# MPS AC Subcommittee on MPS Facilities and Major Research Infrastructure

First Report, March 2022

# 1st Report
## from the
# MPS AC Subcommittee
## on
# MPS Facilities & Major Research Infrastructure
## March 2022


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# I. Introduction

Over the past 75 years, research infrastructure and facilities have had an increasingly crucial role in driving discovery and probing the mysteries of the universe, from nature's smallest to largest scales ("microscopes to telescopes"). The science and technology that will define our future and power our economy will only flourish in the U.S. if we sustain a strong scientific ecosystem that includes leading-edge research instruments.

> *"The science and technology that will define our future, and power our economy, will only flourish in the U.S. if we sustain a strong scientific ecosystem that includes leading-edge research instruments."*

Research infrastructure and facilities are a central part of the stated NSF MPS mission:

*"...to harness the collective efforts of the mathematical and physical sciences communities to address the most compelling scientific questions, educate the future advanced high-tech workforce, and promote discoveries to meet the needs of the Nation."*

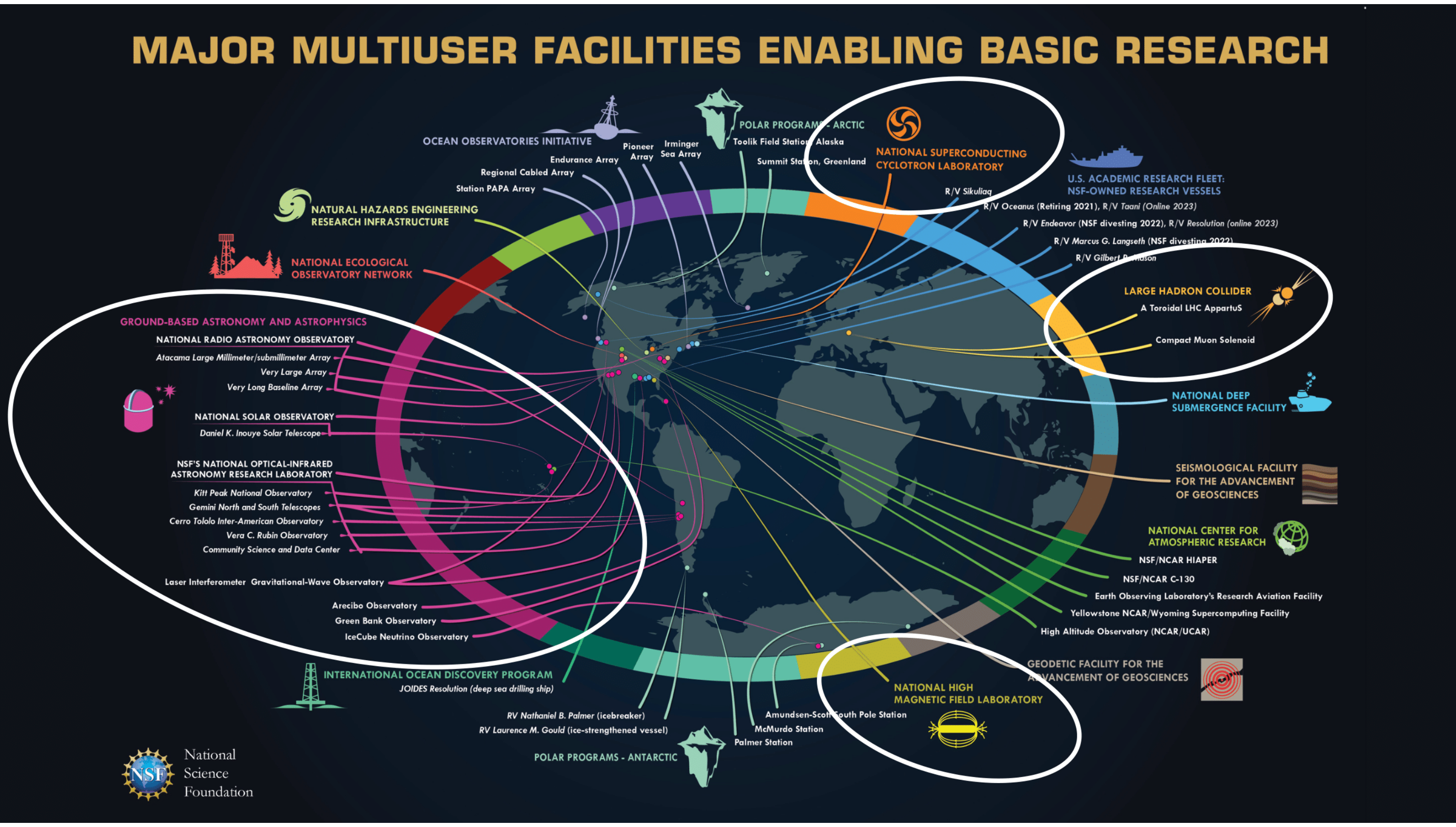
In support of this mission, NSF MPS facilities:

- ***Are essential for advances in science*** that would not have happened, and will not continue to happen, without their unique, world-class capabilities;
- ***Enable broad access*** to instrumentation for the scientific community, that no single investigator or small group could construct, operate, and sustain;
- ***Deliver research that spans scales*** of size (telescopes that probe the universe, light sources that reveal structure of materials, particle colliders that reveal new fundamental particles), time (the lifetime of the universe, attosecond chemical reactions), and complexity (supporting quantum information sciences and revealing complex protein dynamics and structures);
- ***Provide exceptional workforce training*** for a broad set of users at facilities that are open to all, with ease of access and excellent scientific and technical support;
- ***Create and sustain the infrastructure and scientific ecosystem*** necessary to develop novel and critical concepts, such as multi-messenger astronomy and multi-modal probing of materials, and last, but not least,
- ***Promote the public's interest in science.***

# II. Positive Impact of NSF-MPS Facilities

NSF MPS has an exceptional record of building and operating large, unique, and impactful facilities. These facilities made possible critical scientific collaborations that led to four Nobel prizes in the last 30 years and continue to enable remarkable scientific breakthroughs and deliver technologies to society. Breakthroughs such as the spectacular direct detection of gravitational waves (at the Laser Interferometer Gravitational-Wave Observatory, LIGO), the first image of a black hole (made by the Event Horizon Telescope which includes the Atacama Large Millimeter Array, ALMA), and the long-awaited discovery of the Higgs boson (at Large Hadron Collider, LHC), have given us a better understanding of the fundamental nature of the universe. In addition, each of the major NSF MPS facilities is meeting the needs of the nation by catalyzing advances in computing, lasers, microchip design, medical imaging, magnet technologies, advanced materials, and much more. The MPS Facilities are well integrated into and make a positive contribution to the full portfolio of NSF Multiuser Facilities (see Figure 1, below).

Figure 1. Major NSF Multiuser Facilities are Essential to the U.S. Scientific Innovation Ecosystem.
*MPS Facilities are highlighted within the white circles.*




*(Credit: National Science Foundation)*

MPS facilities possess unique features that will be critical to securing U.S. global leadership, and that make it imperative for MPS to create, partner in creating, and ensure access to sophisticated, state of the art instrumentation. Responding to that imperative, this report will highlight critical key examples of research facilities developed by MPS, and the distinct ability of MPS to serve the U.S. academic research community and respond to its scientific priorities.

We enumerate below the essential role of NSF Facilities in the MPS portfolio. Specifically, they:

1. Identify and Address Global Grand Challenges
2. Leverage Infrastructure for Discovery Science and Spur the Development of Innovative Technology
3. Develop Foundational Science and Prepare the Next Generation Workforce
4. Broaden Participation through Exemplary Outreach and Community Engagement
5. Build a Collaborative Global Scientific Community and Secure U.S. Leadership in the Physical Sciences and Engineering
6. Forge Leading-edge Interagency Partnerships
7. Create Exceptional Public-Private Partnerships

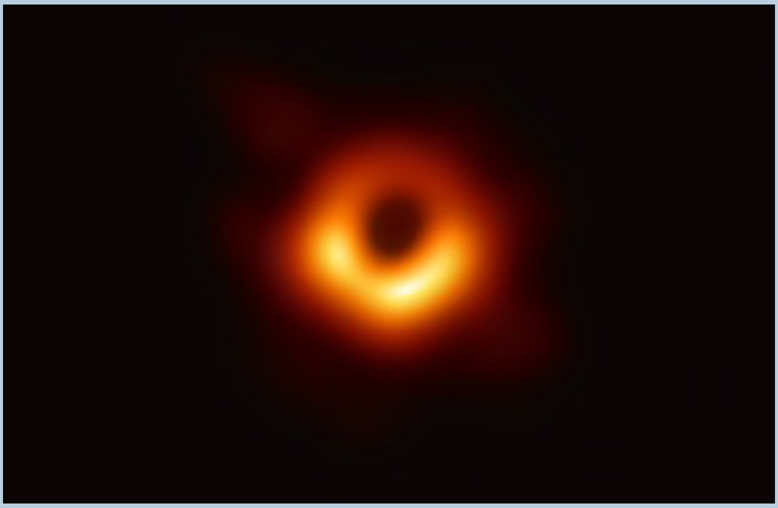
The immense impact of MPS facilities can be seen through the lens of these attributes, along with the realization that each individual facility achieves many, if not all of them. ***We have chosen just one example (from many possible MPS facilities) to illustrate each feature in the sections below.***

## 1. Identify and Address Global Grand Challenges

The NSF's Laser Interferometer Gravitational-Wave Observatory (LIGO) is a remarkable story of NSF's decisions, championed by MPS, to invest in a true long-shot project whose success has made the U.S. the world's leader in gravitational wave science. LIGO enabled the first direct measurements of gravitational waves, a property of space-time that had been predicted by Einstein as a consequence of general relativity theory. This discovery opened a new window on our universe and, along with the NSF-funded IceCube Neutrino Observatory, kick-started the paradigm-shifting concept of multi-messenger astronomy that involves networks of global observational resources to respond to electromagnetic, gravitational-wave, and cosmic ray signals from distant sources and events. LIGO's historic accomplishments include the 2015 measurement of gravitational waves arising from the collision and coalescence of a pair of black holes, and the 2017 detection of gravitational waves from the collision of two neutron stars. The 2017 Nobel Prize in Physics recognized the development and ultimate technical and scientific success of LIGO. Today, several nations and foundations are partnering with the U.S. to upgrade LIGO components in order to improve sensitivity.

## 2. Leverage Infrastructure for Discovery Science and Spur the Development of Innovative Technology

**Inset 1: Leveraging Infrastructure for Discovery: EHT**



*(Credit: Event Horizon Telescope collaboration et al.)*

Using the Event Horizon Telescope (EHT), scientists obtained an image of the black hole at the center of galaxy M87, outlined by emission from hot gas swirling around it under the influence of strong gravity near its event horizon. The EHT links telescopes around the globe, including ALMA observatory, to form an Earth-sized virtual telescope with unprecedented sensitivity and resolution. The members of the EHT Collaboration were awarded the Breakthrough Prize in Fundamental Physics on Sept. 5, 2019.

The Atacama Large Millimeter/submillimeter Array (ALMA) is a major MPS facility partnership that is leveraged by a large base of international astronomical observers to make key scientific discoveries, from the formation of planets in other stellar systems to imaging interstellar gas in the most distant galaxies in the universe. In addition, ALMA has played a key role in the innovative, multiple-facility observations of the Event Horizon Telescope (EHT) that revealed the first image of the shadow of the black hole in galaxy M87 (see Inset 1, on the left). The EHT is an international project, supported as a cross-division initiative within MPS' Physics and Astronomical Sciences Divisions, that has enabled technological advances at each core facility of EHT as well as the necessary computer modeling strategies and teams of scientists to make this discovery possible.

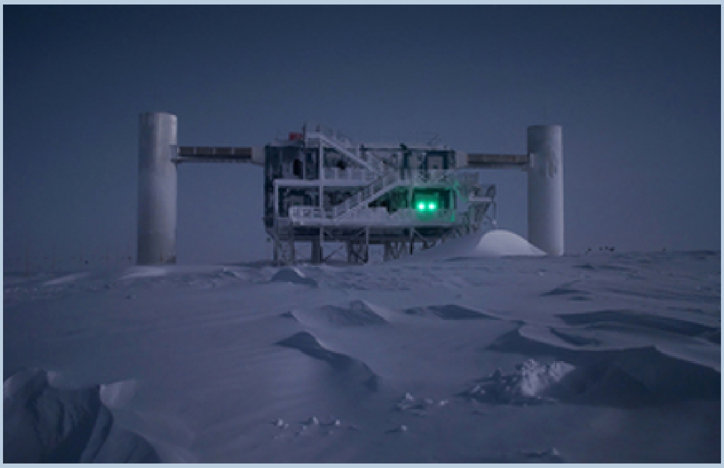
## 3. Develop Foundational Science and Prepare the Next Generation Workforce

The NSF's National High Magnetic Field Laboratory (MagLab) fields the world's highest-powered magnets, providing significant advances in magnet science and technology. MPS' wise stewardship of this facility, including the transition of location of the central facility and refresh of its approach and mission, enabled the continuing evolution of a superb facility serving many fields of science and engineering. Using the MagLab's uniquely strong magnetic fields, scientists aim to understand quantum matter and make fundamental discoveries about superconducting materials while also gaining new insights into chemistry, biology, and materials science. The drive to support the needs of a broad scientific user base, combined with a strong in-house understanding of magnetic field technology, has enabled the lab to develop novel scientific tools and to expand new research areas, becoming an extraordinary community resource. This facility provides a unique interdisciplinary and convergent learning environment, including education and outreach activities to raise scientific awareness and to inspire more participation in science. MagLab hosts more than 2,096 users worldwide from nearly 300 institutions (2019 data). Roughly 76% of those users are from universities, illustrating the significant impact on workforce training of the lab.

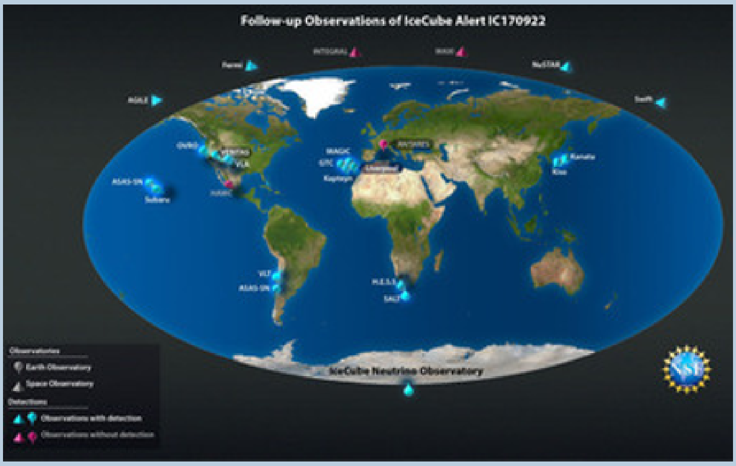
## 4. Broaden Participation through Exemplary Outreach and Community Engagement

The Arecibo Observatory's 305-m dish radio telescope in Puerto Rico enabled the first discovery of ultra-stable millisecond period pulsars that rival atomic clocks in their regularity. The systematic observations of a binary neutron star pulsar system, which became a test laboratory for Einstein's General Relativity, provided the first indirect evidence for gravitational waves (Nobel Prize 1993). Arecibo is an iconic radio observatory that inspired an entire generation of radio astronomers through opportunities for students to engage in summer research opportunities and the annual single-dish summer school, as well as university participation in key science projects. Technology development at Arecibo, especially around pulsar timing to detect gravitational waves, has transferred to other major facilities, such as the Green Bank Observatory. An additional aspect of the significant impact of the Arecibo Observatory is its sustained commitment to broadening participation in STEM through outreach and engagement with the Puerto Rican and international community in science education. STEM outreach is a hallmark of all major MPS facilities.

### Inset 2: Building A Unique Global Science Community and Developing Multi-Messenger Astrophysics - The IceCube Neutrino Observatory (ICNO)



*(Credit: Emanuel Jacobi, IceCube/NSF)*




*(Credit: Nicolle R. Fuller/NSF/IceCube)*

On Sept. 22, 2017, NSF's IceCube Neutrino Observatory (figure on the left) alerted the international astronomy community about the detection of a high-energy neutrino. Approximately 20 observatories (figure on the right) on Earth and in space made follow-up observations, which allowed identification of what scientists deem to be a source of very high energy neutrinos, and thus, of cosmic rays. With an estimated energy of 290 tera electron volts (TeV), this was the 10th alert of this type sent by IceCube to the international astronomy community and launched a series of multi-messenger observations that allowed the identification of the first source of high-energy neutrinos and cosmic rays. The observatories are operated by international teams involving a total of more than 1,000 scientists supported by funding agencies in countries around the world.

### 5. Build a Unique Global Scientific Community and Secure U.S. Leadership in the Physical Sciences and Engineering

The NSF's IceCube Neutrino Observatory (ICNO) is a unique, cubic-kilometer neutrino telescope that leveraged NSF's long-time stewardship of infrastructure at the South Pole. It has precision measurement capabilities for neutrino physics, cosmic ray physics, dark matter searches, and glaciology. IceCube was designed to search for high energy neutrinos from transient sources like gamma-ray or supernova bursts; steady and variable sources of high energy neutrinos or supernova remnants; sources of the cosmic-rays; weakly interacting massive particles that may constitute dark matter; neutrinos from the decay of superheavy particles; and more. The Bruno Rossi Prize was awarded in 2021 to the international IceCube Collaboration for the "discovery of a high-energy neutrino flux of astrophysical origin." IceCube's first observations of high-energy cosmic neutrinos won the 2013 Physics World Breakthrough of the Year Award. In 2017, IceCube detected a high-energy neutrino from the direction of a blazar, the first evidence of a source of high-energy cosmic rays. This detection illustrated the anticipated contribution of this facility to the development of multi-messenger astronomy (see Inset 2, above).

### 6. Forge Leading-edge Interagency Partnerships

The Large Hadron Collider (LHC) in Geneva is the world's most powerful particle accelerator and is now the premier facility world-wide for the energy frontier in high energy physics. It was created and maintained through an international collaboration. NSF MPS and DOE were co-leaders in driving U.S. participation in the LHC. Both agencies provided funding for the construction and for recent upgrades of the LHC's massive detectors, and both agencies support researchers at the LHC from U.S. universities and the DOE national laboratories. With the 2013 Nobel Prize recognizing the observation of the Higgs boson in 2012 - the particle associated with the Higgs field that gives mass to all other fundamental building blocks of matter - the LHC achieved its spectacular initial goal. The high-luminosity upgrades underway for LHC are expected to usher in a new era of understanding of these rare particles, and of discovery in physics.

### 7. Create Exceptional Public-Private Partnerships

NSF astronomical facilities incorporated into the NOIRLab (National Optical-Infrared Astronomy Research Laboratory) have been at the forefront of the profound changes in our understanding of the universe in the past several decades. The discoveries include: the observation that most of the matter in the universe does not interact with light and is different than what we know from measurements on the Earth, as well as a subsequent finding of the acceleration in the expansion of the universe due to a dark energy which permeates the universe and opposes gravity (Nobel Prize 2011). Both of these discoveries are based on critical observations from NOIRLab facilities combined with other observations made at private observatories. In addition, MPS has provided support to optical and infrared astronomers to access observing time and data from private observing facilities, such as the W.M. Keck Observatory in Hawaii. Instrumentation as well as observations made at this observatory were supported by NSF funding and allowed for the tracking of stellar orbits that confirmed the presence of Galaxy's supermassive black hole (Nobel Prize 2020).

***In summary***, each NSF MPS Facility plays a unique and essential role in its scientific subfield as demonstrated by, but not limited to, the selected, key examples highlighted above. The stewardship of MPS in ensuring that facilities like these are available to the U.S. research community is critical in order for the U.S. to maintain leadership in cutting-edge science as well as to develop, recruit and retain a competitive scientific workforce.

***Looking ahead***, it is clear that, without strategic and decisive investment in MPS facilities, there will be significant gaps in U.S. scientific and technological infrastructure, and therefore in U.S. Leadership.

***"Looking ahead, it is clear that, without strategic and decisive investment in MPS facilities, there will be significant gaps in U.S. scientific and technological infrastructure."***

# III. Scientific Imperative for Research Infrastructure in the Physical Sciences

Research infrastructure has been foundational to expand the frontiers of science and technology (S&T), which in turn drives innovation and economic development in the U.S. However, growing scientific excellence elsewhere, including in the European countries as well as in China, is seriously challenging U.S. leadership. Escalating world-wide competition is driven by the increasingly rapid dissemination of information, the increased connectivity and mobility of talent, and importantly, the increasing recognition that investments in research infrastructure are critical to the research and development (R&D) that drives S&T. There is an understanding that the return on such investments is high as a result of subsequent economic benefits derived from technology, innovation, and translation. The pace of investments in overall R&D in the U.S. in recent decades has declined by over 10%, while in China the rate has rapidly increased by over 15% (see Figure 2, below). Such investments include those made in instrumentation and facilities, and the data implies that the U.S. will fall behind other nations in the absence of attention to a growing gap in research infrastructure.

Figure 2. Shares of worldwide R&D expenditures, by selected region, country, or economy: 2000, 2010, and 2019.(NSB-2022-1, Fig. 14) Note: The pace of investments in overall R&D in the U.S. has declined by over 10%, while in China the rate has rapidly increased by over 15%.


**Note(s):**
EU is European Union. Other East-Southeast and South Asia includes Cambodia, India, Indonesia, Japan, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, and Vietnam.

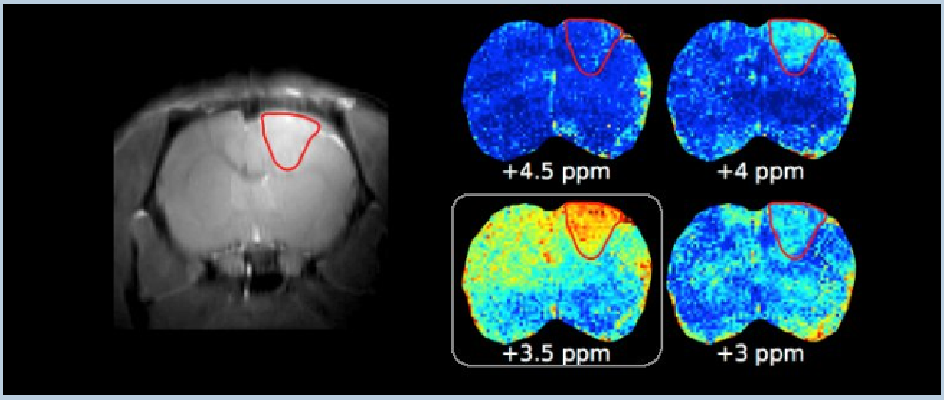
**Source(s):**
NCSES, National Patterns of R&D Resources; OECD, MSTI March 2021 release; UNESCO, UIS, R&D dataset.

*Indicators 2022: R&D*

Research enabled by MPS facilities yields many tangible benefits for society in addition to advancing our fundamental understanding of ourselves and the universe. Critical technological advances have benefited from building and operating major MPS research facilities. Examples include: advances in microchip design and manufacturing made possible by EUV lithography along with development of vibration isolation systems; advanced high-field magnets for Nuclear Magnetic Resonance (NMR) methods for probing chemical structures and Magnetic Resonance Imaging, MRI, for evaluating human health (see inset 3); high-power lasers for machining, femtosecond lasers for cataract surgery, and optics technology for atomic clocks (satellite position systems); and X-ray imaging for structural biology. The stable radio sources, physical optics and detectors developed in NSF's radio telescope labs are the basis for technology relevant to the safe scanning of traveling people and packages (using mm electromagnetic waves, rather than X-ray imaging). NSF's National Solar Observatory has made measurements of solar activity including transient magnetic fields ("space weather") that negatively impact conditions on Earth, enabling better planning to mitigate effects causing instabilities in communications and the power grid.

The U.S. scientific community's access to state-of-the-art research infrastructure is essential.

**Inset 3: Delivering Benefits Beyond MPS: NSF's NHMFL**




*(Credit: Roussel et al., 2018 )*

Using National High Magnetic Field Laboratory's (NHMFL) powerful, one-of-a-kind 21.1-tesla Magnetic Resonance Imaging (MRI) magnet, researchers found new potential disease markers for brain tumors. An international team of scientists used a novel image contrast technique called chemical exchange saturation transfer (CEST), as well as advanced signal processing algorithms, to acquire these detailed images of a rat brain with a tumor (red circled region). This study demonstrates how ultra-high magnetic fields can help detect new biomarkers for cancer and elucidate biochemical interactions within tumors. About 2,000 scientists from around the world use NHMFL's facilities each year, leveraging the power of high magnetic fields to explore new physical phenomena, develop materials for future generation technology, overcome energy challenges, and increase understanding of the human brain and life in general.

Without investments in both current and cutting-edge future facilities, ***the U.S. risks losing leadership*** in critical science and technology as well as the ability to partner in the most advanced infrastructure, wherever it may be located. Additionally, many scientific discoveries may be delayed, or not happen at all. Other discoveries will be achieved without U.S. participation.

Equally important, the U.S. risks losing its ability to attract and develop talent in frontier scientific fields. Users of infrastructure are researchers who may not otherwise have access to sophisticated and enabling instrumentation or are students who receive valuable training in modern instrumentation and state-of-the-art techniques from experts at facilities. The critical role of research infrastructure in workforce development, including opportunities for ingenuity to meet experience and practice, and broadly engage technical staff, is a crucial component to ensuring national competitiveness and advancing science.

# IV. Looking to the Future – Investing Wisely

Selecting the best new MPS facilities for investment is a crucial task. Areas that are ripe for fundamental discovery, as well as moonshot-type programs, are currently under discussion through focused, community-based planning activities. Reports emerging from such planning activities do an excellent job of distilling the many opportunities and suggesting paths forward to advance science and infrastructure. For example, the subcommittee has heard about exciting investments that include a broad spectrum of astronomical telescopes, advanced light sources, computational facilities, novel technologies for energy, and many others.

The National Science Board's "VISION 2030" report on the future of the U.S. research enterprise captured elements of science and engineering leadership that will be essential for the U.S. to remain the world leader in innovation in 2030. It described the global growth in science and engineering, knowledge, and technology-intensive industries, and highlighted the demand for STEM talent. The Report noted that:

> *"Infrastructure needs for 2030 and beyond will range from desktop microscopes, to billion-dollar telescopes, to deep ocean submersibles, to the research cyberinfrastructure resources that underpin revolutions in big data and AI."*

Conclusions in the Report reinforce the necessity of facilities for advancing the frontiers of science and the need to be bold in supporting these tools that are becoming more capable, sophisticated, complex, and expensive to build and operate.

# V. Future, Focused Discussions

Following review of many excellent reports by National Academies of Sciences, Engineering, and Medicine (NASEM), National Science Board (NSB), NSF Mathematical and Physical Sciences (MPS), and the broader scientific community, the Subcommittee suggests the following topics to guide future, focused discussions regarding facilities:

1. **Addressing increasing costs of construction, operations, recapitalization, and upgrades of major facilities:** Over recent decades, major facility costs have escalated, in large part because the facilities themselves are increasingly advanced and far more technically challenging to construct, thus requiring increased construction costs/schedules and significantly increased staffing costs. These challenges must be overcome to ensure that MPS has a robust infrastructure portfolio.
2. **Establishing cradle-to-grave stewardship of the facilities:** It is essential, at the outset of facility planning, to capture all costs: continuous operational and renewal expenses to maintain facilities at an internationally competitive level; whether and how facilities will be recompeted; and eventual deactivation and decommissioning, with its often-substantial attendant costs.
3. **Drafting guidelines for upgrading and planning of future facilities:** Criteria must be established so that the community and Federal decision makers can assess the potential impact and readiness to proceed for upgrades and future facilities. Inputs should be derived from the scientific community, and NASEM and other organizations' reports; from lessons learned from prior NSF and other-agency facility investments (e.g., the history and stunning impact of LIGO – a high-risk project undertaken by NSF without partners); and from Administration support and priorities.
4. **Investing strategically across MPS in mid-scale and large-scale facilities:** MPS and its Divisions, together and individually, will need to strategically invest across scales for maximum impact. These strategies must address: (1) the requirements of, and for, mid-scale instrumentation, major facilities, and the various scales of infrastructure to support them, and (2) the competing, yet intertwined/interdependent, demands of individual investigators and large research teams/centers. Current data for investments in MPS show that an optimum balance might vary considerably across the MPS Divisions.
5. **Detailing the role of partnerships:** Increasingly NSF (and other U.S. funding agencies) are assessing the benefits and challenges of facility partnerships of many kinds: intra- and inter-agency, international, private sector, and philanthropic. Partnering requires an in-depth understanding of the legal and social aspects of the engagement, including lessons learned from successful or unsuccessful past partnerships involving U.S. agencies.

6. **Defining broader impacts criteria for facilities:** NSF requires a discussion of the broader impacts of a proposed activity. How facilities address the broader impacts criteria should be a key step in decisions related to upgrades, new construction, and regular facility operations reviews.
7. **Identifying additional forward-looking topics:** Several were discussed, including S&T areas enabled only by facility and other infrastructure investments; international cooperation vs. competition; how to encourage scientific leadership in facility planning and catalyze innovative ideas for new facilities from the (academic) research community; and the vision for facilities near term (10 years) and far term (50 years).

# VI. Conclusion

Future U.S. leadership requires MPS's support for facilities that will allow us to observe farther back in time to better understand the beginning and evolution of the universe, to look with higher resolution in the continuing search for life on other planets, to understand and control the behavior of advanced quantum materials on all spatial scales, to design and fabricate novel materials with new functionalities, and to attract and educate the next generation of discoverers.

Identifying and ensuring access to such MPS Facilities is essential for NSF to meet its mission:

***"... to address the most compelling scientific questions, educate the future advanced high-tech workforce, and promote discoveries to meet the needs of the Nation."***

# VII. MPSAC Subcommittee on MPS Facilities & Major Research Infrastructure

Version 2021.05.25

## Background

The Mathematical and Physical Sciences Directorate (MPS) has responsibility for the funding and oversight of development, design, construction, and operations and maintenance (O&M) of a set of large and mid-scale facilities. These components of research infrastructure represent strategic investments that enable transformational science. Such activities, whether at the Major Facility or Mid-scale level, accounted for more than $363 million out of the total budget of $1,491 million in FY 2019 MPS Research and Related Accounts (R&RA), plus an additional $73 million of facilities construction in Major Research Equipment and Facilities Construction (MREFC) spending for FY 2019. MPS funding for facilities O&M accounted for over 35% of NSF's total O&M budget for major multi-user research facilities in FY 2019, the largest of any Directorate in NSF.

In 2004, in response to a request from Congress, the National Academy of Sciences issued a report[1] regarding NSF's process for identifying, approving, constructing, and managing large-research-facility projects. The report includes a number of recommendations for actions by NSF and recommends that NSF implement a set of well- defined criteria for the selection of large projects for construction. The National Science Foundation (NSF) and the National Science Board (NSB), in a joint report[2], responded by embracing the spirit of the Report's recommendations and addressed the principles of the primary recommendations, leaving the detailed mechanisms to be addressed in consultation with its communities, the Office of Management and Budget (OMB), and Congress. In particular, the NSB/NSF response states "NSF will also continue to use NSF directorate advisory committees for input to the process, and will continue to involve members of the community in the merit review of MREFC projects." More recently, theNSB issued a study on the costs of operations and maintenance of NSF facilities[3] and a report on the importance of Mid-scale Research Infrastructure[4], which further illuminate the complex and important challenges that MPS faces in its development and operations of the research infrastructure upon which much of its science relies.

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*1 Setting Priorities for Large Research Facility Projects Supported by the National Science Foundation, The National AcademiesPress, 2004 (https://www.nap.edu/catalog/10895/setting-priorities-for-large-research-facility- projects-supported-by-the-national-science-foundation).*
*2 Setting Priorities for Large Research Facility Projects Supported by the National Science Foundation (NSB-05-77), http://www.nsf.gov/pubs/2005/nsb0577/index.jsp.*
*3 Study of Operations and Maintenance Costs for NSF Facilities (NSB-2018-17), https://www.nsf.gov/pubs/2018/nsb201817/nsb201817.pdf.*
*4 Bridging the Gap: Building a Sustained Approach to Mid-scale Research Infrastructure and Cyberinfrastructure at NSF (NSB-2018-40), https://www.nsf.gov/nsb/publications/2018/NSB-2018-40-Midscale-Research- Infrastructure-Report-to-Congress-Oct2018.pdf.*

NSF directorate advisory committees have specific responsibilities with respect to facilities under consideration for future construction. NSF policy requires that when a directorate intends to request NSB action to authorize the inclusion of a new, large facility project in a future NSF MREFC budget request to Congress[5], the Directorate's advisory committee should first examine and provide their endorsement of the proposed facility. This examination can be conducted in the context of the ranking criteria found in theAcademy's report (Appendix I) and/or other criteria, as appropriate. With the recognition of the strategic importance of Mid-scale investments, including the new, agency-wide programs in Mid-scale Research Infrastructure that were developed in response to the NSB report4 on the importance of mid-scale strategic investments, the subcommittee will also be asked to examine the MPS portfolio of investments through the mid-scale initiatives (at both Division and agency-wide levels) and assess their strategic value to fostering the science supported by the Directorate. This applies especially to mid-scale investments at the larger scale (greater than $20M) that are funded via the MREFC account. Consideration of the role of current and potential future cyberinfrastructure facilities and/or institutes both as stand-alone entities and as integral components of large facilities is also a critical element of the research infrastructure that must be considered.

**The primary purposes of the MPSAC Subcommittee on Facilities & Major ResearchInfrastructure are to support the MPSAC responsibilities with respect to potential new facilities and provide strategic advice on issues, opportunities, and challenges posed by the MPS large and mid-scale research infrastructure portfolio.** In order for the subcommittee to accomplish these tasks, it will need to acquire an understanding of the existing MPS research infrastructure portfolio and the impacts on the divisions and on MPS concerning resources needed to carry out proposed projects and ongoing operations. Because the Subcommittee members will be knowledgeable of the MPS portfolio and associated challenges, the Assistant Director may also periodically request the Subcommittee provide advice on other elements of facilities planning and implementation.

*5 The MREFC process is described in NSF's Major Facilities Guide (NSF 19-068),* *https://www.nsf.gov/pubs/2019/nsf19068/nsf19068.pdf*

## Charge to the MPSAC Subcommittee on Facilities & Major Research Infrastructure

The MPSAC Subcommittee on Facilities & Major ResearchInfrastructure is charged with the preparation of a strategic report to the MPSAC that:

- Assesses the potential contribution of new proposed major and mid-scale infrastructure projects to the scientific communities of MPS, as well as to those communities outside MPS if applicable; the role of such projects within the existing MPS research infrastructure portfolio; the impact of this infrastructure on future plans and resources of MPS and its divisions; and the role of the resulting investment in the international context. This assessment should take into account as many of the community planning efforts as possible in the time available so as to provide a broadly informed, truly strategic report.
- Provides recommendations to the MPSAC for statements to the MPS Assistant Director concerning requests for inclusion of MPS major facility projects in NSF budget requests to Congress.
- Provides strategic advice on elements of the evolving MPS research infrastructure portfolio at the request of the MPS Assistant Director.
- Provides guidance and decision rules that will lead to a robust 10-year program of strategic investment in the development, construction, and operation of large and mid-scale infrastructure for the physical sciences.

Given the extensive nature of the advice sought and the timescales of the various community studies, both underway and planned, a number of interim reports will be required as the subcommittee prepares its full recommendations.

## Membership

Membership of the subcommittee will consist of selected current MPSAC members representing all five MPS divisions plus up to seven additional external members as deemed appropriate by the MPS Assistant Director and the MPSAC Chair.

Members of the subcommittee will be appointed for two-year terms. The MPSAC and MPS Assistant Director may invite members to serve additional terms in order to provide the best advice to pursue opportunities and confront challenges on the horizon for MPSand its facilities portfolio.

### Duration

The subcommittee will terminate once it has submitted its final report to the MPSAC Advisory Committee, no later than January 1, 2026. The subcommittee charge will be reviewed and revised as needed by the MPSAC and MPS Assistant Director until the termination date. The MPSAC and MPS Assistant Director may include addenda to the charge clarifying the duties of the subcommittee as it conducts its work.

### Schedule of Reports

The subcommittee is asked to submit its final report by January 1, 2026.

The first interim report (Addendum 1) would be most useful on the timescale of September2021, in order to provide the foundation for further discussions, both with the MPSAC as well as within the NSF, regarding upcoming investment opportunities.

The schedule and subjects of subsequent interim reports will be as mutually determined by the AD/MPS and the MPSAC Chair and will become further Addenda to this charge.

### Support

The MPS Directorate will provide appropriate support and documentation to the MPS Facilities Subcommittee in order to enable the subcommittee to develop its recommendations.

### Designated Federal Official

The MPS SeniorAdvisor for Facilities or other MPS Senior Advisor will be the Designated FederalOfficial for the subcommittee, at the discretion of the MPS AD.

# Appendix I

The following criteria have been excerpted from the National Academies' 2004 report, *Setting Priorities for Large FacilityProjects supported by the NationalScience Foundation*. These criteria may serve as a guideline for the work of this Subcommittee.

**Criteria for Developing Large Facilities Roadmaps and Budgets**

Overlapping categories of criteria should guide the preparation of the large facilities roadmap and NSF's annual budget submissions. Scientific and technical quality must be at the core of these criteria. Because these are large facility projects, they must have the potential to have a major impact on the science involved; otherwise, they should not reach the next step.

The rankings show what we would expect to happen first within a field, then within a directorate of NSF, and then across NSF. The criteria from earlier stages must continue to be used as the ranking proceeds from one stage to the next.

- **First Ranking: Scientific and Technical CriteriaAssessed by Researchers in a Field or Interdisciplinary Area**
    - Which projects have the most scientific merit, potential, and opportunities within a field or interdisciplinary area?
    - Which projects are the most technologically ready?
    - Are the scientific credentials of the proposers of the highest rank?
    - Are the project-management capabilities of the proposal team of the highest quality?
- **·Second Ranking: AgencyStrategic Criteria AssessedAcross Related Fields by Using the Advice of Directorate Advisory Committees**
    - Which projects will have the greatest impact on scientific advances in this set of related fields taking into account the importance of balance among fields for NSF's portfolio management in the nation's interest?
    - Which projects include opportunities to serve the needs of researchers from multiple disciplines or the ability to facilitate interdisciplinary research?
    - Which projects have major commitments from other agencies or countries that should be considered?
    - Which projects have the greatest potential for education and workforce development?
    - Which projects have the most readiness for further development and construction?

- Third Ranking: National Criteria Assessed Across All Fields by the National Science Board
    - Which projects are in new and emerging fields that have the most potential to be transformative? Which projects have the most potential to change how research is conducted or to expand fundamental science and engineering frontiers?
    - Which projects have the greatest potential for maintaining US leadership in key science and engineering fields?
    - Which projects produce the greatest benefits in numbers of researchers, educators, and students enabled?
    - Which projects most need to be undertaken in the near term? Which ones have the most current windows of opportunity, pressing needs, and inter- national or interagency commitments that must be met?
    - Which projects will have the greatest impact on current national priorities and needs?
    - Which projects have the greatest degree of community support?
    - Which projects will have the greatest impact on scientific advances across fields taking into account the importance of balance among fields for NSF's portfolio management in the nation's interest?

Ranking projects across disciplines is inherently not an exact science; nevertheless, these criteria, as illustrated by the questions, provide a framework for a discussion of why one project is accorded a higher priority than another and a mechanism for the discussion to be as objective as possible in ranking projects across fields.

Within the ranking categories, the questions might change as governmentwide initiatives and unexpected occurrences shift priorities. Similarly, at times, some questions might have greater weight than others in the judgment of the NSB. The key element is for the questions and weighting to be identified before the ranking process begins and for a clear rationalization to be provided when proposed large research facility projects are ranked.

# Addendum 1:

## Background

In preparation for this and all future requests for input, the MPSAC, through its Subcommittee on MPS Facilities, should establish a general understanding of the opportunity space for investment in next-generation facilities. To this end, the Subcommittee may wish to familiarize themselves with a number of past and future community prioritization efforts that have specific relevance to future mid-scale and large facilities. These include, but are not limited to, the 2020 Astronomy and Astrophysics Decadal Survey, the high energy physics community's next Snowmass/P5 strategic plan, and an upcoming NationalAcademies study on the long-term directions for high magnetic field science and technology development. Other communities in astronomy, physics, materials research, chemistry, and the mathematical sciences will present additional reports in the coming years that address midscale facility opportunities as well as the wealth of data that come from facilities at all scales.Taken as a whole, these studies will set forth a list of scientifically important projects and activities, including potential new world-leading facilities.

These next-generation facilities will be both exciting in their promise and challenging in their realization. The Subcommittee should therefore also aim to develop a high-level understanding of the salient challenges on the horizon, most notably with respect to the impacts of resource limitation across the full facility life cycle of current and future facilities. Topics of interest may include barriers to maintaining a robust development pipeline for new facilities, limitations on support available through the Major ResearchEquipment and Facilities Construction account, escalating operations and maintenance costs, and the relative costs and savings associated with facility divestment.

## Interim Report Request

The request of the MPSAC for this interim Subcommittee report is twofold:

1. After its Subcommittee's due consideration of the motivations and impacts of facility investments, provide a summary for MPSAC consideration articulating the importance of major and mid-scale facilities to NSF's scientific leadership and MPS's role in ensuring that its scientific research infrastructure enables the current and future cutting-edge science of the Directorate.

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2. Pursuing these investments will require the support and buy-in of a diverse set of stakeholders, including NSF senior leadership beyond MPS, Congress, and the Administration. Therefore, the report should **provide advice on how to best "make the case" for this next generation of MPS's Major Facilities and related investments as a critical part of the support MPS provides for the scientific disciplines in its broad portfolio.**

The brief report to the MPSAC, including the summary as well as the Subcommittee's advice and feedback, would be most useful on the timescale of Q3 of CY2021, in order to provide the foundation for further discussions, both with the MPSAC as well as within the NSF, regarding upcoming investment opportunities.