NATIONAL HIGH MAGNETIC FIELD LABORATORY (NHMFL) $40,490,000

+$14,360,000 / 55.0%

National High Magnetic Field Laboratory Funding
(Dollars in Millions)

FY 2021 Actual[1]	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
$26.13	-	$40.49	$14.36	55.0%

[1] Excludes $12.0 million obligated in FY 2020 for FY 2021 operations.

Brief Description

NHMFL is the world's premier high-magnetic-field laboratory, featuring an extensive collection of unique magnet systems and comprehensive support services. The laboratory is an internationally recognized leader in magnet design, development, and construction, including the development of new high-field superconducting magnets. NHMFL offers its users consistent and reliable high magnetic fields, such as the 45-tesla continuous-field magnet, the non-destructive pulsed-field magnet (100 tesla), the 36-tesla magnet for Nuclear Magnetic Resonance, the highest-field superconducting magnet for Fourier Transform-Ion Cyclotron Resonance (FT-ICR) mass spectrometry (21 tesla), and the highest field for magnetic resonance imaging (MRI) studies of living animals (21.1 tesla). These unique facilities are available to thousands of users each year and help define and advance the science frontiers in many disciplines through measurements with state-of-the-art resolution and accuracy. NHMFL is operated by a consortium of three institutions, each of which house NHMFL facilities: Florida State University (FSU), University of Florida (UF), and Los Alamos National Laboratory (LANL).

Scientific Purpose

NHMFL provides the highest magnetic fields and necessary services for scientific research conducted by users from a wide range of disciplines, including physics, chemistry, biology, biochemistry, neuroscience, energy, and environmental sciences. Research conducted by users of NHMFL investigates topics that include quantum phenomena in graphene and other two-dimensional materials, superconductors, and topological materials; electron and nuclear spins of solid, molecular, and biological materials; the structure and dynamics of the macromolecular components of life; and properties and functionalities of various materials essential in energy production, storage, and use.

Major scientific impact is expected from the research on quantum materials conducted by researchers using the NHMFL magnets. These magnets allow for the exhibition, identification, and visualization of new and unusual quantum effects that lead to deeper understanding of quantum materials and enable the discovery of new ones. Over the last several years, NHMFL has contributed to major scientific accomplishments in superconductivity and the frontier field of topological materials, an entirely new class of quantum materials prominently distinguished by the 2016 Nobel Prize in Physics. For example, in 2019 NHMFL's high magnetic fields allowed scientists to discover one of the most important phenomena in the field of superconductivity in the past three decades, a phenomenon called re-entrant superconductivity.[1] This phenomenon had never been seen at high fields, and its

[1] www.nationalmaglab.org/news-events/news/rare-lazarus-superconductivity

occurrence was completely unexpected. Re-entrant superconductivity displays properties that suggest it could be a particularly robust component in quantum computers of the future. Other recent prominent results from NHMFL include the first confirmation of the existence of a three-dimensional topological insulator state, and the first evidence of a long-sought quantum phenomenon known as the chiral anomaly.

Another example of a potential area for advancement by NHFML is new imaging techniques for studying the brain. Magnetic resonance imaging and functional magnetic resonance imaging are currently based on imaging proton spin density and intrinsic tissue relaxation rates. With higher magnetic field strengths, NHMFL is investigating use of other nuclei that would result in new insights into mapping the brain and neuroscience. NHMFL's MRI at high magnetic fields (21.1 tesla) has enabled *in vivo* imaging of brain function and cancer research in rats.

NHMFL's 36 tesla hybrid magnet reached a performance milestone of ultrahigh stability and homogeneity across the sampling volume. This stability has enabled the world's first nuclear magnetic resonance spectrum at 1.5 GHz, which opened new probing capabilities for chemists and biologists.

Status of the Facility

<u>Status with respect to Scientific Community</u>

- A 2013 report by the National Academies of Science, Engineering, and Medicine, *High Magnetic Field Science and Its Application in the United States: Current Status and Future Directions*,[2] found that very high magnetic fields are necessary for many crucial research experiments in condensed matter physics, chemistry, and biology. The success of these experiments may have major impacts on health care and other technologies. High magnetic fields in very large volumes are also required for accelerators in high-energy physics, and in plasma research aimed at the realization of controlled nuclear fusion. Based on these needs, this report provided several recommendations with respect to specific scientific priorities for new magnet developments. In direct response to one of these recommendations, NSF has provided funding[3] for the development and design of a 40-tesla all-superconducting magnet, building on recent advances in high-temperature superconducting magnet technology. Additional recommendations from this report, e.g., for a 60-tesla DC hybrid magnet and higher-field pulsed magnets, may inform NSF's and NHMFL's planning for next-generation capabilities.
- The 2013 report, alongside several other community reports, also highlighted the need to combine high magnetic fields with synchrotron facilities. To this end, NHMFL is partnering with the Cornell High Energy Synchrotron Source (CHESS) on the construction of a new High Magnetic Field Beamline (HMF) that will offer the highest currently available direct-current magnetic fields at any synchrotron facility in the world. The HMF project, led by Cornell University, is being implemented through an NSF Mid-scale Research Infrastructure—Track 2 award, and its future operations (planned to begin in 2025) will be integrated into NSF's Center for High-Energy X-ray Sciences (CHEXS) at CHESS.

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[2] www.nap.edu/catalog/18355/high-magnetic-field-science-and-its-application-in-the-united-states

[3] Funding provided through NHMFL O&M award ($4.20 million in FY 2018) and two separate awards, DMR-1938789 ($4.20 million in FY 2020 for conceptual design) and DMR-2131790 Mid-scale Research Infrastructure-1 ($15.8 million in FY2021 for final design).

COVID-19 Status

Starting in early March 2020, NHMFL imposed access restrictions on its facilities at all three sites (FSU, UF, and LANL) due to health concerns related to the COVID-19 pandemic. These restrictions progressed from travel restrictions to limited access to the NHMFL sites as the COVID-19 pandemic evolved and new mandates were put in place by the Centers for Disease Control and Prevention, as well as state and local authorities. All three NHMFL partner institutions (FSU, UF, and LANL) are responding to changing guidance from both state and national levels by developing plans for ramping-up activities back to normal. All three NHMFL sites are providing on-site access to a limited number of users based mainly on scientific need, and critical need for on-site access. While the on-site user activity is currently below normal, NHMFL's user program remains operational, taking advantage of remote operations for many of the available instruments.

Meeting Intellectual Community Needs

NHMFL is the largest magnet laboratory in the world with the highest-powered magnets and more than 2,000 users annually. The annual number of NHMFL users, which includes senior investigators, postdoctoral researchers, and students, continues to grow with about 20 percent each year being new users. The condensed matter physics, chemistry, and biology user communities have experienced significant growth in recent years.

In September 2017, DMR organized a workshop on Exploring Quantum Phenomena and Quantum Matter in Ultrahigh Magnetic Fields to further identify, assess, and prioritize scientific needs of new large-scale instruments and facilities that include ultrahigh magnetic fields for quantum materials research, and to explore the broader impacts on other areas of materials research, as well as other disciplines. The workshop report[4] affirmed the benefits of both DC- and pulsed-field capabilities for quantum materials research. NSF plans to commission a follow-on report approximately one decade from the 2013 report to provide further recommendations for long-term directions in high magnetic field science and technology.

NHMFL provides a unique interdisciplinary and convergent learning environment. The Center for Integrating Research & Learning at NHMFL conducts education and outreach activities, which include a Research Experiences for Undergraduates program, summer programs for teachers, a summer camp for middle-school girls, and activities to raise the scientific awareness of the general public. Since the onset of the pandemic, much of NHMFL's education and outreach programming has shifted online: several of the summer programs for teachers and students, as well as the annual Open House event that routinely draws thousands of visitors, are now being conducted in a virtual format, and NHMFL is offering live virtual classroom outreach and at-home educational resources.

Governance Structure and Partnerships

NSF Governance Structure

NHMFL is supported and managed by the MPS Division of Materials Research (DMR), with the DMR program officer as the primary contact for most of the laboratory. The Division of Chemistry (CHE) contributes support for the FT-ICR Facility. The Division of Acquisition and Cooperative Support and the Large Facilities Office within BFA provide financial and administrative support and assist with

[4] www.arxiv.org/ftp/arxiv/papers/2103/2103.09155.pdf

agency oversight. The MPS Facilities team, together with the NSF Chief Officer for Research Facilities, also provide high-level guidance, support, and oversight.

External Governance Structure

NHMFL is operated under a cooperative agreement through a consortium of three institutions: FSU, UF, and LANL. FSU, as the primary awardee, is responsible for administrative and financial oversight and for ensuring that lab operations are consistent with the cooperative agreement. The principal investigator, the NHMFL director, reports to the FSU Vice President for Research. Four senior faculty members are co-principal investigators. The NHMFL director receives guidance primarily from the NHMFL executive committee, the NHMFL science council, and the NHMFL diversity committee together with recommendations from an external advisory committee and the users' executive committee.

Partnerships and Other Funding Sources

The State of Florida contributes approximately $12.0 million per year to support NHMFL. While there is no formal partnership at the federal agency level, the Department of Energy (DOE) supports NHMFL through LANL, which contributes approximately $2.0 million per year to the NHMFL. Additional funding, at the level of $4.0 to $6.0 million per year, comes from individual investigator awards, which support activities at NHMFL.

NHMFL collaborates with more than 60 private-sector companies as well as with several national laboratories. These include those supported by DOE, such as Oak Ridge National Laboratory, which hosts the Spallation Neutron Source, and Argonne National Laboratory, which hosts the Advanced Photon Source. Additionally, NHMFL collaborates internationally. The laboratory delivered and commissioned a 26-tesla series-connected hybrid magnet to the Helmholtz-Zentrum Berlin for neutron scattering experiments and is playing a key role in the design and construction of a new 45-tesla hybrid magnet to be located at the High Field Magnet Lab at Radboud University in Nijmegen, the Netherlands; each project was funded by the respective international institution. Collaborations also exist with the International Thermonuclear Experimental Reactor in France, and national magnet laboratories in several countries, including the Netherlands and Germany.

Funding

Total Obligations for NHMFL
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance (DMR)	$24.25	-	$36.18	$36.09	$36.09	$36.09	$36.09	$36.09
Operations & Maintenance (CHE)	1.88	-	2.10	1.73	1.73	1.73	1.73	1.73
Special Projects (DMR+OMA)[2]	-	-	2.21	-	-	-	-	-
Total	**$26.13**	**-**	**$40.49**	**$37.82**	**$37.82**	**$37.82**	**$37.82**	**$37.82**

[1] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in December 2022.

[2] Reflects additional funding for research infrastructure and O&M costs, including additional costs for repairs and maintenance.

The current NSF award for the operation of NHMFL spans CY 2018-2022. Over the five-year award period, DMR's O&M support (initially on the order of $35.0 million per year) is escalated by three percent annually, and CHE provides $1.73 million annually. The actual budget each year varies due to forward funding and supplemental funding actions. The FY 2023 budget request represents estimates for operations under a new award, including $36.18 million from DMR and $2.10 million from CHE. Funding for special projects also includes additional deferred maintenance projects, upgrades necessary for the continued effective operations of the facility, such as replacement of magnet coils and updates to basic power, water, and chiller services. The execution of projects will be prioritized based on the outcome of ongoing facility condition assessments.

Reviews

NSF monitors annual plans and reports, including user metrics, and conducts regular monthly teleconferences with the NHMFL director along with numerous *ad hoc* communications and discussions. NSF conducts annual external site visit reviews to assess the user programs, in-house research, long-term plans to contribute significant research developments both nationally and internationally, and operations, maintenance, and new-facility development. Annual reviews also assess the status of education, training and outreach, operations and management efficiency, and diversity plans. Recommendations from annual reviews are routinely used to inform NHMFL's operations planning and NSF's oversight thereof.

Recent reviews include:

- External Safety Review at all three sites of the NHMFL (July and September 2018).
- Site visit review with external panel of experts, September 2019.
- Virtual site visit review with external panel of experts, October 2020.
- Virtual site visit review with external panel of experts, July 2021.

Renewal/Recompetition/Termination

The current award, in an amount not to exceed $184.05 million, for the operation of NHMFL started on January 1, 2018, and will end on December 31, 2022. MPS developed an analysis of considerations for potential renewal, competition, or divestment of the facility at the end of the current award. Based on that analysis, the NSF Director approved the recommendation to request a renewal proposal for the period 2023-2027. NSF has received the NHMFL renewal proposal, and it is currently under review. Currently there are no plans for divestment of this facility.