The Current Status and Future Direction of High-Magnetic-Field Science and Technology in the United States

High magnetic fields are a vital tool in many areas of science and technology that impact our everyday lives. Magnetic resonance imaging (MRI) enables a wide range of medical diagnostics and research, while nuclear magnetic resonance (NMR) is critical for drug discovery research and more. High magnetic fields are an essential component to many proposed fusion energy reactors and are necessary to push the boundaries toward the development of new quantum technologies and semiconductors.

At the request of the National Science Foundation (NSF), the National Academies of Sciences, Engineering, and Medicine organized a study to identify scientific opportunities and key applications for high-magnetic-field science and technology for the next decade and beyond. The report explores the current state and future prospects for high-magnetic-field technologies and recommends actions to support the workforce, facilities, magnet development, and critical materials access necessary to promote U.S. innovation.

THE IMPORTANCE OF HIGH-MAGNETIC-FIELD SCIENCE AND TECHNOLOGY

High magnetic fields are essential for research across chemical, biological, and physical sciences, and 13 Nobel Prizes have been awarded in areas directly related to or supporting the development of magnetic resonance. Almost no chemical or pharmaceutical product is produced today without using NMR, and recent discoveries in high-magnetic-field science are enabling the design of advanced quantum technologies and materials. High magnetic fields make it possible to probe the fundamental nature of matter in the universe within particle accelerators and they corral electrons to create X-ray sources necessary for research across medicine, chemistry, and materials.
Science. These applications, and many key advances across a range of science and engineering fields, would not be possible without high magnetic fields.

**Supporting the Development of New Magnet Technologies, Materials, and Wire**

Experimental high-magnetic-field facilities have played an important role in characterizing high temperature superconductors (HTS), which were first discovered in the 1980s. Today, HTS magnets have been prototyped and are in research use—they allow for much higher fields at much higher temperatures than the previous generation of superconducting magnets. Such magnets, if commercialized, could support the construction of compact fusion reactors for clean energy generation, spark a new generation of MRI instruments, and enable new particle physics experiments. To move these developments from the laboratory to commercialization at scale will require further investment and oversight that shepherds the research of a variety of wire technologies to ensure that all promising technical paths are explored. The report recommends the following:

- NSF and the Department of Energy (DOE) are urged to **double their support for the development of wire technologies within 2–3 years**, including support to re-establish the U.S. HTS wire industry and the establishment of U.S. test facilities appropriate for characterizing HTS conductors and cables at high field and stress.

- NSF, DOE, and the National Institutes of Health (NIH) should **develop collaborative programs to accelerate the development of HTS magnet technology** to support progress in high-field MRI, NMR spectroscopy, fusion, and accelerator magnets.

**Maintaining U.S. Leadership in High-Magnetic-Field Science Through New Facilities and Access**

The United States, Europe, Japan, and China all maintain large high-magnetic-field user facilities on concentrated sites, providing access to the highest fields for a broad user community. These facilities offer significant differences in their capabilities, as well as variations in their modes of operation. In the United States, the National High Magnetic Field Laboratory (NHMFL) hosts thousands of researchers every year at its three sites in Tallahassee, Gainesville, and Los Alamos.

Other countries, namely China, have made very significant investment in high-magnetic-field science over the past decade and now have some of the highest steady magnetic fields available. However, capabilities in the United States have grown little over the same time period, and several of the larger investments recommended in the National Academies’ 2013 report on the state of high-magnetic-field science have not taken place.

Likewise, the availability of high-field NMR facilities has grown vigorously abroad but remains lacking in the United States. **Failure to invest in high-field NMR and provide stable access to the necessary helium resources are having a deleterious effect on U.S. science, causing many NMR laboratories to close and leaving fewer instruments in the United States to support this work.**

The United States needs to re-establish a level of support for state-of-the-art NMR research that will allow laboratories in the United States to regain a position of leadership in NMR-based research areas. **Within the next 2–3 years, the United States should implement the installation of multiple commercially made NMR instruments with magnetic fields in the 1.0–1.2 GHz range covering all applications from physics and materials through pharma and biophysics.** Such instruments should build on existing infrastructure and provide user access in the democratized science model followed by other national facilities.
COMBINING RESOURCES ACROSS FEDERAL AGENCIES TO SUPPORT HIGH-MAGNETIC-FIELD INSTRUMENT ACCESS AND INNOVATION

Decentralized high-magnetic-field science facilities in the United States (such as those housed at universities) are currently disadvantaged because they have to recover costs through user fees. The lack of funding for operation and maintenance of decentralized facilities is a huge drawback for the advancement of high-magnetic-field research in the United States.

NSF, NIH, and DOE together should establish an operation funding system similar to what the worldwide competition has established, where part of the experimental time at the decentralized facilities is managed centrally and in return the facilities are provided with funds for operation, maintenance, and further technology development.

Centralized high-magnetic-field facilities in the United States, such as those at NHMFL, are well funded, operate instruments with no costs for the users, and produce world-leading science. However, NHMFL is facing increasing competition from abroad. NHMFL could be strengthened by adding the instrumentation-development capacity necessary to support all of the newest modern measurement techniques (such as scanning probe microscopy), which are critical for continuing innovation in condensed matter physics, quantum information science, and molecular biology.

U.S. government agencies, including NSF, NIH, DOE, and the Department of Defense should jointly provide proper resources that are designated to support a team of talents nationally and at NHMFL to develop state-of-the-art instruments and methods for high-magnetic-field science and technology.
WORKFORCE DEVELOPMENT
A highly trained multidisciplinary technical workforce is needed to make progress in magnet design, measurements in magnetic fields of all types, and instrumentation development. Supporting the next generation of high-magnetic-field science researchers will require a coordinated training program, coupled with improved access to facilities and efforts to improve diversity and inclusion so as to enlarge the talent pool.

A high-field magnet science and technology training program should be established in the United States. The school could be modeled after the U.S. Particle Accelerator School, which provides specialized graduate-level training programs in that field. Oversight and support should be drawn from a consortium of government agencies, laboratories, and universities, and possibly, industry.

ENSURING STABLE HELIUM ACCESS AND PRICING
High-magnetic-field instrumentation and experiments are reliant on helium, which serves as a critical refrigerant for all current superconducting magnets as well as for experiments that need to operate at ultracold temperatures. Helium supply uncertainty and price fluctuations have harmed the science, technology, and industrial communities that need superconducting magnets.

To secure helium access for research, as a short-term solution, the U.S. government should immediately establish a royalty “in-kind” program for helium, whereby vendors extracting helium from federal lands would be required to refine and sell the helium to federally funded researchers.

CONSTRUCTING NEW WORLD-LEADING MAGNETS
The United States has had leadership in high-magnetic-field science in the past through groundbreaking work at the frontiers of the field, but that progress has slowed in the past decade. However, given the existing U.S. expertise in magnets and materials, particularly at NHMFL, it may be possible to re-establish leadership. The report recommends the creation of new, ground-breaking magnets to support a wide range of work in the field. Figure 2 illustrates the types and strengths of the new magnets recommended in the report along with their possible applications.

![Figure 2](image-url)

**FIGURE 2** Current magnetic field ranges available internationally are shown for different application areas (blue bars). The report recommends building new magnets to fruitfully extend these ranges in the United States, with black circles showing the proposed improvements. The black triangle for NMR Commercial Instruments implies not just a modest recommended increase in maximum strength (from 24 T to 28 T) but also the need and potential value in producing commercially available magnets in larger quantities. For Pulsed Field, this figure indicates the need for additional capabilities at the current 40 T level.
FOR MORE INFORMATION

This Consensus Study Report Highlights was prepared by the National Materials and Manufacturing Board based on the Consensus Study Report 'The Current Status and Future Direction of High-Magnetic-Field Science and Technology in the United States' (2024).

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