CHANGING WHAT'S POSSIBLE

ALPHA Program Overview

B. PROGRAM OVERVIEW

1. INTRODUCTION

This program seeks to develop and demonstrate low-cost tools to aid in the development of fusion power, with a focus on approaches to produce thermonuclear plasmas in the final density range of 10^{18}-10^{23} ions/cm^3. The program goal is to create a toolset that will allow a significant reduction in facilities costs for fusion development and to enable rapid learning through a high shot rate at a low cost-per-shot.

2. BACKGROUND

Fusion has been pursued for decades because it is perhaps the ideal power source, with abundant fuel, effectively zero emissions, manageable waste, and minimal proliferation risk.[1] Significant resources have been devoted to fusion research in the US and internationally. To date, the largest fusion research efforts have focused on magnetic confinement of plasmas at densities of approximately 10^{14} ions/cm^3 and on inertial confinement of plasmas at densities exceeding 10^{25} ions/cm^3. Advances in scientific understanding and engineering of high energy density plasmas resulting from these research campaigns have been remarkable, but the ultimate goal of self-sustaining, controlled, thermonuclear fusion remains elusive. This reflects the extraordinary technical challenges of high energy plasma physics, which are compounded by the high cost of fusion research. In this FOA, ARPA-E pursues focused investments to develop tools for fusion approaches in the intermediate density regime, between 10^{18}-10^{23} ions/cm^3. This intermediate density regime has been highlighted in recent analyses as a potential low-cost route to fusion power, and because it sits between the operating densities of pure magnetic confinement and inertial confinement, developments in this regime will complement mainline fusion programs.

3. MOTIVATION

A key motivation for this program is to address some of the practical challenges that have slowed progress in fusion research. In addition to the unique scientific challenges of producing a thermonuclear plasma, there are two major, interrelated, practical challenges that make progress in fusion research especially difficult: (1) fusion research facilities have significant capital costs and (2) the shot rate, or number of experiments per day, at existing fusion research facilities is limited by high operating costs and low equipment repetition rate. As a result, there is a transformational opportunity for low cost development and rapid learning enabled by investment in new tools for fusion research. *First*, recent analyses suggest low-cost pathways to fusion in the intermediate density regime[2-3] and recent experimental work, though preliminary, lends support to this analysis.[4] *Second*, improving the shot rate and reducing the cost of shots should directly improve the learning rate and speed progress along new fusion learning curves. To create low-cost tools with improved shot rate, ARPA-E seeks to leverage recent innovations in several areas: pulsed power;[5] MEMS particle acceleration;[6]

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[1] (a) *An Assessment of the Prospects for Inertial Fusion Energy,* The National Research Council, The National Academies Press: Washington, DC (2013); (b) *Program on Technology Innovation: Assessment of Fusion Energy Options for Commercial Electricity Production,* Electric Power Research Institute: Palo Alto, CA (2012); (c) Jones, S. and F. von Hippel. The Question Of Pure Fusion Explosions Under the CTB, *Science & Global Security* (1998), *7*, 129-150; (d) Glaser, A and R. Goldston. Proliferation risks of magnetic fusion energy: clandestine production, covert production and breakout, *Nuclear Fusion* (2012), *52*, 043004

[2] Lindemuth, I. and R. Siemon. The fundamental parameter space of controlled thermonuclear fusion, *Am. J. Phys*. (2009), *77*, 407-416

[3] (a) Thio, Y. C. F. Status of the U.S. program in magneto-inertial fusion, IFSA2007, *Journal of Phys.: Conf. Series 112* (2008), 042084; (b) Rosner, R. (chair) and D. Hammer (co-chair). "Basic Research Needs for High Energy Density Laboratory Physics," Report of the Workshop on High Energy Density Laboratory Physics Research Needs, November 15-18, 2009, U.S. Department of Energy (Chapter 2); (c) "Advancing the Science of High Energy Density Laboratory Plasmas," Report of the FESAC Panel on High Energy Density Laboratory Plasmas, U.S. Department of Energy, January 2009, (Sections 7.1.6, 9.1.4)

[4] (a) Hohenberger, M. et al. Inertial confinement fusion implosions with imposed magnetic field compression using the OMEGA Laser, *Phys. of Plasmas* (2012), *19*, 056306; (b) Herrmann, M. Update on Magnetized Liner Inertial Fusion, *Fusion Energy: Visions of the Future, 32nd Annual Meeting and Symposium*: Washington, DC. December 10, 2013. http://fire.pppl.gov/fpa_annual_meet.html (accessed May 22, 2014)

[5] (a) Saddow, S.E. and A. Agarwal, eds. Pulsed Power Applications. In *Advances in Silicon Carbide Processing and Applications*, Artech House/ Massachusetts (2004), 93-95; (b) Anderson, D.E. Recent Developments in Pulsed High Power Systems. *Proceedings of LINAC*: Knoxville, TN (2006), 541-545; (c) Hegeler, F. et al. A Durable Gigawatt Class Solid State Pulsed Power System, *IEEE Trans. on Dielectrics and Electrical Insulation* (2011), *18*, 1205

plasma formation, plasma acceleration, and liner technologies;[7] and other areas. By funding the development of low-cost tools capable of high shot rates, ARPA-E seeks to open the field of fusion research to a broader range of approaches by a variety of institutions, both public and private, thereby facilitating more rapid progress along new learning curves towards economical fusion power.

The Department of Energy and others have made previous investments into intermediate density fusion experiments, including work over the past decade on magneto-inertial fusion (MIF, or alternatively magnetized target fusion, MTF). While many MIF/MTF approaches fall in the density range of interest for this program, this program's technical goals and anticipated research tool development differ from previous efforts. Principally, this program focuses on technologies that can achieve a high shot rate at low cost, with the goal of enabling rapid experimentation and learning in intermediate density regimes both within the program and in future research. This focus distinguishes the current program from previous work exploring intermediate density plasmas, much of which has focused on solid liner implosions. The use of high energy pulsed power or chemical explosives to drive implosions of solid liners has yielded valuable insights and identified significant technical challenges.[8] While such systems are perhaps the only currently available tools that can provide the performance required in target-implosion approaches in these regimes, the destructive nature of these drivers makes it difficult to conduct a large number of experiments in a short amount of time. Plasma liner approaches have been explored as a possible solution, but plasma liner compression has not yet been demonstrated and significant technical challenges remain.[9] The ALPHA program posits that a large number of experiments can greatly accelerate learning in the intermediate density regime, and the focus on low-cost, high shot rate technologies is intended to lay the groundwork for that rapid experimentation and development. The goal of this program is to address the significant technical challenges in developing low-cost, high shot rate tools capable of accessing the intermediate density regime and demonstrating that these tools provide a path to Lawson conditions and beyond after the program.

ARPA-E acknowledges that the path to commercial fusion power will be exceptionally difficult, and that the risk of failure is substantial. However, the potential for reliable, low-cost power generation with abundant fuel resources and zero emissions is unparalleled. The ARPA-E mission is to seek opportunities for transformational energy technologies, and developing tools for fusion power is an appropriate, if high risk, piece of the agency's portfolio. It is also important to note that the technologies pursued in this program will draw on expertise from a broad range of communities, and the tools developed will likely find a number of high value applications outside of fusion, e.g. medical treatment, materials processing and characterization, and space propulsion. While these spinoff technologies are not the main motivation for the program, the potential value to areas outside of fusion energy research will be helpful in finding first markets, reducing costs, and ultimately pushing the newly developed tools towards economical fusion power.

C. PROGRAM OBJECTIVES

The purpose of this funding opportunity is to create new tools for the low-cost development of fusion energy. By program completion, performers will be expected to demonstrate prototype tools that help enable a path to economical fusion power through low-cost, high shot rate development. This program focuses on the intermediate ion density regime (10^{18}-10^{23} ions/cm^3), which may open up new pathways to economical fusion power[2]. Working in the intermediate ion density regime also avoids duplication of effort with mainline fusion research programs. Participants will not be expected to build a complete fusion reactor. Rather, performers are expected to demonstrate prototype tools to form, heat, and/or confine

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[6] Shi, Y. and A. Lal. Integrated all-electric high energy ion beam guidance on chip: Towards miniature particle accelerator, *24th IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2011)*: Cancun, Mexico. January 23-27, 2011

[7] (a) Hsu, S.C. et al. Spherically Imploding Plasma Liners as a Standoff Driver for Magnetoinertial Fusion, *IEEE Trans. on Plasma Sci. (2012), 40, 1287; (b) Slough, J.; Votroubek, G.; Pihl, C. Creation of a high temperature plasma through merging and compression of supersonic field reversed configuration plasmoids, Nuclear Fusion (2011), 51,* 053008

[8] (a) Degnan, J. et al. Recent magneto-inertial fusion experiments on the field reversed configuration heating experiment, *Nucl. Fusion*, (2013), *53*, 093003; (b) Cuneo, M. et al. Magnetically Driven Implosions for Inertial Confinement Fusion at Sandia National Laboratories, *IEEE Trans. On Plasma Sci*., (2012), *40*, 3222-3245; (c) Richardson, D. MTF Progress Update and Compression Heating of Spheromaks, *Fusion Energy: Visions of the Future, 32nd Annual Meeting and Symposium*: Washington, DC. December 11, 2013. http://fire.pppl.gov/FPA13_Richardson_Gen_Fusion.pdf (accessed August 7, 2014); (d) Garanin, S. et al. The MAGO System: Current Status, IEEE Trans. On Plasma Sci., (2006), 34, 2273-2278; (e) Sefkow, A. et al. Design of magnetized liner inertial fusion experiments using the Z facility, *Phys. Of Plasmas*, (2014), *21*, 072711; (f) Laberge, M. Sustained Spheromak at General Fusion, *Workshop on Exploratory Topics in Plasma and Fusion Research (EPR) and US-Japan Compact Torus (CT) Workshop:* Madison, WI August 5-8, 2014.
http://www.iccworkshops.org/epr2014/proceedings.php (accessed August 7, 2014)

[9] (a) Kim, H. et al. On the structure of plasma liners for plasma jet induced magnetoinertial fusion, *Phys. Of Plasmas,* (2013), *20*, 022704-1-10 ; (b) Merritt, E.C. et al., Experimental characterization of the stagnation layer between two obliquely merging supersonic plasma jets, *Phys. Rev. Lett.*, (2013), *111*, 085003-1-5.

plasmas at performance levels that establish the viability for low-cost fusion approaches in the intermediate density regime. These tools will also achieve the high shot rates required to enable continued rapid development towards economical fusion power. Tools that can leverage existing equipment to enhance technological progress within the project timeframe are of interest.

D. TECHNICAL CATEGORIES OF INTEREST

This program will develop tools in two broadly defined categories, “targets” and “drivers,” that may in certain cases overlap. While these terms are commonly used in the context of inertial confinement fusion, their use in this FOA is not intended to limit applications to target-implosion approaches. Instead, the two categories are intended to ground discussion to a common set of challenges across diverse fusion approaches.

Within the context of this FOA, “target” is defined as the plasma that is heated to reach Lawson conditions, and “driver” is defined as the device that provides the necessary energy to the target to achieve Lawson conditions. Applicants may submit ideas that address one or both Categories:

Category 1: Drivers

Systems to deliver energy to plasma targets with sufficient power density, symmetry, and mitigation of instabilities to achieve Lawson conditions at a final density of 10^{18}-10^{23} ions/cm^3.

Category 2: Targets

Plasma formation technologies to produce plasmas with sufficient lifetime, transport properties, and geometry to pair with a driver and achieve Lawson conditions at a final density of 10^{18}-10^{23} ions/cm^3.

As noted above, there may be areas of overlap where a single system can both form a plasma target and drive it to fusion conditions. These systems are within the scope of this FOA. Applicants submitting “combined” approaches where target formation and driver technologies overlap are required to clearly define their system requirements according to the terms outlined in Section E.

Applicants for a single Category must state assumptions on performance levels and constraints on the rest of the system. That is, a Category 1 (Drivers) application must define the parameters for the plasma target (at a minimum: density, temperature, lifetime, size, magnetic field, and transport properties) for which the driver will be designed. A Category 2 (Targets) application must define the performance of the driver (at a minimum: the power, intensity, precision, timing jitter, and symmetry) that will take the proposed plasma target to Lawson conditions. All applications (i.e. for Category 1, Category 2, or both) must describe conceptually how the intended target and driver technologies will work together in future development. Applicants are strongly encouraged to support the performance estimates for complementary drivers or targets with references or preliminary modeling.

ARPA-E will consider innovative partial solutions/proof of concept for plasma formation technologies or low-cost drivers that are not yet fully integrated into a conceptual fusion approach. For partial solutions, Applicants will not be required to fully quantify the performance levels and constraints on all components of the conceptual fusion system. However, applications for partial solutions will be limited to proof of concept funding.

E. TECHNICAL PERFORMANCE TARGETS

This section describes goals, metrics and performance requirements for the ALPHA program. Applicants will be required to address these items in detail in the full application, and the information is provided here for Applicants’ consideration as they prepare Concept Papers. However, space is limited for Concept Papers and Applicants, therefore, should prioritize the content requirements outlined in Section IV.C.

This program will develop tools to enable low-cost development and rapid learning toward fusion reactors with final densities between 10^{18}-10^{23} ions/cm^3. It is beyond the scope of this program to build a complete fusion reactor, but Applicants should include a conceptual plan of the envisioned fusion reactor that their tool(s) will enable.

Partial solution/proof-of-concept applications are required only to provide quantitative analysis on the specific Category (Targets or Drivers) for which they are applying. However, partial solution/proof-of-concept Applicants are strongly encouraged to provide complete system analysis as outlined below in order to provide a more complete accounting of the impact for their component technology.

Overall Goals:

Each Applicant must present a final set of metrics for drivers and/or targets that can meet the set of parameters described below for a fusion reactor. Please note that these metrics do not need to be met within the Period of Performance of the ARPA-E award, but Applicants should present an aggressive and logical development path to achieve these performance goals in a fusion reactor based on the team's technology.

Table 1 outlines the long-term objectives for the envisioned fusion reactors. Each proposal must include quantitative analysis, with supporting calculations and references, to demonstrate that the envisioned reactor with the proposed new tool(s) developed in this program will meet the metrics described below.

Parameter	**Requirement**	**Motivation**
Ion density at Lawson conditions (ions/cm^3)	10^{18}-10^{23}	ARPA-E seeks to catalyze research in the intermediate density regime to open up a new potential pathway for economical fusion power.
$\eta_d G_d$ (product of driver efficiency and gain)	> 5	Modest recirculating power is needed for a practical power plant. The product $\eta_d G_d$ represents the ratio of fusion energy out to wall-plug electricity input to the drivers.*
Driver cost (amortized over full lifetime of driver)	< $0.05/MJ (MJ measured as delivered by driver over its full life)	A low-cost driver is required for economical fusion power. Cost per MJ delivered by the driver must include capital expenses (amortized over full lifetime of driver) and operating expenses (cost of electricity and driver maintenance).
Target cost	< 0.05 ¢/MJ (MJ measured as energy content of fuel. Note that this corresponds to 0.2 ¢/kWh.)	Low cost targets are required for economical fusion power. Target cost must include capital expenses for hardware (amortized over its full life) and operating expenses.
Repetition rate	≥ 1 Hz	Moderate to high rep rate allows lower energy per pulse and enables more compact power reactors

* The ηG requirement is intended to enable a practical recirculating electrical power ratio after conversion of thermal energy to electricity. If a proposed concept can achieve higher efficiency conversion (for example, through direct conversion of charged products), or if energy recovery can reduce the required recirculating power, lower ηG systems may still be considered provided that no more than half of the generated electricity from a reactor must be recirculated. Teams proposing a relaxed ηG requirement must demonstrate quantitatively, with references where appropriate, that the proposed energy conversion or recovery systems are based on proven technologies.

All applications, except those for partial solution/proof of concept efforts, should present a conceptual development plan to move from the prototype tools in the ARPA-E program to demonstration of a power reactor (beyond the ARPA-E program). As outlined in Section IV.D.1 of the FOA, the information that applicants should provide in Section 4.1 (Technology to Market) of the Technical Volume of the Full Application should include a brief discussion of the costs, timeframe, and approximate number of shots required for each of the following steps:

- Scale-up from prototype tools developed under the ARPA-E award to reactor-scale components;
- Integrated experimental reactor with plasma formation, driver, and confinement vessel;
- Demonstration of scientific breakeven;
- Demonstration of engineering gain required for competitive power reactor; and
- Prototype power reactor.

Maintenance and materials compatibility issues (e.g., first wall materials, replacement schedule for other components exposed to neutron flux, etc.) should also be addressed in this discussion. All assumptions about the required components must be supported with references, including tools/components that will be developed under the ALPHA program and those that are expected to be available to integrate with the new tools. Applications should quantitatively describe low-cost, fast development pathways to breakeven and beyond. Please note that this program is not intended to fund a power reactor or to address maintenance and materials issues, but Applicants are expected to give thoughtful consideration to these issues at the time of their application.

A successful project under the ALPHA program will establish the viability of the proposed approach to meet the long-term goals in Table 1, and provide a quantitative basis for scalability for the development path towards fusion power beyond the ALPHA program, as discussed above. Applicants should include detailed justifications for how each task in the proposed ALPHA effort is critical to establishing the viability of the concept, including a breakdown of the schedule and budget on a by-task and by-institution basis. Tasks that are not central to proving the physics of the proposed concept (such as scale-up of an existing machine design beyond what is needed to validate scaling laws and benchmark simulations; design of new diagnostics not required to meet the measurement objectives in Table 3; or engineering of rep-ratable components) should not be included in the proposed tasks.

Category 1: Drivers

Table 2 outlines the minimum performance requirements for driver technologies in this program:

Parameter	Requirement	Motivation
η_d (efficiency from wall-plug to useful energy delivered)	>20%	High efficiency drivers allow greater flexibility in fusion gain and an easier path to economical power.
Number of successful* shots in program	>100 shots	Practical shot rate and low cost per shot are required for rapid learning and development
Total number of shots in program (including development, testing, and demonstration)	>500 shots	Practical shot rate and low cost per shot are required for rapid learning and development
Power or intensity	Defined by Applicant	See discussion below
Precision, timing jitter, and symmetry	Defined by Applicant	See discussion below

*A 'successful' shot is one that meets or exceeds the performance requirements to demonstrate and validate physics of tools for scale up and integration beyond the ARPA-E program. See Section I.G for further details on driver performance requirements.

Driver requirements in power, intensity, precision, timing jitter, symmetry, and other relevant parameters will be dictated by the conceptual design of the reactor, and Applicants must define the performance requirements of the driver to achieve fusion conditions in the envisioned reactor. Proposals must address:

1. State-of-the-art performance for the proposed driver technology.
2. Performance level required to achieve Lawson conditions.
3. Performance level that will be demonstrated in prototype tool (i.e. a hardware demonstration, not just a simulation) under the ARPA-E program, and a quantitative discussion of how this performance level is sufficient to establish the pathway to (2) upon scale-up.
4. Envisioned plasma target for proposed driver technology, including quantification of the size, density, magnetic field, temperature, and lifetime of the target plasma, and note whether the stated properties of the target are measured, modeled, or calculated (e.g., assuming Bohm transport), using references where possible.
5. What other components (separate from the proposed ARPA-E driver development) are required for an integrated reactor and continued development towards a power reactor. Specifically:
    a. Identify other components that are known, demonstrated technologies.
    b. Identify other components that are likely to require significant development.

Category 2: Targets

Table 3 outlines the minimum performance requirements for plasma target formation technologies developed in this program:

Parameter	Requirement	Motivation
Number of successful* target preparation shots in program	>50 shots	Practical shot rate and low cost per shot are required for rapid learning and development. Note: ARPA-E will consider lower shot numbers for approaches requiring access to external or user facilities, provided the proposed effort provides exceptionally high impact in validating the physics and defining the path forward for a low-cost pathway

		approach.
Total number of shots (including development, testing, and demonstration)	>500 shots	Practical shot rate and low cost per shot required for rapid learning and development Note: ARPA-E will consider lower shot numbers for approaches requiring access to external or user facilities, provided the proposed effort provides exceptionally high impact in validating the physics and defining the path forward for a low-cost pathway approach.
Plasma lifetime	$\mathrm{Max}(\tau_{\mathrm{Lawson}}, \tau_{\mathrm{driver}}) < \mathrm{Min}(\tau_{\mathrm{thermal\ losses}}, \tau_{\mathrm{lifetime}})$	All loss mechanisms must be considered and quantified to establish a viable path to Lawson conditions within the timescale of the driver action.
Plasma parameters	n, T, τ, r, B defined by Applicant and measured within ±20% for each shot	A diagnostic suite capable of greater precision is preferred where existing diagnostics can provide better measurements.
Modeling	Plasma codes defined by Applicant	See discussion below

*A successful shot is one that meets all the required plasma parameters (within diagnostic error) to demonstrate and validate physics of tools for scale up and integration beyond the ARPA-E program.

Required plasma parameters will be dictated by the conceptual design of the reactor, and Applicants seeking funding for development of target formation technologies must define the required plasma attributes to achieve fusion conditions in the envisioned reactor. Proposals must address:

1. State of the art performance for the proposed target formation technology, including a discussion of the modeling approach to guide and validate experimental measurements of the target plasma.
2. Performance level required to achieve Lawson conditions.
3. Performance level that will be demonstrated in prototype tool under this program and a quantitative discussion of how this performance level is sufficient to establish the pathway to (2) upon scale-up.
4. Envisioned driver for proposed plasma target technology, including quantification of the power, intensity, precision, timing jitter, and symmetry of the driver (using references where possible)
5. What other components (separate from the proposed target formation technology development) are required for an integrated reactor and continued development towards a power reactor. Specifically:
    a. Identify other components that are known, demonstrated technologies.
    b. Identify other components that are likely to require significant development.

Applicants are strongly encouraged to include preliminary plasma simulations to demonstrate the viability of the proposed approach in their proposals. Consideration will be given to the impact of the proposed research to validate the theoretical and computational models to guide future development, including scaling laws for scale-up and integrated demonstration beyond the ARPA-E program. In the course of this program, teams will be required to verify their simulation results. Any limitations of code should be clearly noted in the proposal, and an experimental or modeling strategy to overcome these challenges, perhaps through collaboration, should be presented.

F. APPLICATIONS SPECIFICALLY NOT OF INTEREST

The following types of applications will be deemed nonresponsive and will not be reviewed or considered (see Section III.C.2 of the FOA):

- Applications that fall outside the technical parameters specified in Section I.E of the FOA
- Applications that were already submitted to pending ARPA-E FOAs.
- Applications that are not scientifically distinct from applications submitted to pending ARPA-E FOAs.

- Applications for basic research aimed at discovery and fundamental knowledge generation.
- Applications for large-scale demonstration projects of existing technologies.
- Applications for proposed technologies that represent incremental improvements to existing technologies.
- Applications for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Applications that do not address at least one of ARPA-E's Mission Areas (see Section I.A of the FOA).
- Applications for proposed technologies that are not transformational, as described in Section I.A of the FOA and as illustrated in Figure 1 in Section I.A of the FOA.
- Applications for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress (see Figure 1 in Section I.A of the FOA).
- Applications that are not scientifically distinct from existing funded activities supported elsewhere, including within the Department of Energy.
- Applications that propose the following:
  - Approaches based on low-energy nuclear reactions (e.g., cold fusion)
  - Technologies that cannot be used or scaled to access the intermediate density regime of 10^{18}-10^{23} ions/cm^3 at Lawson conditions.
  - Incremental improvements to existing fusion devices.
  - Fusion-fission hybrids.
  - Devices without a plausible pathway to electricity production.
  - Approaches requiring chemical explosives for drivers.
  - Efforts that do not include target and/or driver development and a hardware demonstration, such as: purely conceptual power-plant designs; efforts devoted to materials solutions or balance of plant issues for an existing reactor design; or purely theoretical work.

G. TECHNICAL SYMBOLS AND GLOSSARY

n	Density, principally ion density n_i [#/cm^3]
T	Temperature, principally ion temperature T_i [K]
τ_{Lawson}	Lawson time [s]
$\tau_{lifetime}$	Lifetime of plasma target to maintain its structure [s]
$\tau_{thermal\ losses}$	Timescale for thermal (or particle) losses in plasma [s]
τ_{driver}	Timescale for driver to input energy into target to achieve Lawson conditions [s]
χ	Thermal diffusivity of plasma target [m^2/s]
r	Radius of plasma target [m]
B	Magnetic field [Tesla]
β	Ratio of plasma pressure to magnetic pressure [unitless]
η_d	Driver efficiency (wall-plug to useful energy delivered by driver) [unitless]
G	Fusion gain, typically driver gain G_d (ratio of fusion energy to energy from driver) [unitless]

Driver: The device that delivers energy to the target in order to achieve fusion conditions. The power and intensity provided by a driver must be sufficiently high to overcome thermal losses in the plasma target. Fig. 2.a and 2.b are derived from data presented at the ARPA-E workshop and Lindemuth and Siemon[2, 10] to show minimum driver intensity to reach Lawson conditions (at 10 keV) for plasma targets with 20% thermal losses.

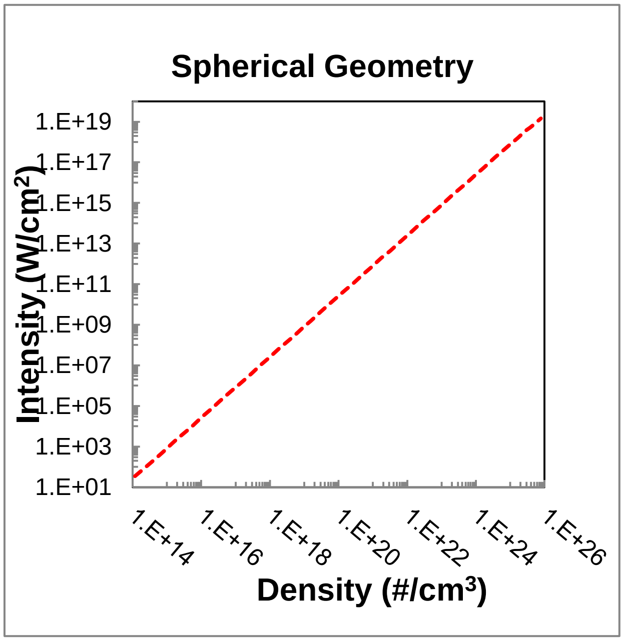

Fig. 2.a – Minimum driver intensity (W/cm^2) for (10 keV) D-T targets in spherical geometry[10]

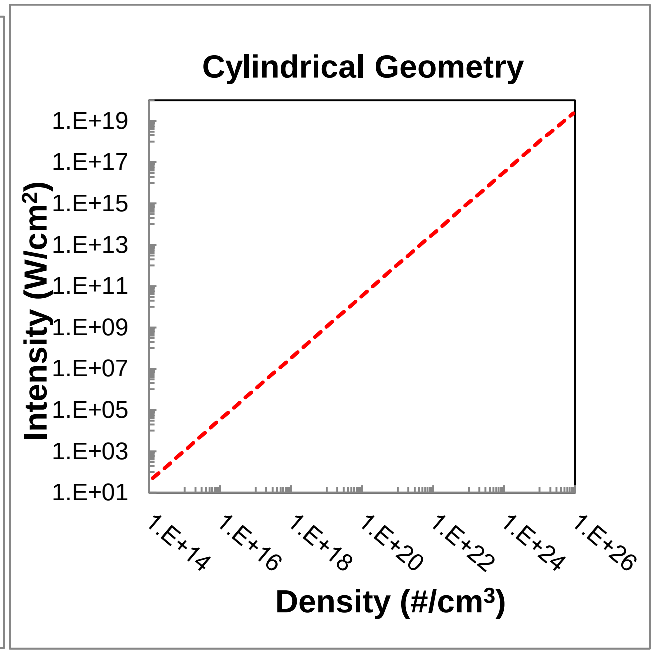

Fig. 2.b – Minimum driver intensity (W/cm^2) for (10 keV) D-T targets in cylindrical geometry[10]

Driver efficiency (η_d): The efficiency of the driver should be measured as the ratio of the driver's useful energy output (e.g. kinetic energy of liner used to compress plasma) to the initial wall-plug electricity input.

Driver gain (G_d): The gain should be measured as the ratio of fusion power output to the initial energy supplied by the driver. Driver gain therefore must account for losses in coupling energy from the driver into the plasma. The product of driver efficiency and driver gain therefore represents the ratio of fusion power output to the initial wall-plug electricity input.

Liner: An imploding solid, liquid, or plasma shell used to compress and heat a plasma target.

Target: The fuel to be heated to fusion conditions. Plasma targets must maintain stability with sufficient lifetime to meet the Lawson condition for a given ion density and temperature. The target must also maintain sufficiently low thermal losses to reach fusion temperatures in the τ_{driver} timeframe.

[10] ARPA-E Drivers for Economical Fusion Technologies Workshop. http://arpa-e.energy.gov/arpa-e-events/drivers-economical-fusion-technologies-workshop (accessed May 13, 2014)