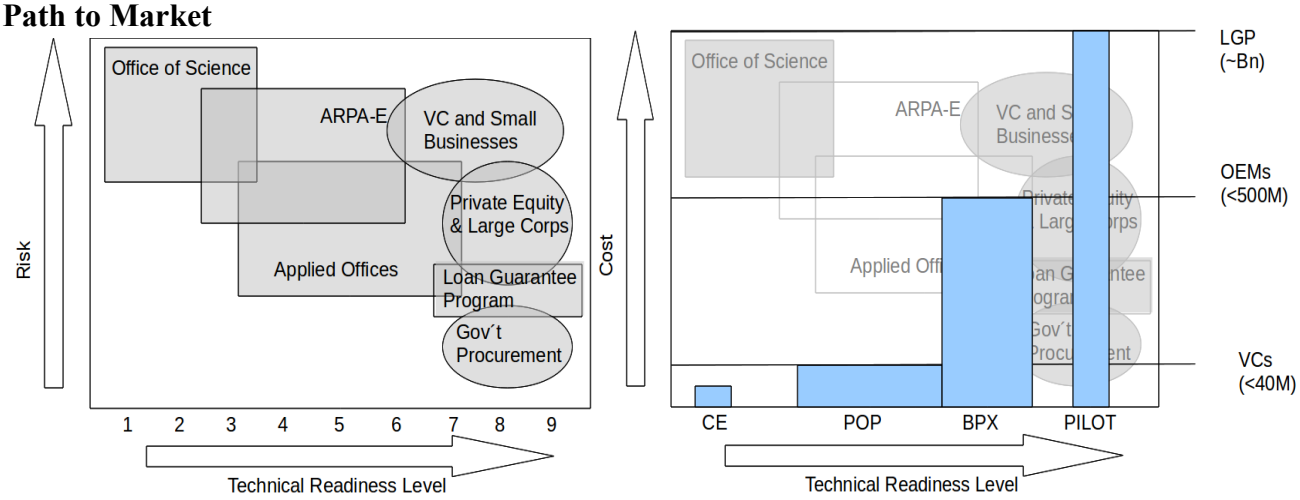

Figure 1. a) Roles of various organizations in the development of a new energy technology, shown in a plot of technical risk against Technical Readiness Levels. b) path to market for fusion systems that are constrained by 'typical' investment ceilings from Venture Capital, OEM and Government Loan Guarantee program, showing organizations, and cost vs technical readiness levels, where e.g. Proof of Principle translates to a TRL of 3-5.

Dr Arun Majumdar (ex Director of ARPA-E) mapped out all of the organizations needed for the development of any new energy technology[2]: Fig 1a) shows the risk vs Technical Readiness Level

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1This discussion was circulated widely in 2011, presented at the Fusion Power Associates meeting in Dec 2011 and published as S. Woodruff, J. K. Baerny, N. Mattor, D. L. Stoulil, R. Miller, T. Marston. Woodruff *Path to market for compact modular fusion power cores* Journal of Fusion Energy *01/2011*

2 A. Majumdar, Committee on Science and Technology, House of Representatives (2010)

(TRL) of a technology, or how close it is to market, with TRL 1 at the basic research level and TRL 9 being first commercial deployment. The path to market therefore embraces Office of Science (at TRL of 1-2), ARPA-E and Applied Offices (at TRLs 3-5), Small Business, Venture Capital, OEMs and other institutions (through to TRLs of 9). All fusion energy development occurs currently through the Office of Science. However, the Office of Science is mandated to invest in value science and perform research at a fundamental level, not to develop technology. Fusion technology must transition somehow to the private sector. Fig. 1b) shows the path to market for a fusion concept charted through the various organizations, with monetary caps on the development stage costs, by VC, OEM and loan programs. Cost constraints applied to any normal technology development will exclude any of our current GW-scale systems from development in the private sector. To succeed, the first step on the path to market is at the VC level: we have to think of a Proof of Principle that costs less than $100M, that leads to a Pilot Plant stage for under $1Bn.

Compact modular fusion systems

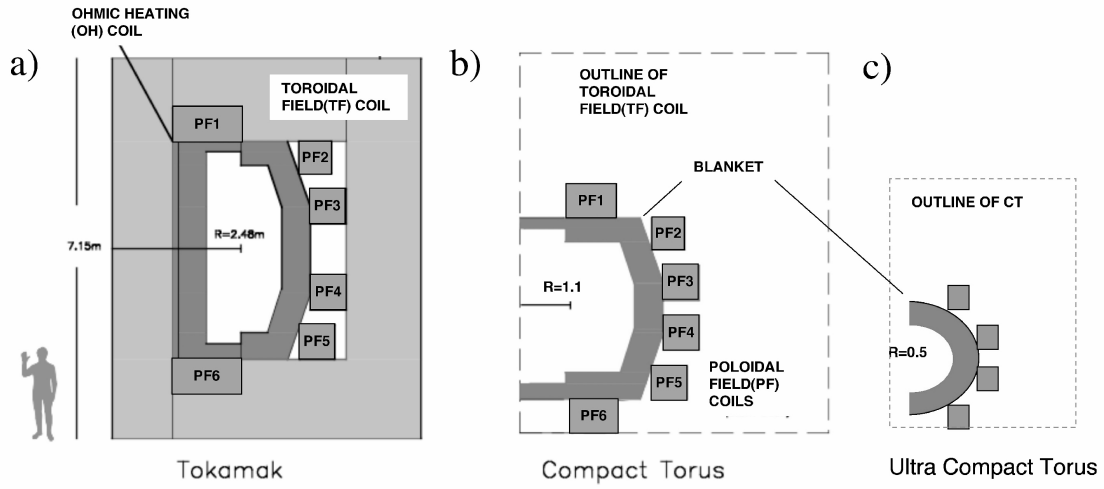

Figure 2. It is not sufficient only to reduce complexity in GW scale reactor systems: in order to move towards the market, it is necessary to reduce the size of the system to fit in with usual development cost constraints placed by industry. Shown are a traditional tokamak, Compact Torus and an even smaller system.

Given the market demand for distributed power systems in the range of 100-400MW, with great modularity, we are compelled to think about smaller reactor cores that could be highly modular and give deep cost savings due to ability to mass-produce and ship reactor cores fully assembled. Compact fusion has it's own set of issues – they require strong magnetic fields for example, which are actually enabled by recent advances in high temperature superconductors.

We suggest a timely (ASAP) introduction of a fusion power source meeting the (EPRI) goals[3] of public acceptance, safety and environmental advantages, and competitive economics coupled with an emphasis on those fusion systems most likely to take advantage of simple-engineering, modularity, factory fabrication, and reduced construction lead time as a path to lower COE.

3 Criteria for Practical Fusion Power Systems: Report from the EPRI Fusion Panel Journal of Fusion Energy, Volume 13, Nos. 2/3, 1994