# U.S. Department of Energy
# Advanced Research Projects Agency – Energy (ARPA-E)

# Request for Information (RFI)
# DE-FOA-0002499
# on
# Nonconventional Fusion Approaches and Energy Applications

**Introduction**

This RFI solicits input for a potential future ARPA-E research program on nonconventional fusion approaches and energy applications, defined further below. This is a new "hybrid" RFI format where you may choose to (1) provide a written response, as with past ARPA-E RFI's, **and/or** (2) participate in a related online **"incubator" and "ask me anything" (AMA) session hosted on a platform developed by Polyplexus, LLC**. Guidance for (1) is provided at the end of this document. For (2), please follow this weblink: https://polyplexus.com/incubator?idIncubator=577&initialTab=overview. The incubator and AMA, **which are scheduled from March 17 to April 7, 2021 and March 26 (1–3 PM EDT), respectively,** are like an online chat forum that allows for dynamic, evidence-based discussions moderated by an ARPA-E Program Director, providing an opportunity for interested parties to actively influence the discussion and interact with the Program Director. The incubator discussions and AMA will be visible to any registered Polyplexus user; registration is free and available to anyone according to the terms available at the site linked above. Your participation in the incubator and AMA are not required in order to provide feedback on this potential future program, but strongly encouraged.

Recent studies[1] show that including a firm, low-carbon primary energy source in the overall energy mix will dramatically lower electricity system costs in deep-decarbonization scenarios. Fusion energy is one of a very few potential firm, low-carbon energy sources that can scale to global proportions, and is therefore an important technology option to develop, both to help meet mid/late-century decarbonization targets and to provide a long-term sustainable energy solution for humanity. Worldwide fusion research and development (R&D) focuses on thermonuclear approaches[2] using deuterium-tritium (D-T) fuel because (1) thermonuclear approaches appear to have the most likely path to demonstrating net energy gain, and (2) D-T has the highest thermal fusion reactivity at the lowest required temperatures of all known fusion reactions. Significant progress has been and continues to be made toward demonstrating energy breakeven via thermonuclear D-T fusion, with recent community and expert panel reports[3] all recommending that the U.S. should immediately increase investments in resolving the remaining scientific and technical issues in order to realize a "fusion pilot plant" (FPP) by or before 2040. Indeed, ARPA-E's ALPHA, BETHE, and GAMOW fusion programs[4] all had or have an emphasis on enabling timely, commercially viable thermonuclear D-T fusion energy.

[1] See, e.g., N. A. Sepulveda et al., Joule **2**, 2403 (2018); https://doi.org/10.1016/j.joule.2018.08.006.
[2] Thermonuclear fusion refers to the fuel ions having a nearly Maxwell-Boltzmann velocity distribution function characterized by a very high temperature, e.g., tens of millions of degrees K or higher.
[3] A Community Plan for Fusion Energy and Discovery Plasma Sciences (2020), https://sites.google.com/pppl.gov/dpp-cpp; Powering the Future: Fusion & Plasmas, report of the DOE Fusion Energy Sciences Advisory Committee (2020), https://usfusionandplasmas.org; *Bringing Fusion to the U.S. Grid* (National Academies Press, Washington, D.C., 2021), https://doi.org/10.17226/25991.
[4] See "Energy Brief" webinar on ARPA-E's fusion portfolio: https://www.youtube.com/watch?v=dU7pNwZW7ws.

While thermonuclear D-T fusion is the most scientifically mature approach for realizing an FPP by 2040, it also faces daunting engineering challenges beyond the remaining physics challenges of achieving and sustaining high energy gain. Two particular challenges that may increase cost, complicate regulations, and hinder public acceptance of thermonuclear D-T fusion are (i) lack of naturally abundant tritium, necessitating tritium breeding and relatively large onsite tritium inventory, and (ii) approximately 80% of the fusion energy released as 14.1-MeV neutrons that damage and activate materials in the surrounding structure, requiring new low-activation materials and producing low-level waste (LLW) requiring short-term radiological disposition. These challenges, though being actively addressed with potentially viable solutions, motivate the continued pursuit of nonconventional fusion approaches that may sidestep or mitigate these challenges and potentially better fulfill the holistic socio-techno-economic requirements[5] of a commercially attractive energy system. **Seeking broad input on nonconventional fusion approaches, i.e., other than thermonuclear D-T, is the first objective of this RFI**.

Pursuit of fusion energy is typically motivated by grid-scale electricity as the eventual application. However, grid-scale electricity is highly competitive with extremely low costs in certain markets (e.g., see Handley et al. in footnote 5), which is a headwind for fusion development. **Thus, a second objective of this RFI is to seek input on potential energy-related applications, other than grid-scale electricity, for fusion or its enabling technologies.** Although we are open to hearing about niche, high-value applications, any potential ARPA-E program arising from this RFI should support technologies that could scale to “quad-level” energy impacts and/or “gigaton-level” carbon-emissions reductions, domestically or worldwide. Examples include but are not limited to applications of large fusion-generated energetic neutron or charged-particle fluxes, low- or high-grade process heat below approximately 1000 K, or new markets that might be enabled by a dense energy source sited in the middle of population centers or if micro-reactor-class (e.g., kW to 50 MW) fusion systems can be successfully developed.

**Targeted Questions**

As discussed above, we seek input on (A) nonconventional fusion approaches[6] that may overcome or strongly mitigate the two challenges of thermonuclear D-T fusion laid out above, and (B) energy applications other than grid-scale electricity for which fusion or its enabling technologies may be well or uniquely suited. Please provide responses and information about any of the following. ARPA-E does not expect any one respondent to answer all, or even many, of these prompts. Simply indicate the question letter/number in your response (e.g., A2, B1, etc.). Citations to refereed publications are strongly encouraged. When possible, please identify relevant metrics and be as quantitative as possible.

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[5] See, e.g., J. Kaslow et al., J. Fusion Energy **13**, 181 (1994), https://doi.org/10.1007/BF02213958; D. Maisonnier, Fus. Eng. Des. **136B**, 1202 (2018), https://doi.org/10.1016/j.fusengdes.2018.04.102; S. Hoedl, ``A social license for nuclear technologies,'' in *Nuclear Non-Proliferation in International Law – Volume IV* (Asser Press, The Hague, 2019), p. 19, https://arxiv.org/abs/2009.09844; and M. C. Handley et al., ``Potential Early Markets for Fusion Energy,” submitted for publication (2021), https://arxiv.org/abs/2101.09150.

[6] All known alternative fusion approaches to thermonuclear D-T fusion that have been considered over 50+ years have significantly more difficult scientific challenges (e.g., of reaching and sustaining the required fuel physical conditions), inadequate scientific basis (e.g., cold fusion or low-energy nuclear reactions, LENR), or other challenges precluding net energy gain (e.g., beam-dominated fusion, muon-catalyzed fusion, etc.). In short, nonconventional fusion is an “ARPA-E-hard” problem that motivates an ARPA-style R&D approach.

## A. Technical Approaches

1. Non-thermonuclear fusion approaches capable of scaling to net energy gain[7] and/or very high neutron production rates (see metric in Table 1), including both low and high-temperature approaches;[8]
2. Fusion approaches with a substantially reduced fraction of energy released as energetic neutrons (relative to 80% for thermonuclear D-T fusion), including but not limited to fusing "advanced fuels"[9] such as D-D, D-$^{3}$He, or p-$^{11}$B (see also footnote 8);
3. New or emerging component materials/technologies that can better enable A1 and/or A2.

Table 1. Non-exhaustive list of technical metrics. RFI responses are encouraged to provide such a table.

| **Possible metrics** | **Possible R&D need** | **Aspiration** |
|---|---|---|
| Fusion cross section $\sigma_{fus}$ and reactivity $\langle\sigma v\rangle$ | Methods for enhancement by many orders of magnitude | Required enhancement factor[10] depends on center-of-mass energy |
| Fuel density × energy confinement time ($n\tau$) and temperature ($T$) | Methods for reducing minimum required thresholds[11] by an order of magnitude or more | Physics and/or engineering approaches to reduce or mitigate fuel thermal and radiative losses, and/or employ non-thermal fusion while still permitting net energy gain |
| Tritium site inventory | Develop non-D-T fusion approaches | Enable total recirculating tritium inventory < 20 mg/MW$_{fus}$ (100× below aggressive D-T system) |
| Class and volume of radioactive waste produced | Reducing/eliminating energetic neutron flux, revolutionary low-activation materials | Generation of only Class A radiological waste[12] or below |
| Energetic neutron production rate per $ (neutrons/s/$) | Advances in low-cost fusion concepts and/or accelerator-driven fusion systems | >1E10 n/s/$ (where $ is capital cost of device, including required sustainable tritium supply if device is D-T based) |
| Enter your metric… | | |

RFI responses for A1–A3 will have higher impact if they clearly address/articulate the following:

- Based on sound physics and precisely identifies knowledge gaps;
- Plausibility of net energy gain (e.g., show overall power flow diagram with assumptions); see footnote 7.
- Highest-priority R&D needs and aspirational outcomes consistent with an ARPA-E-sized project (e.g., ≤ few $M over 2–3 years);
- Possible energy-related market(s) that may be impacted, their market size(s), quantitative impacts on potential energy-usage and/or carbon-emissions reductions, and economically

[7] "Net energy gain" is defined here as the fusion energy or power (for pulsed or steady-state approaches, respectively) exceeding the total energy or power invested to initiate and sustain the fusion reactions.
[8] Many possibilities and research questions are presented in this talk by T. R. Rider, ``Is There a Better Route to Fusion?", http://secureservercdn.net/198.71.233.129/f5o.aea.myftpupload.com/wp-content/uploads/2019/11/INFERNO6.pdf, especially slides 24–25.
[9] See, e.g., J. Santarius et al., J. Fusion Energy **17**, 33 (1998), https://doi.org/10.1023/A:1022565231919, and ARPA-E webinar "Fusion Energy with Advanced Fuels," https://www.youtube.com/watch?v=hDwu9Wj766o.
[10] Enhancement is relative to conventional fusion reactivities based on, e.g., H.-S. Bosch and G. M. Hale, Nucl. Fusion **33**, 1919 (1993), https://doi.org/10.1088/0029-5515/33/12/513; W. M. Nevins and R. Swain, Nucl. Fusion **40**, 865 (2000), https://doi.org/10.1088/0029-5515/40/4/310; and/or S. V. Putvinski et al., Nucl. Fusion **59**, 076018 (2019), https://doi.org/10.1088/1741-4326/ab1a60.
[11] Compared to, e.g., Fig. 4 of W. M. Nevins, J. Fusion Energy **17**, 25 (1998), https://doi.org/10.1023/A:1022513215080; see also https://en.wikipedia.org/wiki/Lawson_criterion.
[12] https://www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0055.html.

competitive cost target(s);
- Quantitative technical metrics that are informed by the preceding bullet.

**B. Energy-related markets other than grid-scale electricity for fusion or its enabling technologies**

1. Identify the potential market and present state-of-the-art (SotA) technology (if any);
2. Estimate the present and/or projected market size (domestic and/or global), including impact on total market energy usage and/or carbon-emissions reductions;
3. Identify the relevant techno-economic cost metric(s) to exceed present SotA technologies, and estimate the required cost entry point for new technologies.

**Please carefully review the REQUEST FOR INFORMATION GUIDELINES** below for written responses. Please note, in particular, that the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME.**

**Purpose and Need for Information**

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future research programs. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI without any attribution to the source. This RFI provides the broad research community with an opportunity to contribute views and opinions.

**REQUEST FOR INFORMATION GUIDELINES FOR WRITTEN RESPONSES**

No material submitted for review will be returned, and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents shall not include any information in the response to this RFI that could be considered proprietary or confidential.**.

Participation in the optional incubator and AMA described at the beginning of this RFI will be subject to each participant completing a user agreement available on the Polyplexus website (https://start.polyplexus.com) and following any applicable rules and requirements for those events. While ARPA-E may have access to “MicroPubs” (also known as “µPubs”) on the Polyplexus website, ARPA-E will not review or have access to information or discussions regarding related “proposals” prepared and/or shared by Polyplexus users.

Responses to this RFI should be submitted in PDF format to the email address **ARPA-E-RFI@hq.doe.gov** by **5:00 PM Eastern Time on 4/30/2021**. Emails should conform to the following guidelines:

- Please insert “Response to RFI on Nonconventional Fusion - <your organization name>” in the subject line of your email;
- In the body of your email, include your name, title, organization, type of organization (e.g. university, non-governmental organization, small business, large business, federally funded research and development center (FFRDC), government-owned/government-operated (GOGO), etc.), email address, telephone number, and area of expertise;
- Responses to this RFI are limited to no more than 5 pages in length (12-point font size).