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

Request for Information (RFI)
DE-FOA-0003531
on
Magnetic Materials

Introduction:

The purpose of this RFI is to solicit input for a potential ARPA-E program focused on the development of the next generation of magnetic materials. The goal for this potential program is the evaluation of technologies capable of substantially improving the properties of magnets in energy systems, such as: (1) increasing the magnetic energy density in permanent magnets by a factor of two or (2) increasing the magnetic strength of any magnet to 3 Tesla.

The potential uses for these improved materials for energy applications include wind turbines and traction motors among others.

Areas Not of Interest for Responses to this RFI:

This potential program is focused on increasing the magnetic energy density in permanent magnets. Approaches not of interest include:

- Processing changes to already commercialized magnet materials;
- Incremental changes to already commercialized magnet materials; and
- Electromagnets.

RFI Guidelines:

CAREFULLY REVIEW ALL RFI GUIDELINES BELOW.

Note 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 RFI DOES NOT CONSTITUTE A FUNDING OPPORTUNITY. NO FUNDING OPPORTUNITY EXISTS AT THIS TIME.**

The purpose of this RFI is solely to solicit input for ARPA-E's 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.

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**.

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 January 7th, 2025.** Emails should conform to the following guidelines:

- Insert "<your organization name> - Response to RFI on Magnetic Materials" in the email subject line.
- 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]), email address, telephone number, and area(s) of expertise.
- Responses to this RFI are limited to no more than 10 pages in length (12-point font size).
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential materials, designs, or processes.

Technical Background:

High-performance permanent magnets are indispensable for everyday life applications, including hybrid and electric vehicles, and electric generators such as wind power. Offshore wind power alone is expected to reach 1 terawatt (TW) (30 quads per year) globally by 2050. Permanent magnet generators are an indispensable technology and use about 1 tonne of permanent magnets per megawatt (MW) of power produced. Electric motors consume 40% of all electricity produced today (over 1 TW or 35 quads/yr). By 2050 the majority of the world's transportation (5 TW or 150 quads/yr) is expected to be driven by electric motors. Permanent magnet motors are about 5% more efficient, are lighter weight, and are less costly than motors without permanent magnets. Strong magnets are also an enabling technology for new applications requiring high power density, such as electric flight.

The performance of a powerful magnet is determined primarily by its saturation magnetization (M_s) and its maximum energy density (BH_{max}). The driving force in a motor (torque) is proportional to M_s but must also have a similar coercive field (H_c) to withstand the induced magnetic field. Hard magnets have a large M_s and large H_c to produce a large BH_{max}. In many applications, soft magnets with large M_s but low BH_{max} can be used in conjunction with a hard magnet. The H_c, and therefore BH_{max}, is limited by M_s and the magnetocrystalline anisotropy, characterized by the magnetocrystalline anisotropy energy (MAE). The microstructure (i.e., grain alignment, grain size, and grain boundary phases) is typically important to achieve a high BH_{max}. Such ferromagnets need to function well below the Curie temperature (T_C), where the spontaneous magnetization vanishes.

Many commercial ferromagnets (e.g., iron, ferrites) have been known for centuries and have simple crystal structures. Neodymium iron boron ($Nd_2Fe_{14}B$) based magnets, discovered in the 1980s, have a complex anisotropic structure and have become a standard commodity for energy applications. Applications typically require grams to thousands of kilograms of bulk material where the material and processing cost is less than $1,000 per kilogram.

New approaches for materials discovery offer the potential to create more powerful magnets. Such advances may include:

- Machine learning and artificial intelligence;
- First principles calculations;
- Multiscale and integrated material thermodynamics with microstructure modeling;
- Lower temperature bulk material synthesis techniques;
- High-throughput laboratories;
- New microscopy techniques; and
- New understanding of grain boundary phases (complexions) and their effect on material properties.

This RFI and a potential subsequent workshop seek to initiate a broad discussion of possible new approaches to understanding long-standing problems in ferromagnetic materials.

RFI Questions:

Respondents may provide responses and information about any of the following questions. **ARPA-E does not expect any one respondent to answer all, or even many, of the questions in this RFI.** In your response, indicate the question number from the list below. Appropriate citations are highly encouraged. Respondents are also welcome to address other relevant avenues or technologies that are not outlined below, with the exception of those that fall under the "Areas Not of Interest for Responses to this RFI" described above.

1. What are the theoretical limits to M_s and BH_{max}? What metrics are most relevant for understanding new magnetic materials?
2. What potential advances in materials chemistry or materials design could exceed the M_s and BH_{max} of commercial materials such as $Nd_2Fe_{14}B$ materials today?
3. What are the potential approaches and limitations for calculating M_s, T_C, and MAE from the crystal structure, including structures containing elements with f-shell electrons (rare earth elements)?
4. What is the potential for the existence of new, unknown structure types with high M_s, T_C, and MAE? How can one most effectively search for them?
5. What are the promising methods to predict the BH_{max} or H_C of a magnet with a given microstructure, and then optimize the microstructure?
6. What new techniques for materials synthesis and processing can achieve these new structures and microstructures within a reasonable cost?
7. What new applications or hardware designs would most benefit from more powerful, new magnet materials?
8. What has been attempted for new magnet materials discovery? Was the approach successful in finding stronger magnets? If not, why was it not successful?