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Annual Portfolio Review of Facilities
FY 2012

National Science Board
Committee on Strategy and Budget
Subcommittee on Facilities

NATIONAL SCIENCE BOARD

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National Science Board

July 18, 2012

MEMORANDUM FROM THE CHAIRMAN OF THE NATIONAL SCIENCE BOARD

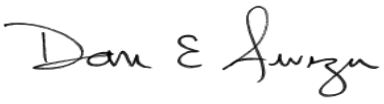
SUBJECT: FY 2012 *Annual Portfolio Review of Facilities*

The National Science Board established the Subcommittee on Facilities of the Committee on Strategy and Budget in May 2009 to oversee the National Science Foundation's portfolio of facilities and to provide guidance to the Board on strategic planning for the NSF funded research equipment and facilities portfolio. The National Science Board is pleased to present the FY 2012 *Annual Portfolio Review of Facilities*, which reviews both existing and planned research facilities and infrastructure and their long-term impact on budgets within the Foundation.

In creating this Annual Portfolio Review, the subcommittee reviews all phases of a facility – design, development, construction, operations, and retirement. The resulting report, together with the NSF's annual *Facility Plan* presentation to the Board, helps us understand the interrelationships between proposed facility development and other areas across the Foundation and thus to maintain the appropriate balance of investment in infrastructure and research. It is intended not only to aid the Board in evaluating budgetary consequences, operations costs, and future liabilities of proposed infrastructure, but it also guides NSF in managing risk and being able to respond to opportunities.

Although the highest-profile use of the Annual Portfolio Review is in Board decision-making on large, high-cost facilities such as those created through the NSF's Major Research Equipment and Facilities Construction account, this report is perhaps unique among NSF planning analyses in that it also addresses many of the mid-scale facilities and instruments that are often vital for science and engineering research.

The Board hopes that this report will not only aid us in our decision-making and policy development, but will also serve as a resource for the broader community. We believe that an accurate understanding of our entire portfolio of research infrastructure investments is essential to ensure continued excellence in science and engineering across the NSF.



Dan E. Arvizu
Chairman

EXECUTIVE SUMMARY

The Committee on Strategy and Budget's (CSB's) Subcommittee on Facilities (SCF, subcommittee) of the National Science Board (NSB, Board) was charged with undertaking an annual review of the portfolio of all National Science Foundation-funded research facilities, considering projects from the Major Research Equipment and Facilities Construction (MREFC) account, as well as large and mid-size research facilities and infrastructure funded by the Research and Related Activities (R&RA) account.

The purpose of the Annual Portfolio Review (APR, portfolio review) is to assess the impacts of specific projects and the overall facilities portfolio on the long-term budgets of NSF divisions, offices, directorates, and the National Science Foundation (NSF, Foundation) as a whole. In executing its charge, SCF identified those aspects of NSF facilities where strategic guidance and policy development would be most effective in ensuring continued excellence in science across NSF. For the purposes of this APR, the subcommittee has adopted a broad definition of facilities that includes all research-enabling resources that serve an extended community of scientists and engineers, as distinguished from NSF-supported activities serving individual investigators or small groups. These "multi-user" facilities include centers, observatories, networks, platforms, equipment, instrumentation, data-infrastructure, and cyber-infrastructure.

The APR addresses the scientific merit, adequacy and appropriateness of NSF multi-user facilities portfolio; the extent to which NSF multi-user facilities apply and share best practices in facility management and operation; the processes that NSF organizations use to assess facilities' productivity, cost-effectiveness, and responsiveness to community needs; and the attributes of NSF's portfolio of multi-user facilities, including interagency, international and industrial partnering, interdisciplinary aspects, and contributions that address scientific problems of national priority. Through the portfolio review, SCF also considers the processes by which NSF identifies and assesses future opportunities, horizon projects, new technologies, and emerging priorities that might strengthen the NSF facility portfolio.

The APR is constructed around four key questions:

1. **What is the distribution of facilities types and disciplines across the National Science Foundation?**

The subcommittee found that the distribution of facilities across NSF organizations is largely a result of historical factors stemming from NSF support for high priority facilities identified through peer review of unsolicited proposals. Generally, input from advisory committees and National Academy of Science studies have been the impetus for larger projects, while mid-scale facilities originate from a variety of mechanisms. It is unclear whether there are mechanisms currently in place for assessing the degree to which mid-scale facilities are meeting the needs of the respective research communities.

Currently, the subcommittee sees no rationale for substantial changes in the processes by which new facilities are established. NSF should continue to pay careful attention to the balance between facility funding and support for individual research grants to ensure decisions are made strategically and with full awareness of the budgetary impact of new activities. To enable informed and strategic decision-making, particularly with respect to long-term trends, SCF recommends that NSF improve the consistency and comparability of the data it collects on the facilities portfolio. In addition, NSF should develop qualitative and/or quantitative metrics by which to evaluate the extent to which multi-user facilities are meeting the needs of the communities they serve.

2. What is the projected annual cost of ongoing operation and maintenance of the portfolio as it currently exists and how are those costs distributed across Directorates/Divisions?

The projected annual operations and maintenance costs of major multi-user facilities at NSF are projected to grow at the rate of about 2.5 percent per year between FY 2013 and FY 2018. The percentage of a given Division's budget devoted to operation and maintenance versus individual research grants varies greatly depending on the scientific needs of a given research community, with some Divisions investing between 30 and 60 percent of their budget in facilities.

The subcommittee recognizes the distinct communities that NSF organizations serve and does not feel there is a need to set any target for the amount invested in facilities relative to individual research grants. However, all organizations should apply formal project management practices in managing facilities, regularly review the cost-appropriateness of their facilities investments, use sound and realistic life-cycle planning to develop budgetary initiatives, and monitor the balance between investments in multi-user facilities and individual research grants. Through the APR, the subcommittee should consider how investments across Directorates and Offices vary with time and, when appropriate, make broad recommendations to ensure the respective science communities are well served.

3. How are facilities and projects adhering to project management best practices?

Except for MREFC projects, the subcommittee found little evidence of consistent life-cycle planning of facilities. NSF should adopt standards and guidance for life-cycle planning of all multi-user facilities. Although such a standardized approach may not be necessary for all facilities, it should be a starting point from which Program Officers and the relevant organizations can make sound decisions regarding best practices to be applied. Similarly, NSF should adopt a means to identify risk factors for all its facilities, including the mid-scale facilities. In cases where common risks are identified, the Board and NSF should consider developing policies and strategies to mitigate those risks

4. How Do Attributes of the Portfolio Align with NSF Strategic Goals?

The subcommittee found that the large multi-user facilities have been extremely effective in leveraging with external partners, enabling multi-disciplinary research, and addressing high priority scientific problems. There are indications that mid-scale facilities, which constitute a

significant investment on an annual basis, have been equally successful in these areas, but NSF does not routinely compile the information needed to definitively make this assessment.

Through the APR, the subcommittee should monitor the extent to which facilities supported by NSF are helping the Foundation achieve its strategic goals. Requisite information for this evaluation should be collected routinely to ensure NSF investments in facilities continue to encourage interdisciplinary research, effective leveraging, and societally relevant outcomes.

SECTION 1: INTRODUCTION

Background

As stated in the CSB charge, "One of the Board's most important responsibilities is the provision of strategic budget guidance." Planning for the development, construction, operations, maintenance, and disposition of research equipment and facilities supported by the NSF is an essential component of annual and long-term budget planning undertaken by the NSB.

The Board established SCF in May 2009 to assist the NSB in strategic budget planning with responsibility for the NSF-funded research equipment and facilities portfolio. SCF was charged with undertaking an annual review of the portfolio of all NSF-funded research facilities, considering projects from the MREFC account and large and mid-size research facilities and infrastructure funded by the R&RA account.

In executing its charge, SCF identified those aspects of NSF facilities where strategic guidance and policy development would be most effective in ensuring continued excellence in science across the NSF. For the purposes of this APR, the subcommittee defines facilities as research-enabling resources that NSF supports, and which serve a larger number of scientists and engineers than typical research grants. These "multi-user" facilities include centers, observatories, networks, platforms, equipment, instrumentation, data-infrastructure, and cyber-infrastructure. The APR addresses:

- The scientific merit, adequacy and appropriateness of the NSF multi-user facilities portfolio, including:

    1. the distribution of multi-user research facilities within and across disciplines
    2. the balance between multi-user research facilities investments and other research within and across disciplines, and
    3. the possible impacts existing and new multi-user facilities will have on the overall NSF budget.

- The extent to which NSF multi-user facilities apply and share best practices in facility management and operation, which includes performance indicators, life-cycle planning and risk assessment.

- The processes that NSF organizations use to assess facilities' productivity, cost-effectiveness, and responsiveness to community needs.

- The attributes of NSF's portfolio of multi-user facilities, including interagency, international and industrial partnering, interdisciplinary aspects, and contributions that address scientific problems of national priority.

Through the APR, the SCF will also consider the processes by which NSF identifies and assesses future opportunities, horizon projects, new technologies, and emerging priorities that might strengthen the NSF facility portfolio.

SCF conducts its Annual Portfolio Review in May, following the NSB's receipt of NSF's snnual *Facility Plan* in February. The APR takes place within the context of the larger Board process for reviewing and making decisions about for major facilities.[1] As further illustrated in the process, the review is based on non-advocate presentation of projects and includes a detailed assessment of projects that have passed Conceptual Design Review (CDR). The APR is used to inform NSB decision-making and guidance on project prioritization and strategic budget planning.

The FY 2012 APR builds on the SCF's development of the review structure from previous years. The previous reviews focused on segments of the overall portfolio (a Directorate, the MREFC account). The goal of the FY 2012 APR is to build on the previous reviews to develop a *reliable* and *repeatable* process. In particular, the 2012 review:

- establishes a set of **baseline assessment questions** for this and future reviews;
- develops a set of common **attributes** to define and evaluate the portfolio (funding, type, phase, start year, projected funding, and management strategies);
- refines the **review scope**, in particular adding consideration of mid-scale facilities; and
- emphasizes **operations costs** and **balance** between core research and facilities in facility-intensive Divisions.

The APR is an important element in ensuring that the NSF's facilities in operation, under construction and in planning are aligned with NSF investment priorities. SCF will regularly examine the breadth and depth of the APR to ensure its charge can be effectively implemented.

Inputs to the Review

The SCF Annual Portfolio Review takes its principal informational input from NSF in the form of the annual NSF *Facility Plan*, presented to the NSB in February. The *Facility Plan* is a non-advocate input prepared by the NSF Large Facilities Office (LFO), and it covers MREFC in planning, construction, and operation.

Typically, the *Facility Plan* includes current budget information and budget requests for the following year. Because release of the FY 2013 budget occurred after the February 2012 NSB meeting, the FY 2012 Facility Plan was based on the FY 2012 Current Plan budget information. SCF subsequently received budgetary updates (FY 2013 request) for use in the present review.

The FY 2012 NSF *Facility Plan* also included consideration of several topics that the SCF had requested for the APR, including interconnections among facilities and life-cycle planning.

The following additional documents and analyses were considered in the present review:

- FY 2013 and previous NSF Budget Requests to Congress;
- an update provided by NSF to NSB in May 2011 on changes to the early-stage MREFC process;
- an analysis of projected facility budget shares in facility-intensive Divisions under several budget scenarios, produced by the Board Office;
- feedback from the SCF on prior reviews; and
- The NSB Report to Congress on *Mid-Scale Instrumentation at NSF* (NSB-11-80) December 2011, prepared by SCF in response to section 507 of the America COMPETES Reauthorization Act 2010, and initial analysis of mid-scale instrumentation.

Baseline Assessment Questions

To continue the development of a reliable and repeatable APR, the subcommittee developed a working set of baseline assessment questions for this and future reviews.

1. What is the distribution of facilities types and disciplines across the NSF?
   - How was the distribution established; how is it maintained and tracked?
   - Are the multi-user facilities meeting the scientific needs of the intended communities?

2. What is the projected annual cost of ongoing operation and maintenance of the portfolio as it currently exists and how are those costs distributed across Directorates/Divisions?

3. How are facilities and projects adhering to project management best practices?
   - Is a life-cycle plan in place that considers decommissioning, renewal and recompetition? If so, how is this managed?
   - What processes do NSF organizations employ to evaluate facility success?
   - How are facilities assessing risks and challenges? How are these risks being mitigated in planning and operating the facilities?

4. How do attributes of the portfolio align with NSF strategic goals?

The NSF annual budget requests and *Facility Plan* contain well-defined information useful for answering many of these questions. However, although NSF routinely collects data on the Major Multi-User Research Facilities (MMURFs) defined in its annual budget request, data for mid-scale facilities and other research infrastructure are not yet captured thoroughly and unambiguously. Thus, one of the goals of this review was to assess the adequacy of the baseline questions and determine what additional information is needed.

SECTION 2. SCOPE AND DEFINITIONS

Definition of Facilities

For the purposes of the Annual Portfolio Review, the common feature of all NSF facilities is that they serve a community of scientific users that goes beyond a single investigator or even a group of investigators at a single institution. The user base for NSF facilities may be local, regional, statewide, national, or international. The size of the user base dictates the need for significant NSF involvement in the way the facility is operated to ensure responsiveness to the needs of the research community, sustained scientific productivity, effective strategic planning, and cost effectiveness of operations. NSF facilities are expected to operate for more than one award cycle and typically a great deal longer. Some have been operating for many decades. In many cases, the instrumentation or equipment is owned by the NSF or the Federal Government, necessitating proactive stewardship in the operation, maintenance, and disposition of the facility.

Some NSF facilities are multi-disciplinary in that they serve several different research communities. Almost all facilities have strong education, outreach, and diversity programs. The NSF expects that all data from its facilities will be made openly available and accessible according to a carefully developed data distribution and dissemination plan. Facilities tend to involve varying degrees of technical complexity that warrant careful oversight and planning to maintain and upgrade them as needed. Though often managed by a single principal investigator (PI), facilities often have more complex management structures involving consortia of institutions, multiple collaborative PIs, or a dedicated organization established for the sole purpose of operating the facility. Larger facilities will also include external advisory groups or other means for ensuring community involvement in operations. The annual cost for operating NSF facilities is typically greater than the average award size within the NSF organization funding the facility. Larger facilities may have multiple funding sources requiring continued nurturing of interagency and international partners. Most NSF facilities are funded through cooperative agreements to ensure the necessary NSF involvement in their operation and use.

Current Portfolio of NSF Facilities by Category

The following subsections describe the types of facilities at NSF.

Potential MREFC Projects

The APR considers potential future large facility projects at the post-Conceptual Design Review (CDR) stage whose NSF sponsors are preparing for potential funding through the MREFC account. Such projects are developed by proponents and overseen by the NSF according to the established NSF policies and procedures for large facilities, which are defined in the NSF *Large Facilities Manual*.[2]

Currently for FY 2012, there is one post-CDR project, the Large Synoptic Survey Telescope (LSST). The LSST project successfully completed the Preliminary Design Review (PDR), and was reviewed internally by the MREFC Panel.

One early-stage potential large facility project that has recently advanced to the Conceptual Design Stage is the Regional Class Research Vessels (RCRV). A CDR for this project is not expected until next year. A solicitation for a managing organization to develop the RCRV project through CDR was released in April 2012.

Major Research Equipment and Facilities Construction Projects

Congress established the MREFC account in 1995 to support the acquisition, construction, and commissioning of large-scale facility projects. Since its inception, the MREFC account has funded the construction of 17 large facilities, of which 12 are in the operational stage (see the next subsection on Major Multi-User Research Facilities) and 5 are in the construction stage. Many details on these construction projects, including out-year estimates for construction and initial operations, are found in the MREFC section of the NSF budget requests and in the annual NSF Facility Plan.

Major Multi-User Research Facilities

MMURFs are in the operational stage and include large facilities constructed with MREFC funds as well as others whose construction predated the MREFC account. Detailed information on these facilities, including out-year estimates for operations, is found in the facilities section of NSF budget requests.
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Federally Funded Research and Development Center Projects

The NSF sponsors three facility Federally Funded Research and Development Centers (FFRDCs). All are currently operational. No new FFRDCs are currently in development or planned. Detailed information on these FFRDCs, including out-year estimates for operations, is found in the facilities section of NSF budget requests, and the NSF often includes these activities together with MMURFs as “major facilities.”

Mid-scale Instrumentation

In FY 2012, the SCF discussed how to also include consideration of mid-scale facilities, informed in part by the NSB’s report to Congress on midscale instrumentation as directed by America COMPETES Reauthorization Act of 2010. For that report, SCF conducted a survey of mid-scale infrastructure across the Foundation and identified approximately 100 projects that met a broad definition of multi-user mid-scale instrumentation. Little budgetary or project-level information is available in NSF budget requests concerning these activities.

Major Cyberinfrastructure Projects

Projects in this category are High Performance Computing (HPC) and other networking and computational activities sponsored by the NSF Office of Cyberinfrastructure (OCI), and large-scale computing projects sponsored by the Directorate for Computer and Information Science and Engineering (CISE). Project descriptions and current (but not forecasted) budgetary

information are available in the OCI section of NSF budget requests concerning OCI infrastructure activities. Brief programmatic and budgetary information on major CISE infrastructure is found in the corresponding section of NSF budget requests.

Table 1. Facilities considered in this APR by category and life-cycle stage

Potential MREFC Projects (Stage: Planning)	
Large Synoptic Survey Telescope (LSST) (Post-CDR: Preliminary Design); select early stage projects	
MREFC Projects (Stage: Construction)	
Alaska Region Research Vessel (ARRV) Advanced Technology Solar Telescope (ATST) Advanced Laser Interferometer Gravitational-Wave Observatory (AdvLIGO)	National Ecological Observatory Network (NEON) Ocean Observatories Initiative (OOI)
Major Multi-user Research Facilities (Stage: Operations)	
Academic Research Fleet (ARF) Arecibo Observatory Atacama Large Millimeter Array (ALMA) Cornell High Energy Synchrotron Source (CHESS)/Cornell Electron Storage Ring (CESR) EarthScope Gemini Observatory IceCube Incorporated Research Institutions for Seismology (IRIS) Integrated Ocean Drilling Program (IODP)	Large Hadron Collider (LHC) Laser Interferometer Gravitational-Wave Observatory (LIGO) National High Magnetic Field Laboratory (NHMFL) National Nanotechnology Infrastructure Network (NNIN) National Solar Observatory (NSO) National Superconducting Cyclotron Lab (NSCL) Network for Earthquake Engineering Simulation (NEES) Polar Facilities and Logistics
Federally Funded Research and Development Centers (Stage: Operations)	
National Center for Atmospheric Research (NCAR) National Optical Astronomy Observatories (NOAO)	National Radio Astronomy Observatory (NRAO)
Selected Examples of Cyberinfrastructure Projects (Beyond Mid-scale Instrumentation)	
Global Environment for Network Innovation (GENI) eXtreme Science and Engineering Discovery Environment (XSEDE)	
Mid-scale Instrumentation Projects (Stages: Various)	
For the America COMPETES Reauthorization Act 2010, 100 mid-scale instrumentation projects were identified	

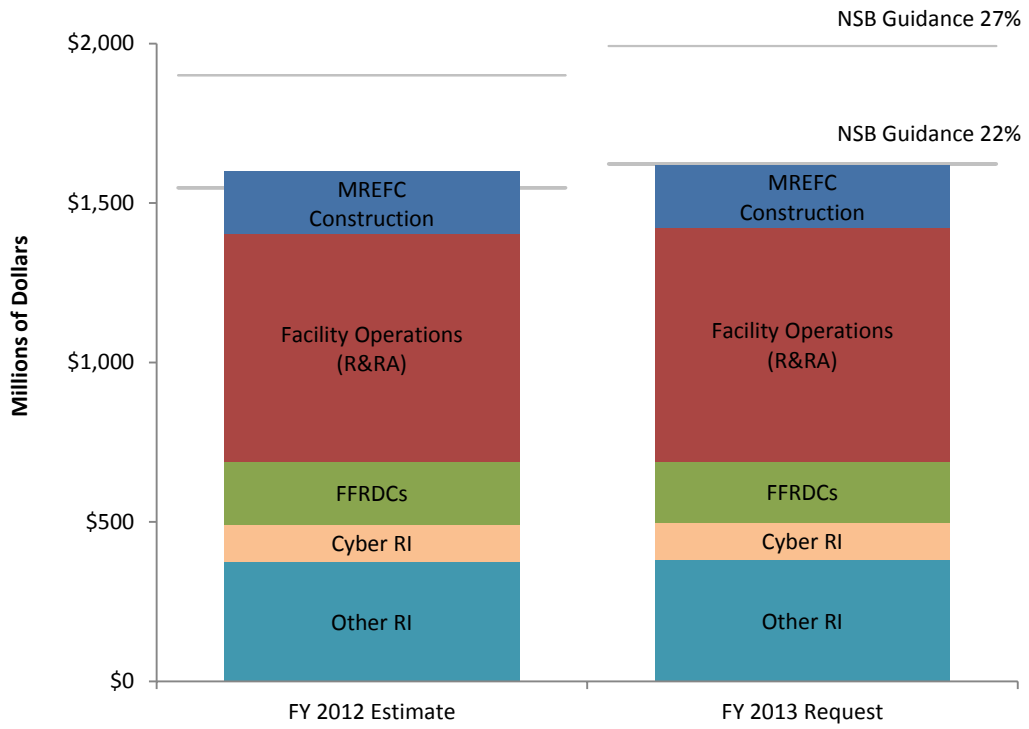
SECTION 3. PORTFOLIO ASSESSMENT

Question 1. What is the distribution of facilities types and disciplines across the National Science Foundation?

- How was the distribution established; how is it maintained and tracked?
- Are the multi-user facilities meeting the scientific needs of the intended communities?

The NSF provides funding for a variety of research infrastructure in support of the U.S. scientific community. This infrastructure includes facilities, instrumentation, computer models, cyberinfrastructure, survey databases, and other resources supporting the scientific enterprise. Research infrastructure provides essential capabilities that enable NSF-supported researchers to advance the frontiers of science. An effective facilities portfolio should have a balance of facility types and sizes distributed across all areas that NSF supports. This balance helps maintain an appropriate level of support, as well as the means by which to nurture and develop new technologies.

Research Infrastructure as identified in the NSF budget includes MREFC, facilities operation costs from the Research and Related Activities (R&RA) account, FFRDC costs, cyber-research infrastructure, and other research infrastructure as illustrated in Figure 1.

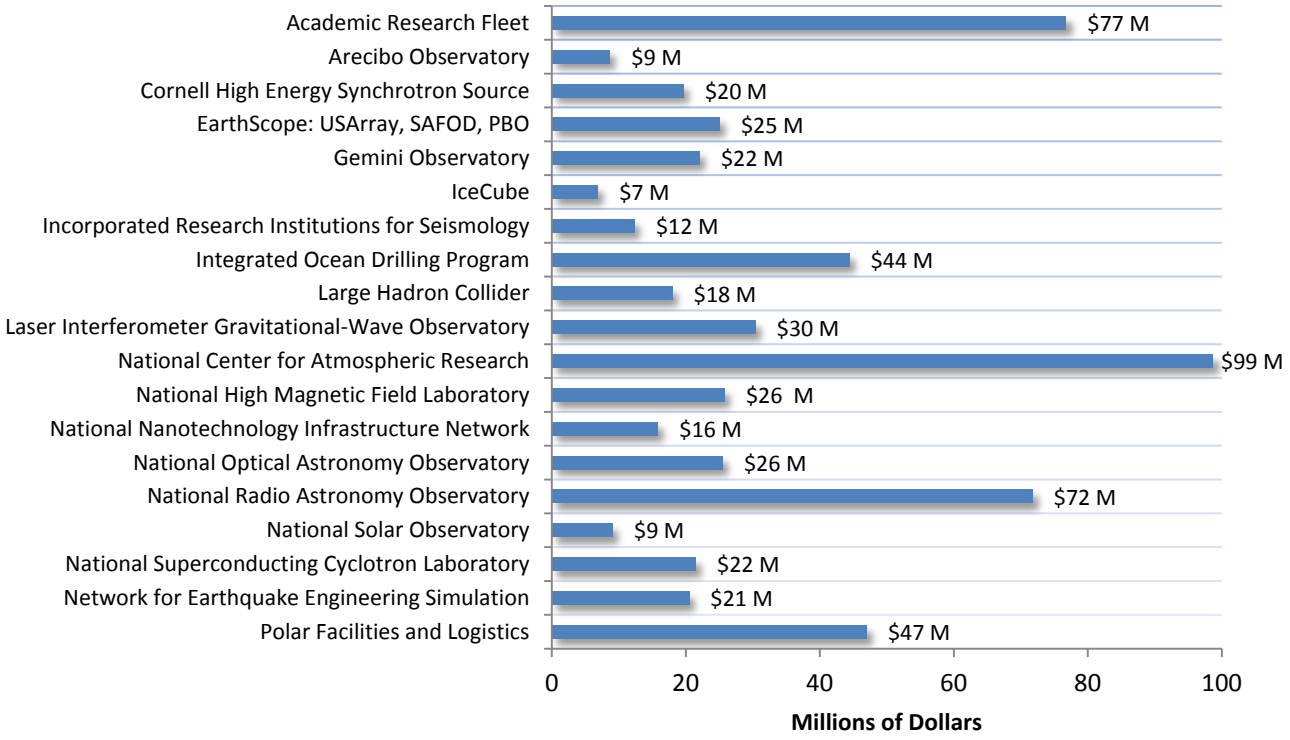


Source: "National Science Foundation FY 2013 Budget Request to Congress," February 13, 2012, http://www.nsf.gov/about/budget/fy2013/pdf/EntireDocument_fy2013.pdf.

Figure 1. FY 2012 estimated and FY 2013 request levels for facilities within NSF Research Infrastructure

As Figure 1 indicates, the NSF's current and proposed levels of total research infrastructure investment are presently at the minimum level relative to the NSB guidance of 22 percent to 27 percent. For each fiscal year shown, the relative portions of each infrastructure investment category remain relatively unchanged.

For the large facilities in operation, Figure 2 shows the estimated funding levels in FY 2012. Note the large range in annual operating costs within the NSF portfolio.



Source: "National Science Foundation FY 2013 Budget Request to Congress," February 13, 2012, http://www.nsf.gov/about/budget/fy2013/pdf/EntireDocument_fy2013.pdf.
Note: Funding listed for Polar Facilities and Logistics does not include $256.74 million of Antarctic Infrastructure and Logistics Support.

Figure 2. FY 2012 estimated funding in millions for MMURFs and FFRDCs in operation.

Figures 3 and 4 show the investment in research as percentages of the Directorate and Division budgets, respectively. The relative investment in instrumentation across NSF organizations reflects different priorities and approaches to conducting research in the science communities served by those organizations. There are historical bases for the current distribution rooted in these differences. NSF organizations track investments in instrumentation to various degrees of granularity, and the extent to which they attempt to control these investments varies greatly as well. Regardless of the levels of investment, NSF organizations strive to track infrastructure funding levels through the years to ensure changes are consistent with community needs and priorities.

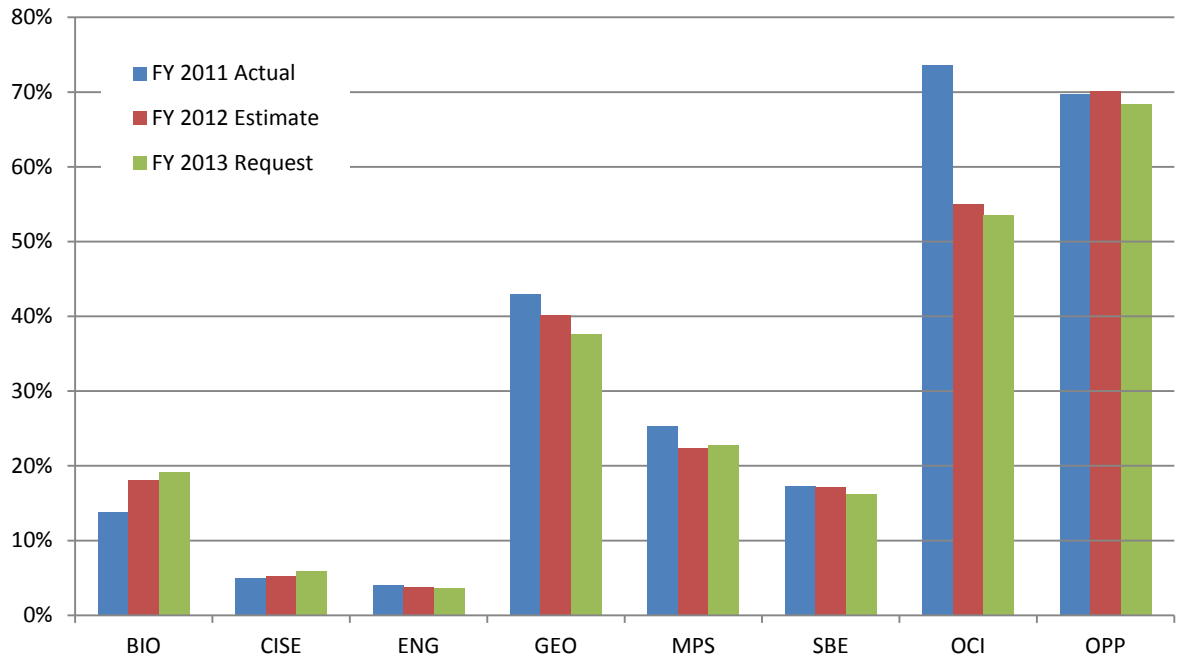


Figure 3. Research infrastructure costs for major facilities and FFRDCs as a percentage of Directorate budgets for the previous, present, and next (requested) fiscal years

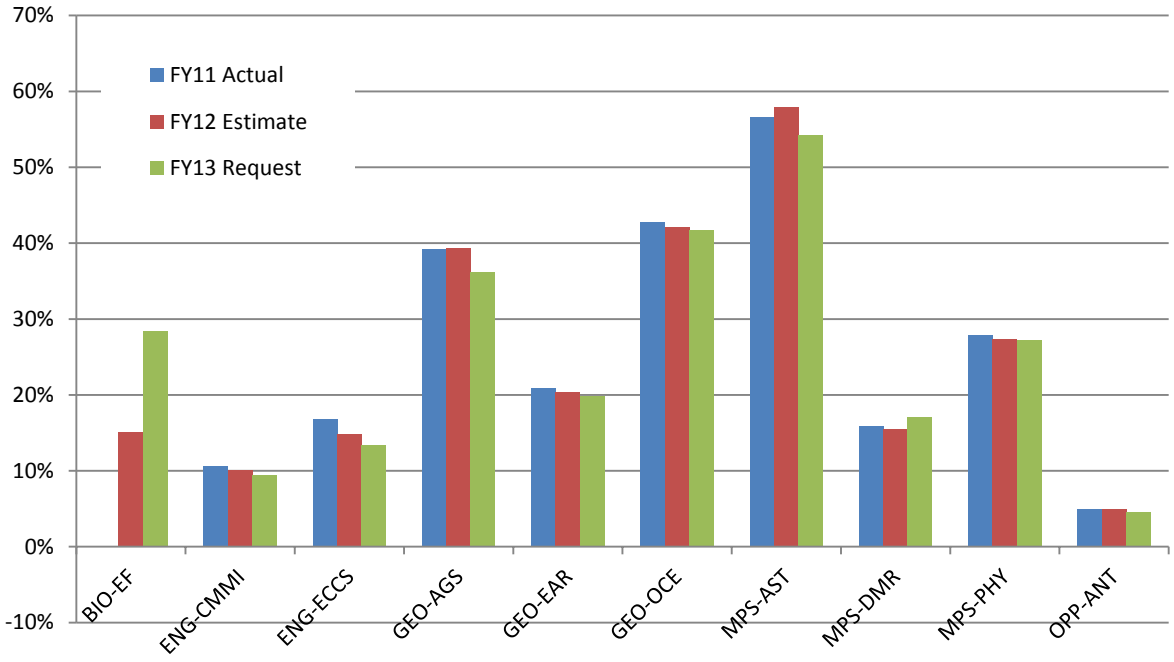


Figure 4. Research infrastructure costs for selected Divisions as a percentage of Division budgets for the previous, present, and next (requested) fiscal years

To further understand the potential future effects of facility operating costs, the Board Office conducted a projection analysis at the Directorate and Division levels under several NSF budget growth scenarios: –5 percent, flat, and +5 percent (see Question 2 and Appendix B).

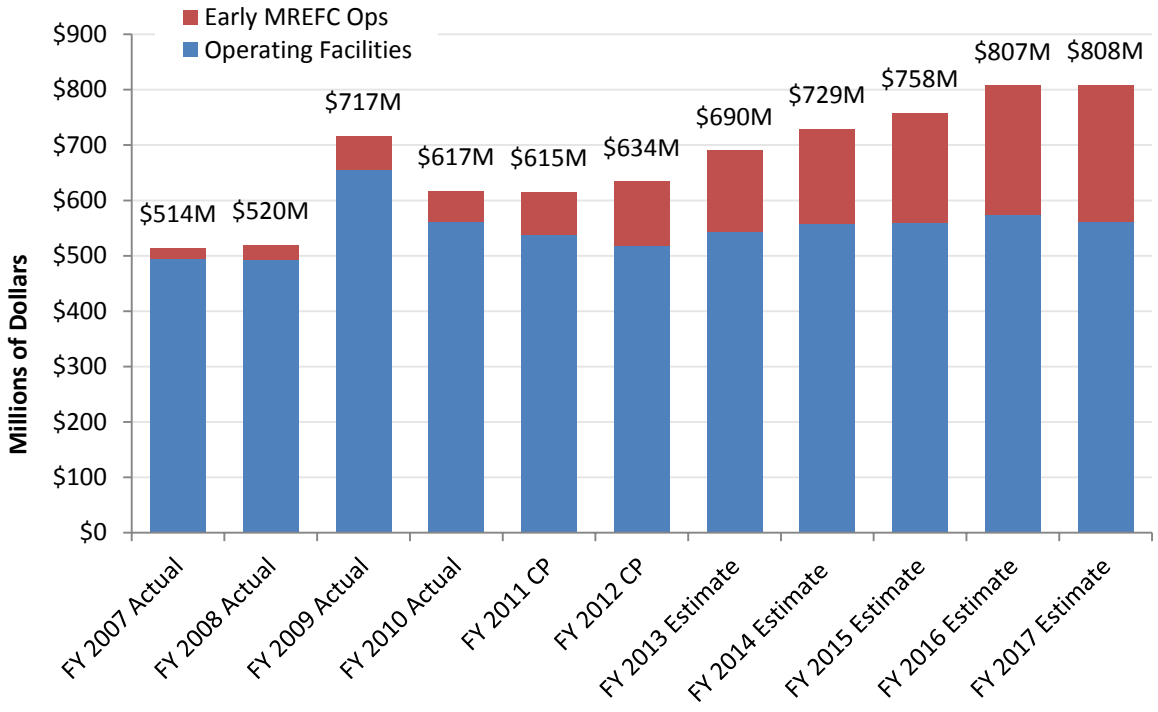
Finding: SCF found that the distribution of facilities across NSF organizations is largely a result of historical factors stemming from NSF support for high-priority facilities identified through peer review of unsolicited proposals. Generally, input from advisory committees and National Academy of Science studies have been the impetus for larger projects, although mid-scale facilities originate from a variety of mechanisms. Also, it is unclear whether there are any mechanisms currently in place for assessing the degree to which mid-scale facilities are meeting the needs of the respective research communities.

Recommendation: Currently, SCF sees no rationale for substantial changes in the processes by which new facilities are established. NSF should continue to pay careful attention to the balance between facility funding and support for individual research grants to ensure decisions are made strategically and with full awareness of the budgetary impact of new activities. To enable informed and strategic decision-making, particularly with respect to long-term trends, SCF recommends that NSF improve the consistency and comparability of the data it collects on the facilities portfolio. In addition, NSF should develop qualitative and/or quantitative metrics by which to evaluate the extent to which multi-user facilities are meeting the needs of the communities they serve.

Question 2. What is the projected annual cost of ongoing operation and maintenance of the portfolio as it currently exists and how are those costs distributed across Directorates/Divisions?

Major Multi-User Research Facilities and Federally Funded Research and Development Centers

NSF support for the operation and maintenance (O&M) of MMURFs and FFRDCs combined constitutes approximately $700 million in annual NSF investment. Many MMURFs were constructed with MREFC funds. Figure 5 shows the projected operations funding for MMURFs, including funds for early operation of MREFC projects in construction. The projected growth is approximately 5 percent. The anomalously high funding level in 2009 is due to the increase in funding from the American Recovery and Reinvestment Act of 2009 (ARRA).



Source: FY 2012 Budget Request and Current Plan.
Note: FY 2009 funding included a number of one-time investments made possible by ARRA, primarily to address upgrades and deferred maintenance.

Figure 5. Projected growth in operation and maintenance costs for major facilities

Major Multi-User Research Facilities Operations and Maintenance Analysis

Given the long-term life cycles of these facilities, it is useful to investigate the potential future impact of O&M costs on future sponsoring Directorate and Division budgets, particularly in the context of the current period of reduced economic growth and consequent Federal budgetary austerity. To further understand this issue, the Board Office analyzed the potential impact of O&M costs under three NSF budget scenarios.

Data Sources and Analyses. The facilities section of the annual NSF budget request provides current and projected O&M funding for the individual activities. These O&M budget data were used to examine trends in estimated costs over time. The FY 2013 budget request provides these estimates through FY 2018, and the "actuals" data from previous NSF budgets provide historical funding information.[3] Additionally, the FY 2013 and previous budgets provide current-year, previous, and requested total budgets for individual Directorates and Divisions. These can be used to develop historical and projected percentages of facility O&M relative to the budgets of these organizations, if certain scenario assumptions are made about future overall NSF and Division or Directorate budget growth.

To gauge the relative potential future effect of O&M expenditures on organization budgets, the following three budgetary assumptions were employed for a bracketed comparison:

- NSF (and Division/Directorate) budgets increase by 5 percent per year;
- Budgets remain flat in nominal dollars at FY 2012 levels;
- Budgets decrease by 5 percent per year.

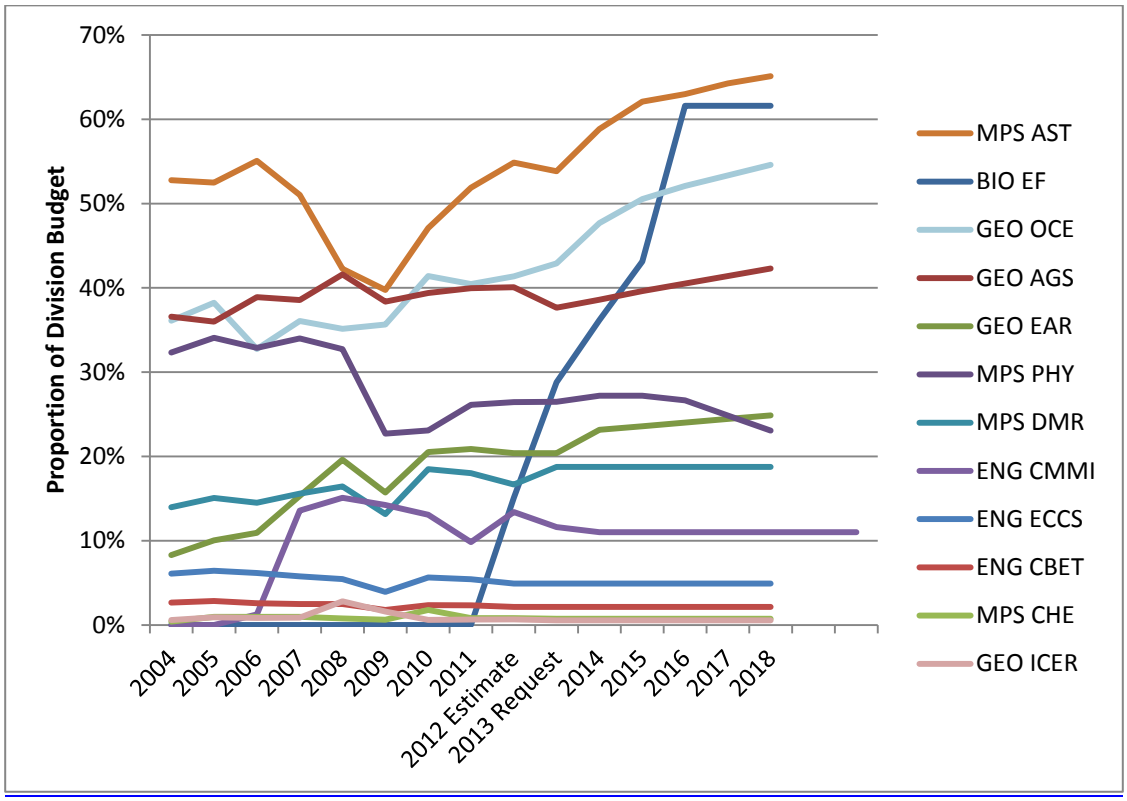
Figure 6 shows summary results for selected Divisions under the flat-funding scenario. Additional details and projections under the other two scenarios are contained in Appendix B.

Caveats. In calculating out-year projections for O&M costs relative to organizational budgets, some assumptions must be made. In particular, Divisions across the NSF may not employ the same projection methodology, with some estimates increased on an inflationary basis, some not increased, and some adopting a more tailored, facility-specific approach. Moreover, out-year projections may not translate into a realized expenditure, as Divisions, Directorates, and the Foundation as a whole are likely to *adapt O&M costs in response to budget uncertainty*.

In addition to the difficulty inherent in predicting out-year costs, relying on budget request data to analyze long-term trends in O&M costs poses challenges from a portfolio perspective. The projects included on the MMURFs list vary slightly from year to year, and some Divisions themselves are no longer extant. In other cases, such as the Advanced Modular Incoherent Scatter Radar (AMISR), O&M costs are no longer reported in the MMURF category once construction ends, presumably because ongoing O&M costs after construction has ceased no longer exceed the "major" facility threshold. Still others, such as the Cornell Electron Storage Ring (CESR) or the Laser Interferometer Gravitational Wave Observatory (LIGO), evolved into next-generation facilities. Finally, some facilities, notably the National Center for Atmospheric

Research (NCAR), do not consistently report O&M costs from year to year. Although SCF has assembled a data set that captures overall trends in O&M expenditures on a divisional basis, these limitations must be borne in mind.

Overall Trends. Although current O&M costs are important, it is useful to summarize historical trends regarding budget growth. Between 2004 and 2012, the R&RA budget grew an average of 3.6 percent a year in nominal dollars.[4] Over the same period, inflation averaged 2.3 percent per year and the real growth in R&RA budgets was 1.3 percent per year. [5] O&M costs for the MMURFs in Figure 6 grew from roughly $425 million in FY 2004 to over $580 million in FY 2012. This is 4 percent per year, outpacing inflation over the same period by about 2 percent. Thus, overall spending on MMURFs has grown faster than inflation over this period and slightly faster than the rest of the R&RA account.



Notes: 2004-2011 = Actual; 2012-2018 = Estimated. Assumes a flat out-year budget. Cyberinfrastructure, now funded under OCI, but once funded under CISE as an MMURF, is omitted, as it is now treated independently in the FY 2013 budget request. Office of Polar Programs (OPP) and Office of International Science and Engineering (OISE) are omitted because they have a qualitatively different mission and institutional structure than the research Directorates and Divisions that support MMURFs O&M.

Figure 6. Percentage of Division/Directorate budgets spent on O&M.

The projected growth rate for overall MMURFs overall O&M costs is broadly consistent with the rate of growth between 2004 and 2012. Although the projections in the budget should be not be taken as immutable, overall O&M spending for MMURFs is expected to grow at a rate of 2.5 percent per year between FY 2013 and FY 2018. This outpaces expected inflation by 0.8 percent

per year. MMURF funding proportions shown in Figure 6 may not take into account any Division/Directorate-level planned terminations or other facility dispositions.

Although most Division/Directorates, even under a flat funding scenario, are projected to have roughly constant O&M costs, some Divisions show increasing percentages of their budgets being devoted to MMURF O&M. Results for these Divisions are shown in further detail in Appendix B.

Mid-Scale Instrumentation

Incorporating mid-scale facilities into the APR is challenging. The NSF MREFC projects and major multi-user facilities are well-documented and -tracked: project-level funding for construction and operations (and increasingly, planning) are centrally collected, vetted, and published each year, along with detailed narratives. These activities have distinct life-cycle stages, each funded via defined mechanisms, and defined life-cycle policies and processes are in place.

Conversely, as the analysis for the Mid-Scale Instrumentation report mandated by the American COMPETES Reauthorization Act of 2010 demonstrated, mid-scale instrumentation details are not reported in the budget process. Mid-scale instrumentation and facility activities are distinguished by variety and flexibility in funding mechanisms. There can be multiple awards for a single mid-scale facility; and a single award may cover multiple types or phases of activity. In addition, management policies and processes are not specifically defined or required.

Figure 7 shows the investment in mid-scale facilities by NSF organizations as estimated from the survey conducted in 2011 to compile data for the Mid-Scale Instrumentation report. The data represent approximately 100 mid-scale facility awards for which data were captured for the survey. The results are broken out according to whether the facilities are physical infrastructure or cyberinfrastructure (including multi-user databases). Both operating facilities and those in construction are included. The total FY 2011 investment was $163 million, on a total value of $1.6 billion for active awards.[6]

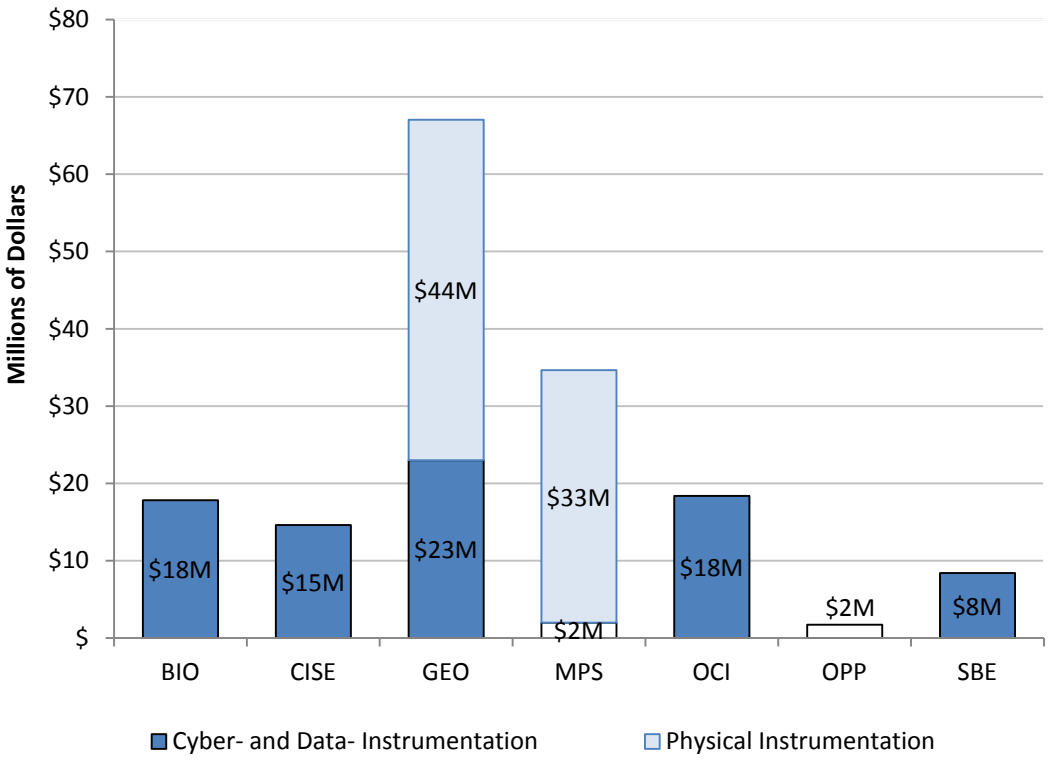


Figure 7. Total FY 2011 investments in mid-scale instrumentation by NSF organization, distinguishing between physical instrumentation and cyberinfrastructure/databases

Finding: The annual operations and maintenance costs of major multi-user facilities at the NSF are estimated to grow at the rate of about 2.5 percent per year between FY 2013 and FY 2018. The percentage of a given Division's budget devoted to O&M versus individual research grants varies greatly depending on the scientific needs of a given research community, with some Divisions investing between 30 percent and 60 percent of their budget in facilities.

Recommendation: SCF recognizes the distinct communities that NSF organizations serve and does not feel there is a need to set any target for the amount invested in facilities relative to individual research grants. However, all organizations should apply formal project management practices in managing facilities, regularly review the cost-appropriateness of their facilities investments, use sound and realistic life-cycle planning to develop budgetary initiatives, and monitor the balance between investments in multi-user facilities and individual research grants. Through the APR, the subcommittee should consider how investments across Directorates and Offices vary with time and, when appropriate, make broad recommendations to ensure the respective science communities are well served.

Question 3. How are facilities and projects adhering to project management best practices?

- Is a life-cycle plan in place that considers decommissioning, renewal, and recompetition? If so, how is this managed?
- What processes do NSF organizations employ to evaluate facility success?
- How are facilities assessing risks and challenges? How are these risks being mitigated in planning and operating the facilities?

In 2002, the Foundation created the Large Facilities Office (LFO) tasked with ensuring effective management and oversight of the Foundation's largest facilities. LFO's purview includes all the MMRUFs specifically listed in NSF's budget request. These facilities are in various phases of development, construction, and operations, and their annual funding levels exceed $8 million.

LFO has developed guidelines and policies for NSF oversight of large facilities that cover a broad range of activities. A collection of documents provides NSF program officers with information and resources necessary to ensure awardee adherence to government regulations and best practices. In addition, LFO schedules an annual seminar on project science, annual large facilities workshops, and monthly forums addressing various topics of large facility management aimed at NSF program officers. LFO also conducts Business Systems Reviews of all large facilities every 5 years. All of these activities have contributed to building a well-connected community of large facility stakeholders that enhances communication and enables sharing of best practices.

Although LFO's purview includes only large NSF facilities, some of the policies and guidelines developed through the years have been applied to facilities in the NSF's mid-scale portfolio. Many of the mid-scale projects are awarded through cooperative agreements with specific terms and conditions that require strategic plans, approved management and operations plans, and performance goals and metrics. The management and operations plans address the facilities organizational structure, science and data management, education and public outreach activities, maintenance and upgrades, risk management, safety and health issues, and cybersecurity. In addition to the oversight activities required for all NSF awards (peer review of proposals, annual and final reports, Committee of Visitors review, etc.), all of the NSF's large facilities and many of its mid-scale facilities are required to undergo mid-term management reviews and regular site visits with external membership selected by the NSF.

Three areas of facility oversight that are currently being targeted for improved guidelines and processes are life-cycle planning, risk management, and facility interconnections. For life-cycle planning, guidelines for the construction and operational phases of large facilities have been developed, but no requirements currently exist for the planned phase-out of facilities. Implementing strategies for phasing out large, complex facilities can take years, and often affects a large number of highly trained personnel whose experience and knowledge are more difficult to replace than the infrastructure itself. Prompt engagement of all stakeholders to prepare for phasing out of a facility is essential, and NSF must be actively involved in such planning from the outset.

Based on prior experience and feedback from program officers and awardees, the NSF has compiled a list of risk factors. Examples of risk factors for two operating facilities are shown in Figure 8.

	Risks	AMISR (Alaska and Canada)	Arecibo Observatory
Technical	Aging technology/obsolescence		
	Unavailability of parts		
	Unproven/immature technology		
	Interference/RFI		
	Manufacturing errors		
	Human error		
	Wear and tear		
	Breakage		
	Design flaws		
	ITAR restrictions		
	Linkages/dependencies on other technology/facilities		
Financial	Funding levels		
	Value of U. S. dollar		
	Value of local currency		
	Cost growth for equipment, materials, fuel, personnel, electrical power, etc.		
	Changes in tax rates		
	Customs and duties		
	Changes in indirect cost rates		
	Law suits/liabilities		
	Dependence on partner contributions		
Management	Competing priorities		
	Lack of experience		
	Poor strategic/budget planning		
	Inadequate business systems		
	Inadequate subaward management		
	Contingency handling		
Personnel	Inadequate staffing levels		
	Single-point failures		
	Unavailability of qualified personnel		
	Turn-over		
	Change due to recompetition		
	Poor succession planning		
	Immigration issues		
Political/Civil	Change in government		
	Civil unrest		
	Vandalism		
	Politically-motivated interference		
	Local opposition		
	ITAR		
Environmental	Production and/or storage of hazardous materials		
	Disruption to local ecology		
	Impact on historical sites and indigenous populations		
	Air quality/toxic emissions		
Health and Safety	Remote/harsh environments		
	Operation on aircraft or ships		
	Hazards due to radio frequency emissions, noise, intense light		
	Operation at high altitudes		
	Operation at large heights		
	Radiation		
	Fire		
Natural Hazards	Earthquakes		
	Floods		
	Fires		
	Hurricanes		
	Tornadoes		
	Tsunamis		
	Solar storms		
Cyber- Threats			

Key	High Risk (Likely Occurrence)	
	Moderate Risk (Possible Occurrence)	
	Low Risk (Unlikely Occurrence)	

Figure 8. Template for capturing risk factors; examples of two operating NSF facilities.

Although the color coding provides a quantitative scale for assessing the various risks, the ratings are largely qualitative in nature. The purpose of this exercise is not to highlight specific risks for each of the large facilities but to identify common risk areas that might be addressed through policy changes, more proactive oversight and management, or NSF strategic investments. All facilities, whether large or small, deal with risk on a regular basis. In all stages of the facility life cycle, risks are identified and assessed (rated) and mitigation plans are developed. The risk probabilities and estimated costs feed into total contingency budgeting. During construction, risks are reprioritized and "retired" as the project progresses. For operating facilities, risk analysis occurs on a continual basis.

Also important in portfolio management is continuous consideration of the interconnections between facilities that might make one facility dependent on another. Facility dependencies can either be constructive or risky; in either case, identification of those linkages is critical to effective management. Some of the different types of linkages between existing facilities are:[7]

- Between facilities:
    - NEES/IRIS/EarthScope
    - Gemini/NOAO/LSST
    - ATST/NSO
    - ALMA/NRAO
- Between facilities and other major activities:
    - IceCube/Polar Facilities and Logistics
    - LHC ATLAS and CMS/OCI Open Science Grid
    - NHMFL/research in engineering, biology, biochememistry, chemistry, geochemistry
    - NEES/social sciences
    - Between facilities and users in other disciplines, other agencies

This list is by no means exhaustive and a more thorough analysis is warranted. Dependences on cyberinfrastructure, in particular, must be more carefully tracked.

For MREFC facility projects and operating MMURFs and FFRDCs, the Foundation has defined performance metrics and oversight policies and mechanisms by life-cycle stage:

- **Policy guideline**: Large Facilities Manual (and modules)—defines process, on-ramps/off-ramps, prioritization, and management expectations;
- **Preconstruction planning:** Milestone reviews (CDR, PDR, and FDR), MREFC Panel, Director and the NSB;
- **Construction:** Monthly reports (with Earned Value), periodic reviews, and reports (see Facility Plan);
- **Operations:** Establishment of performance goals and metrics, annual work plans, annual reports, operations reviews, site visits, and competition/peer review;
- **Business Systems Reviews** (BSRs, mainly for operations).

MREFC facility projects are required to measure and report to the NSF on a monthly basis on project progress and performance. Project performance, in terms of cost and schedule, is measured and reported using Earned Value Management (EVM) methodology.

The combination of uncertain budgets and community demands for new facilities has made it imperative that life-cycle plans and risk management be formalized in such a way that the impacts to the NSF's

overall portfolio can be assessed both tactically and strategically. Across the Federal facility sector, sun-setting and phase-out are continual challenges due to the high cost of decommissioning. NSF guidelines do not presently specify how large facility phase-out should take place. However, this is an important consideration during facility planning.

The following life-cycle planning activities for large facilities are underway. Noted in several cases are intended communications with the NSB.

- Directorate for Mathematical and Physical Sciences (MPS)/ Division of Materials Research (DMR): External assessment of DMR Facilities and Instrumentation portfolio. Due: July 2012.
- National High Magnetic Field Laboratory (NHMFL): Part of a National Academy of Science study of national needs for high-magnetic field facilities.
- National Superconducting Cyclotron Laboratory (NSCL): NSF support for operations will cease once the Department of Energy replacement is in place ~FY 2017.
- Large Hadron Collider (LHC): Experiments are just beginning. Second Cooperative Agreement (CA) now in effect. Operating for 10 years.
- Laser Interferometer Gravitational-Wave Observatory (LIGO): Major upgrade to be completed in FY 2015; construction/operation for 20 years.
- IceCube: Experiments are just beginning. First CA in effect; construction/operation for 10 years.
- MPS/ Division of Astronomical Sciences (AST): Portfolio review underway, as subcommittee of MPS Advisory Committee. A major effort to determine evolutionary strategy. Includes assessment of research and O&M balance. Status report to the NSB planned for July 2012.
- Directorate for Engineering (ENG): ENG plans to provide the NSB with two information items at the July 2012 meeting:
    - Planning for the future of NEES following expiry of the current operating award on 9/30/2014
    - A new open competition to operate National Nanotechnology Infrastructure Network (NNIN) beyond 2013.

Finding: Except for the MREFC projects, SCF found little evidence of consistent life-cycle planning of facilities.

Recommendation: The NSF should adopt standards and guidance for life-cycle planning of all multi-user facilities. Although such a standardized approach may not be necessary for all facilities, it should be a starting point from which program officers and the relevant organizations can make sound decisions regarding best practices to be applied. Similarly, the NSF should adopt a means to identify risk factors for all its facilities, including the mid-scale facilities. In cases where common risks are identified, the Board and the NSF should consider developing policies and strategies to mitigate those risks.

Question 4. How Do Attributes of the Portfolio Align with NSF Strategic Goals?

One of the qualitative measures for evaluating the health of the NSF large facility portfolio is to assess the facilities' contributions to the NSF's strategic goals as shown in Figure 9. In the 2011 APR, an informal survey of the large facilities highlighted the extent to which they (1) enable interdisciplinary research; (2) leverage interagency, industrial, international, and other partner contributions; and (3) contribute to national strategic priorities with high societal relevance. Figures 10a, b, and c show the results of the 2011 survey. No attempt has been made to update or validate these initial survey results. Not addressed in last year's assessment are the facility contributions to capacity building, STEM education, and public outreach. All of the large facilities have active programs in these areas that can be documented and evaluated.

STRATEGIC GOALS	PERFORMANCE GOALS
Transform the frontiers	• Make investments that lead to emerging new S&E fields and shifts in existing fields. • Prepare/engage a diverse STEM workforce … to participate at the frontiers. • Keep the United States globally competitive at the frontiers of knowledge by increasing international partnerships and collaborations. • **Enhance research infrastructure & promote data access to support researchers'/educators' capabilities & enable transformation at the frontiers.**
Innovate for society	• Make investments that lead to results & resources useful to society. • Build capacity of citizenry for addressing societal challenges through S&E • Support the development of innovative learning systems.
Perform as a model organization	• Achieve management excellence via leadership, accountability, responsibility. • Infuse learning as an essential element of the NSF culture.... • Encourage/sustain a culture of creativity and innovation across the agency to ensure continuous improvement & high levels of customer service.

Source: NSF Strategic Plan FY 2011–FY 2016, April 2011, http://www.nsf.gov/news/strategicplan/nsfstrategicplan_2011_2016.pdf

Figure 9. NSF strategic and performance goals

	Astronomical Sciences	Physics	Atmospheric Sciences	Ocean Sciences	Earth Sciences	Engineering	Computer Sciences	Biology	Polar Studies	Social Sciences
NOAO/NSO	■		■							
Gemini	■					■				
NRAO	■				■	■				
NAIC	■		■							
LIGO		■				■	■			
NHMFL		■			■	■		■		
LHC		■				■	■			
CHESS/CESR		■				■		■		■
NSCL		■				■				
NCAR			■			■	■			■
ARF		■	■	■	■	■		■	■	■
IODP			■	■	■	■	■	■	■	■
EarthScope			■	■	■	■	■	■	■	
IRIS			■	■	■	■			■	
NEES				■	■	■	■			■
NNIN		■	■	■	■	■	■	■		■
Polar Logistics	■	■	■	■	■	■	■	■	■	■

Figure 10a. Scientific disciplines at the NSF's Major Multi-User Facilities

	Interagency	International	Industrial	State and Local
NOAO/NSO	■	■		
Gemini		■		
NRAO	■	■		
Arecibo	■	■		■
LIGO		■		
NHMFL	■			■
LHC	■	■		
CHESS/CESR	■			■
NSCL	■			■
NCAR	■	■	■	■
ARF	■	■		■
IODP	■	■	■	■
EarthScope	■	■	■	■
IRIS	■	■		■
NEES		■		
NNIN		■		
Polar Logistics	■	■		■

Figure 10b. Types of partnerships at the NSF's Major Multi-User Facilities

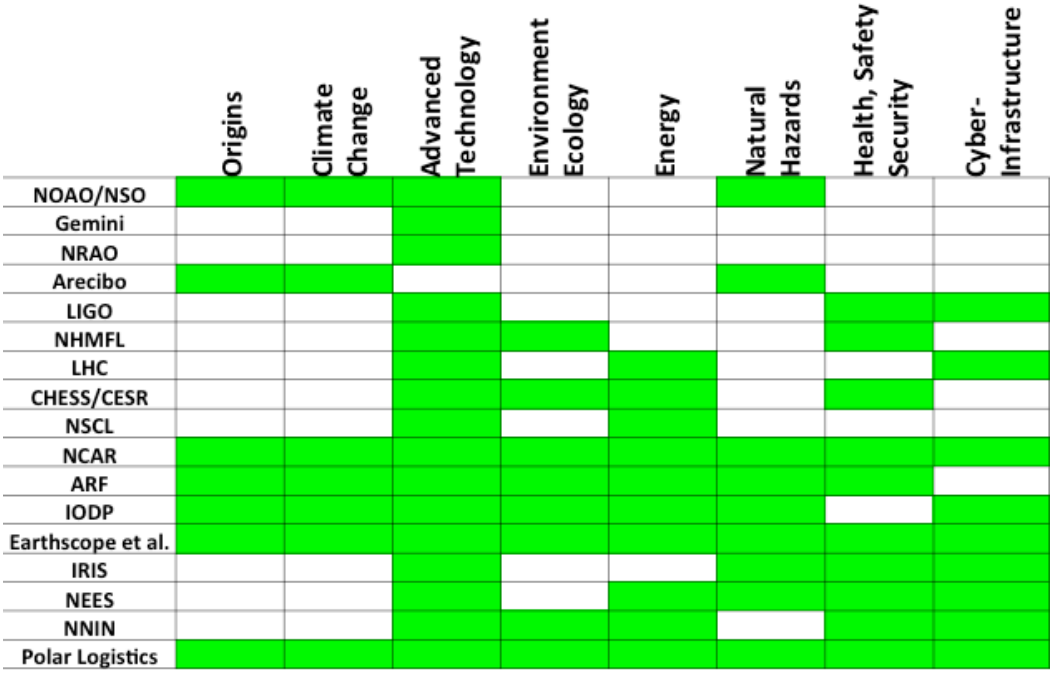


Figure 10c. Contributions of the NSF's Major Multi-User Facilities to strategic priorities

Finding: SCF finds that the large multi-user facilities have been extremely effective in leveraging with external partners, enabling multi-disciplinary research, and addressing high priority scientific problems. There are indications that mid-scale facilities, which constitute a significant investment on an annual basis, have been equally successful in these areas, but NSF does not routinely compile the information needed to definitively make this assessment.

Recommendations: Through the APR, the subcommittee should monitor the extent to which facilities supported by NSF are helping the Foundation achieve its strategic goals. Requisite information for this evaluation should be collected routinely to ensure NSF investments in facilities continue to encourage interdisciplinary research, effective leveraging, and societally relevant outcomes.

APPENDIX A: MANAGEMENT, REVIEW AND PRIORITIZATION OF NSF'S LARGE FACILITIES

The NSF's Large Facilities Office has defined a formal process for preconstruction planning, review, and authorization of large infrastructure projects (multi-user science facilities) in its *Large Facilities Manual* (NSF 10-12). Candidate MREFC construction projects advance through a progressive sequence of increasingly detailed development and assessment steps prior to approval for construction funding. The NSF process is illustrated in Figure A.1 with the analogous NSB process in Figure A.2.

To identify facility projects for potential development, the NSF reacts to opportunities articulated and advocated by the research community during the earliest stage of consideration. These ideas are subjected to external merit review, and those ideas or concepts of exceptional merit are further developed into conceptual designs that define the key research questions the proposed facility is intended to address.

For the most promising projects, the NSF encourages proponents to develop conceptual designs that include the definition and relative prioritization of the research objectives and science questions that the proposed facility will address; a comprehensive statement of the science requirements to be fulfilled by the proposed facility, which establish a basis for determining the project's design goals and infrastructure requirements; and descriptions of the functional requirements of the major subsystems of the proposed facility that are essential to achieve the research objectives.

If the project is selected by the NSF for more intensive development and planning, the NSF requests proponents to provide a Project Development Plan (PDP) that details the scope, schedule, and budget needed to develop the project's Preliminary Design. At this point, if the NSF approves the PDP, this activity is carried out in the Preliminary Design / Readiness Stage. The goal of this stage is to identify and quantify all of the key cost drivers associated with the proposed project into a Preliminary Design, providing detailed descriptions of all major facility subsystems and their interconnections, a bottom-up cost estimate with substantiation for the basis of the estimate, a detailed risk assessment and algorithmically based contingency estimate, and a resource loaded schedule.

After the NSF's review and approval process, a potential large facility project may subsequently be approved for implementation by the Board. At this stage, the project team continues to refine cost estimates, recruit additional construction staff, finalize partnership commitments, and complete other preparatory work that must be accomplished prior to commencing construction. In parallel with the congressional appropriation process, a final pre-construction design is prepared by the project's proponents.

Construction and Operations phases are typically accomplished through Cooperative Agreements (CAs) between NSF and an external entity following peer-review and approval of the respective proposals. In most cases, the entity responsible for constructing and commissioning the facility also has responsibility for initial operation.

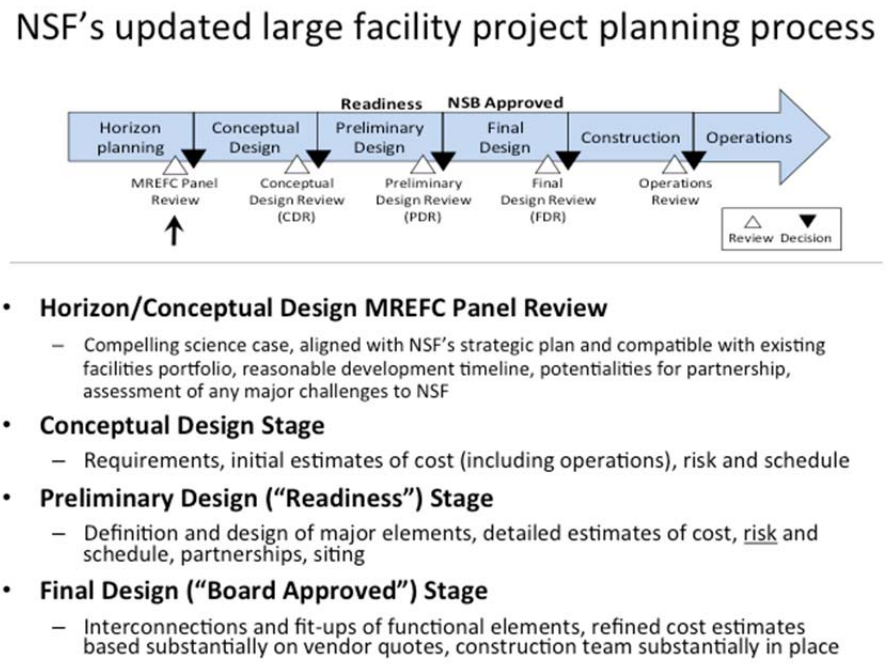


Figure A.1. NSF process for review of MREFC projects.

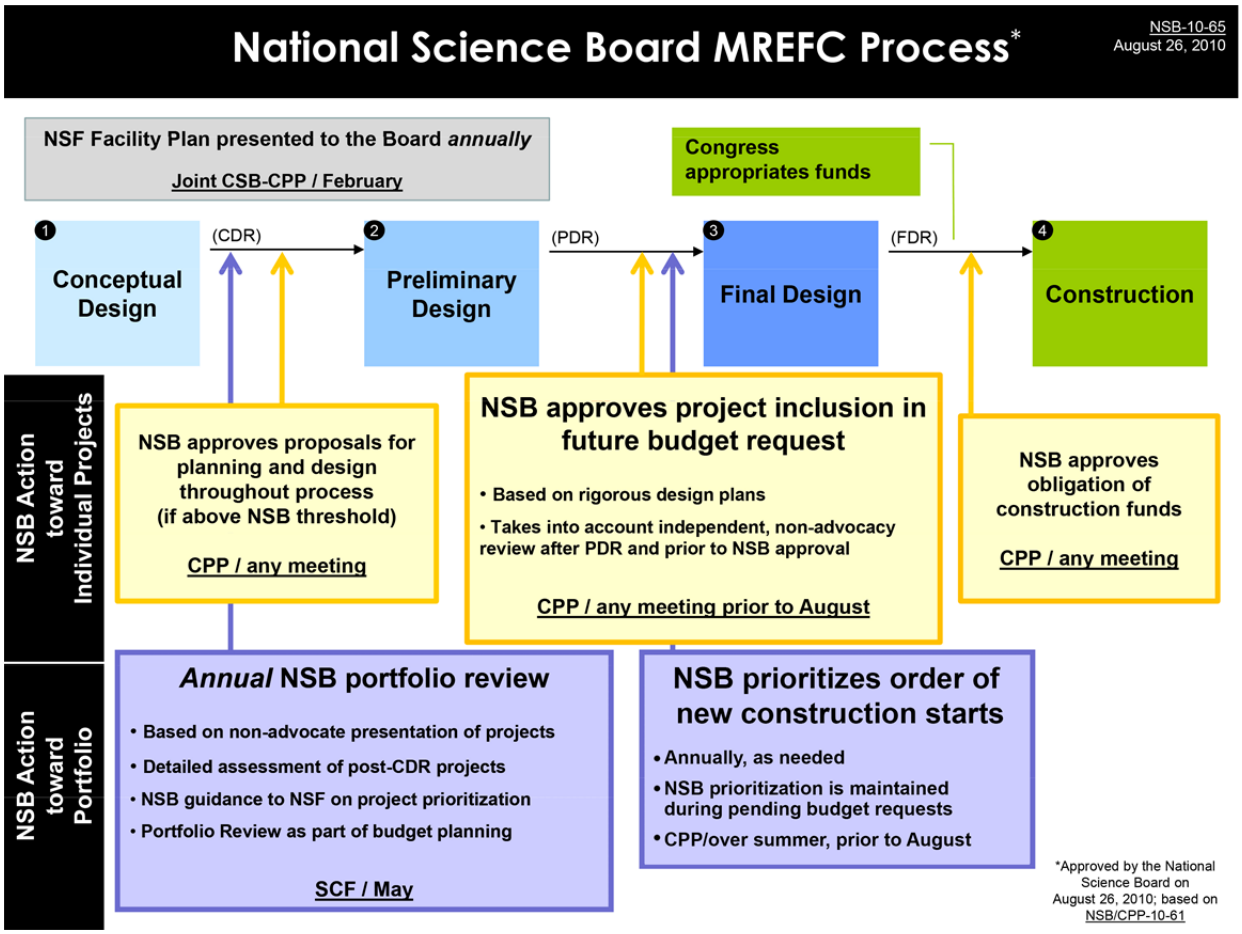


Figure A.2. NSB process for review and approval of MREFC projects.

During construction, large facilities are qualitatively evaluated through periodic project reviews that may include examination of quantitative data, such as cost and contingency, schedule, scope change, and risk reduction. More quantitative assessment is accomplished through Earned Value Management (EVM). The program officer, with support from the LFO, looks at variances in cost and schedule performance relative to a pre-established baseline. These data, along with project status and issues, are reported to the Deputy Director for Large Facility Projects on a monthly basis.

In 2004, the National Academies published a report, *Setting Priorities for Large Research Facility Projects Supported by the National Science Foundation*, that recommended procedures for identifying, approving, constructing, and managing large research facility projects. In addition to the scientific and technical quality of the facility, the report specified three ranking criteria for prioritizing proposed projects:

- First Ranking: Scientific and technical criteria assessed by researchers in a field or disciplinary area.

- Second Ranking: Agency strategic criteria assessed across related fields by using the advice of Directorate advisory committees

- Third Ranking: National criteria assessed across all fields by NSB.

Stressing the qualitative nature of these ranking criteria, the report recommended they be used as a framework for discussions aimed at prioritizing projects across disciplines.

In addition to these criteria, other factors are used in evaluating proposed projects within individual Directorates. These include:

- Scientific Merit—The science must be community driven and the facility must continually perform at the cutting edge of discovery.

- Role of facility in the discipline.

- Technological and management readiness.

- Operational costs through life cycle—The facility must have efficient and cost effective management. When possible, facilities should coordinate activities to take advantage of economies of scale and avoid redundancy.

- Strength and nature of partnerships—The facility should establish partnerships whenever possible with private foundations, industry, government agencies, and international institutions.

- Broader Effects—The facility should have an aggressive program in education, public outreach, and diversity. The accomplishments and outputs of the facility must be well publicized, broadly disseminated, and easily accessible. Timely delivery of data will improve the societal relevance of information and knowledge gained from the facility.

- Balance among other activities in the discipline.

- Multi-disciplinary—By undertaking activities that cross disciplinary boundaries, facilities can enhance scientific contributions while securing a more sustainable future by not being too dependent on the health of one particular area of research.

APPENDIX B: NSB OFFICE O&M ANALYSIS

Section 3, Question 2, examines trends in O&M expenditures at MMURFs, including a plot (Figure 6) that shows historical spending levels and projections under a flat funding scenario. This appendix contains additional details, exploring the potential impact of O&M costs on future sponsoring Directorate and Division budgets under three NSF budgetary scenarios: –5 percent, flat, and +5 percent.

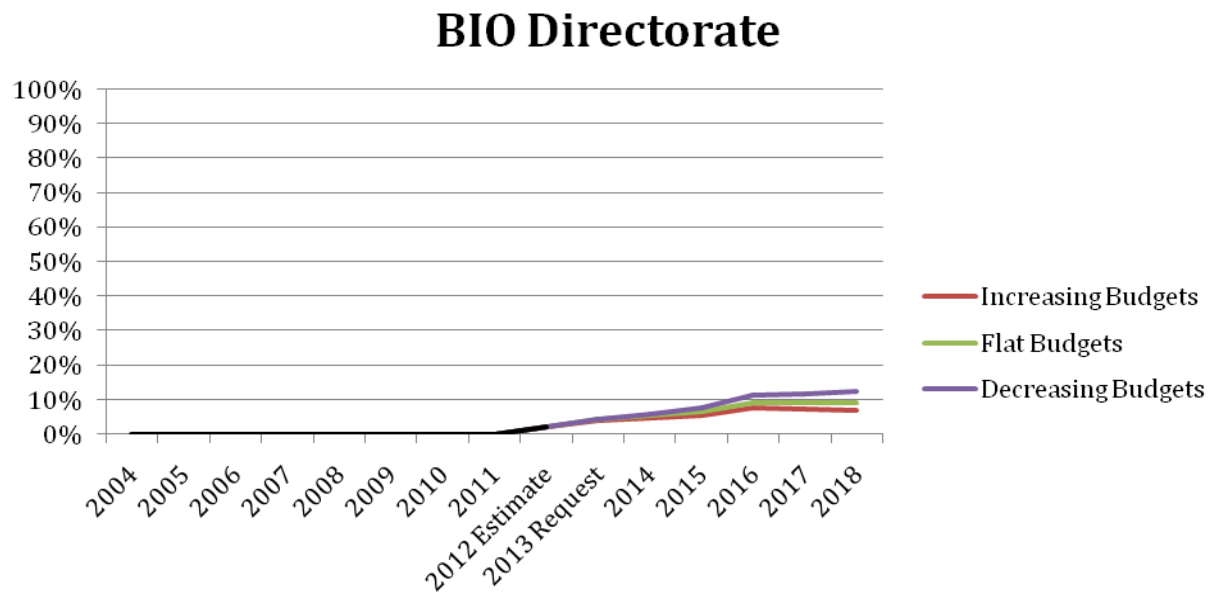
The charts on the pages that follow show MMURF O&M trends for the six Divisions that spend more than 20 percent of their budget in this category. The Divisions, which are spread across three NSF Directorates, are:

- Directorate for Biological Sciences (BIO)
  - Emerging Frontiers Office (EF)
- Directorate for Mathematical and Physical Sciences (MPS)
  - Division of Astronomical Sciences (AST)
  - Division of Physics (PHY)
- Directorate for Geosciences (GEO)
  - Division of Ocean Sciences (OCE)
  - Division of Atmospheric and Geospace Sciences (AGS)
  - Division of Earth Sciences (EAR)

These are also the six Divisions that show the greatest out-year changes in Figure 6. It is important to bear in mind that future budget numbers for these organizations are updated annually as part of the NSF budget process. Directorates, Divisions, and the Foundation as a whole are likely to develop a more nuanced strategic response to budgetary challenges than the FY 2013 out-year projections that underpin this analysis.

BIO / EF: NEON

As the National Ecological Observatory Network (NEON) comes on-line between FY 2012 and FY 2016, it is projected to take a rapidly increasing percentage of the Emerging Frontiers (EF) Division's available funds to operate it. Apart from a negligible amount of funding that BIO's Biological Infrastructure (DBI) Division contributes to NNIN, NEON is the BIO Directorate's only large facility. It is likely simplistic to assume that all NEON funding will continue to come from EF. Instead, the plot below shows NEON's impact on the budget at the Directorate level under three scenarios. For context in absolute dollars, BIO's budget grew from $587 million in 2004 to $712 million in 2012.

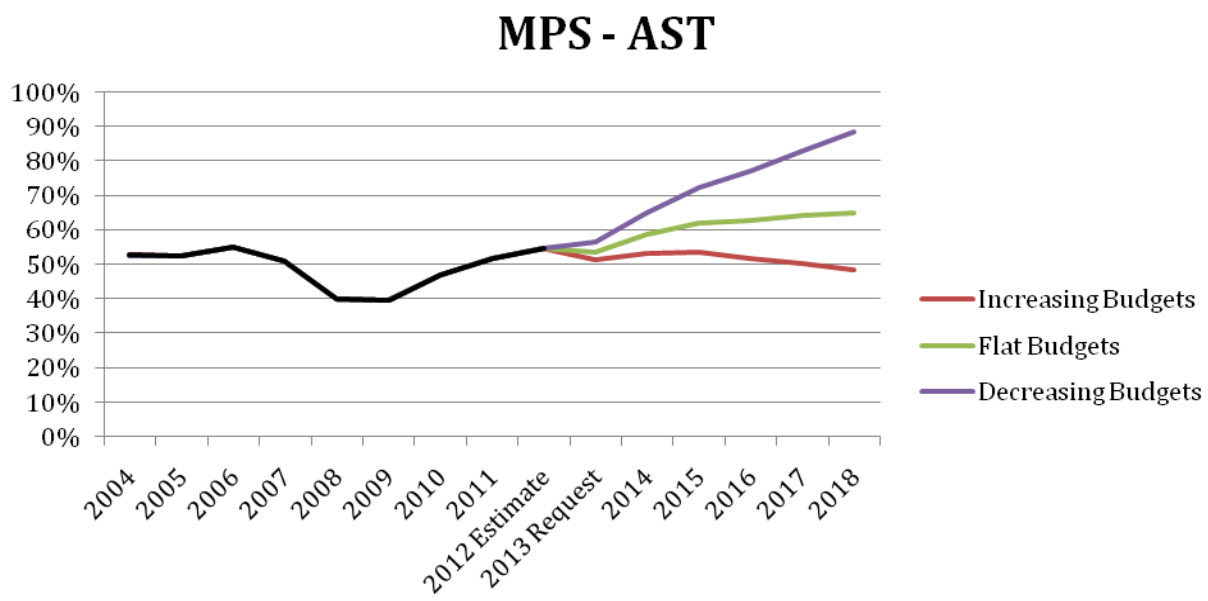


	2004	2005	2006	2007	2008	2009	2010	2011	2012 Estimate	2013 Request	2014	2015	2016	2017	2018
+5% / year	0%	0%	0%	0%	0%	0%	0%	0%	2%	4.1%	4.9%	5.6%	7.5%	7.2%	6.8%
Flat	0%	0%	0%	0%	0%	0%	0%	0%	2%	4.3%	5.4%	6.4%	9.2%	9.2%	9.2%
-5%/ year	0%	0%	0%	0%	0%	0%	0%	0%	2%	4.5%	6.0%	7.5%	11.3%	11.9%	12.5%

Figure B.1. Percentage of BIO budget devoted to NEON O&M.

MPS / AST: Arecibo, Gemini, NSO, ATST, NRAO, NOAO, ALMA

The Division of Astronomical Sciences (AST) supports a number of MMURFs; O&M expenditures for the Advanced Technology Solar Telescope (ATST) and the Atacama Large Millimeter Array (ALMA) are expected to increase in the near future. In aggregate, these facilities have the potential to consume a significant portion of AST's total budget. Although this Division has historically allocated a larger percentage of their budget to O&M than any other, it is not clear whether current plans would allow them to maintain the historical percentage (roughly 50 percent) if future budgets decrease. Although Figure B.2 is potentially disconcerting, it is important to note that increases of 3 percent per year from AST's current budget of $235 million would keep the percentage allocated to O&M costs constant, at 55 percent[8]. This is entirely consistent with historical rates of increases, but may conflict with broader political and budgetary concerns. The requested increase to $245 million in the FY 2013 request would also mitigate this concern.

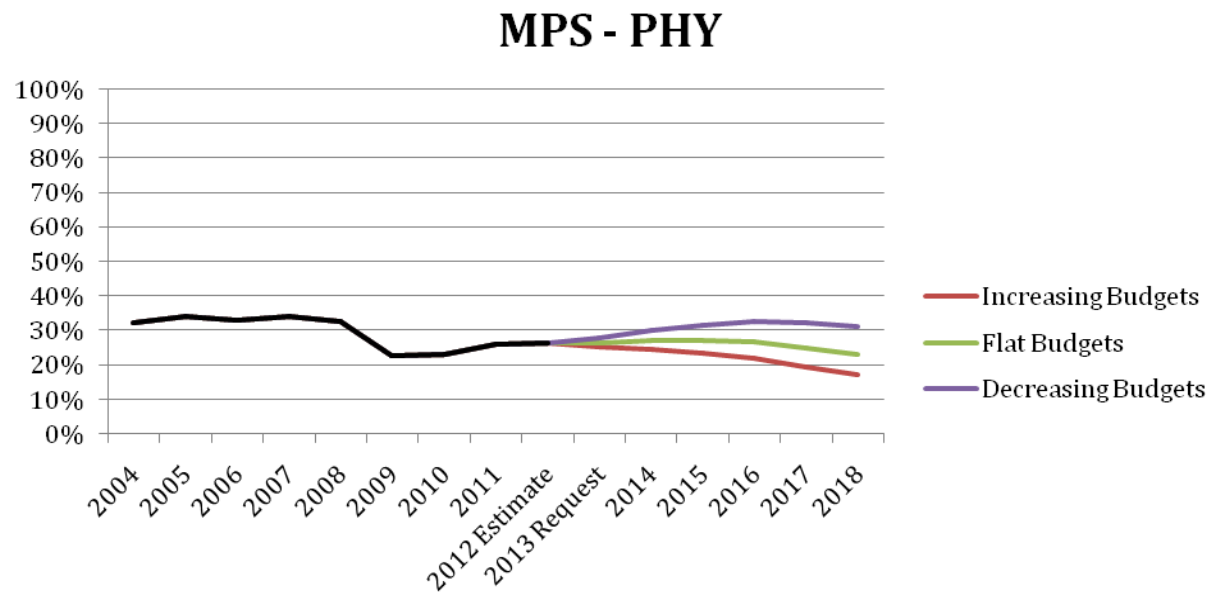


	2004	2005	2006	2007	2008	2009	2010	2011	2012 Estimate	2013 Request	2014	2015	2016	2017	2018
+5% / year	53%	52%	55%	51%	40%	40%	47%	52%	55%	51%	53%	54%	52%	50%	49%
Flat	53%	52%	55%	51%	40%	40%	47%	52%	55%	54%	59%	62%	63%	64%	65%
-5%/ year	53%	52%	55%	51%	40%	40%	47%	52%	55%	57%	65%	72%	77%	83%	89%

Figure B.2. Percentage of AST budget devoted to O&M cost for, Gemini, NSO, ATST, NRAO, NOAO, and ALMA.

MPS / PHY: CHESS / CESR, IceCube, LHC, Advanced LIGO / LIGO, NSCL

The Division of Physics (PHY) is noteworthy because, despite its involvement in a number of MMURFs and its allocation of over 20% of its $277 million budget to these facilities, it is expected to have decreasing future investments in O&M for current facilities. Part of this is explained by the Division of Materials Research (DMR), also within the MPS Directorate, assuming responsibility for Cornell High Energy Synchrotron Source (CHESS) funding in FY 2010. Even if its budget were to decline 2.2 percent per year, PHY would still spend 26 percent of its budget on MMURF O&M.

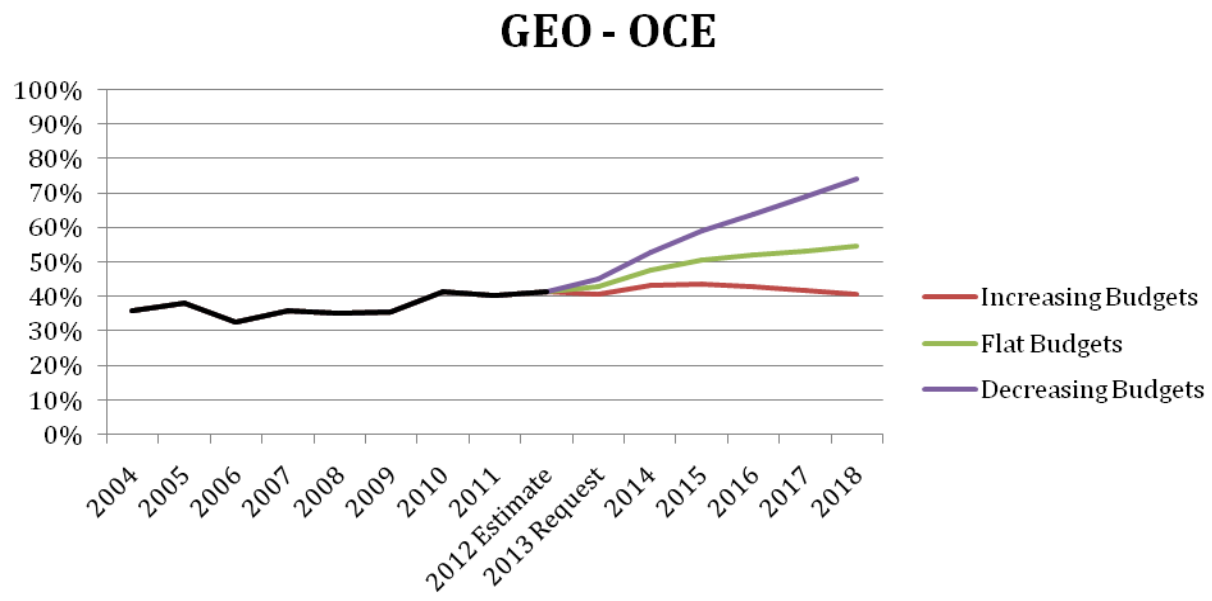


	2004	2005	2006	2007	2008	2009	2010	2011	2012 Estimate	2013 Request	2014	2015	2016	2017	2018
+5% / year	32%	34%	33%	34%	33%	23%	23%	26%	26%	25%	25%	23%	22%	19%	17%
Flat	32%	34%	33%	34%	33%	23%	23%	26%	26%	26%	27%	27%	27%	25%	23%
-5%/ year	32%	34%	33%	34%	33%	23%	23%	26%	26%	28%	30%	32%	33%	32%	31%

Figure B.3. Percentage of PHY budget spent on O&M for CHESS / CESR, IceCube, LHC, LIGO, and NSCL.

GEO / OCE: IODP, OOI, ARRV, Academic Research Fleet

The Division of Ocean Sciences, which operates several major and long-standing MMURFs has significant O&M costs and is exposed to volatility in the price of ship fuel. Ocean Observatories Initiative (OOI) and the Research Fleet continue to be significant, long-standing O&M expenditures. In addition, the OOI began ramping up operations in FY 2010 and the R/V Sikuliaq, formerly the Alaska Region Research Vessel (ARRV), is expected to come on-line in 2014. As shown in Figure B.4 below, these additional projects have the potential to significantly alter the percentage of OCE's $352 million budget spent on O&M costs for MMURFs. In order to hold OCE's MMURF percentage constant, at 41 percent, it would need increases of 4.8 percent per year between FY 2013 and FY 2018.

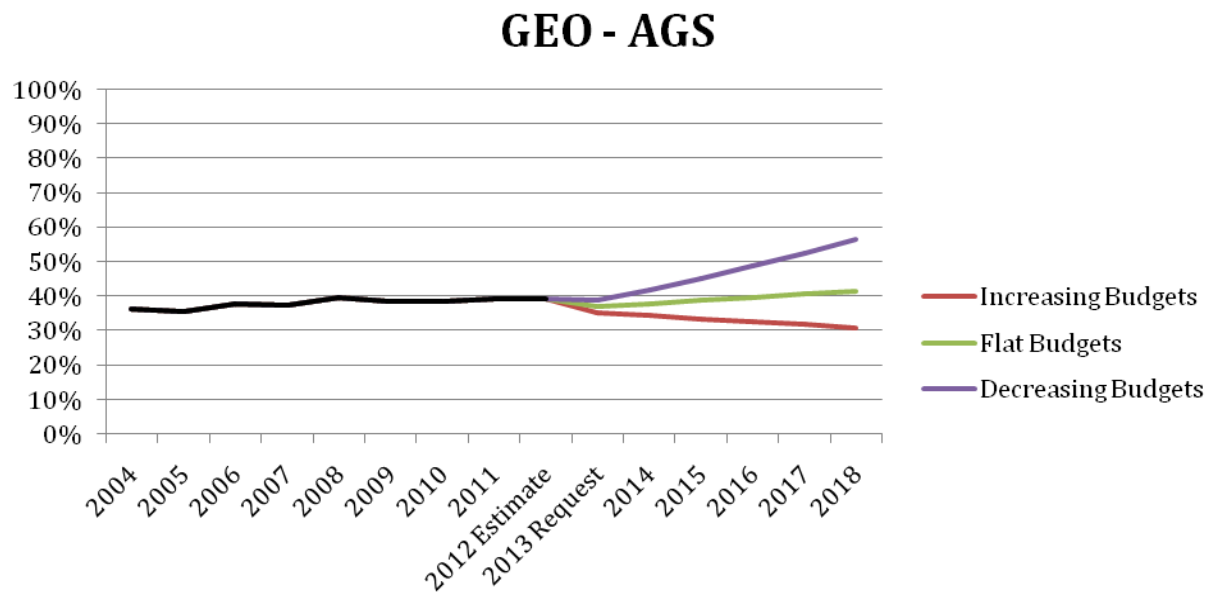


	2004	2005	2006	2007	2008	2009	2010	2011	2012 Estimate	2013 Request	2014	2015	2016	2017	2018
+5% / year	36%	38%	33%	36%	35%	36%	41%	40%	41%	41%	43%	44%	43%	42%	41%
Flat	36%	38%	33%	36%	35%	36%	41%	40%	41%	43%	48%	51%	52%	53%	55%
-5%/ year	36%	38%	33%	36%	35%	36%	41%	40%	41%	45%	53%	59%	64%	69%	74%

Figure B.4. Percentage of OCE budget spent on O&M for IODP, ARRV, OOI, and the Research Fleet

GEO / AGS: NCAR, Arecibo (formerly NAIC)

The Atmospheric and Geospace Sciences (AGS) Division allocates O&M costs to the National Center for Atmospheric Research (NCAR) and the National Astronomy and Ionosphere Center (NAIC), as well as to smaller instruments such as AMISR that are outside of the scope of this MMURF analysis. Its O&M costs are dominated by NCAR, which receives $99 million of the Division's $259 million FY 2012 budget. NCAR, however, does not specifically break out O&M. Thus, it is important to note that the NCAR "O&M" funding shown in Figure B.5 includes investments in research and education. In order to hold the percentage spent on O&M for MMURFs constant, AGS would need modest budget increases of 0.9 percent per year.

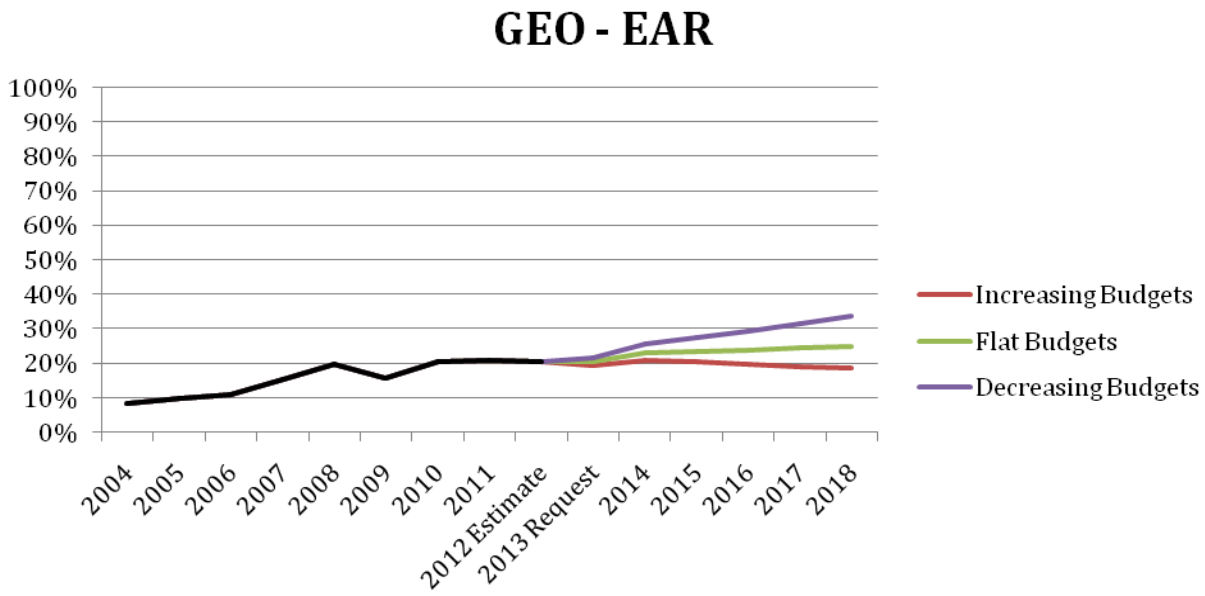


	2004	2005	2006	2007	2008	2009	2010	2011	2012 Estimate	2013 Request	2014	2015	2016	2017	2018
+5% / year	36%	36%	38%	37%	40%	38%	38%	39%	39%	35%	34%	34%	33%	32%	31%
Flat	36%	36%	38%	37%	40%	38%	38%	39%	39%	37%	38%	39%	40%	41%	41%
-5%/ year	36%	36%	38%	37%	40%	38%	38%	39%	39%	39%	42%	45%	49%	52%	56%

Figure B.5. Percentage of AGS budget spent on O&M at NCAR and NAIC.

GEO / EAR: EarthScope, IRIS

The Division of Earth Sciences (EAR) is noteworthy in that an increasing percentage of its now $184 million budget has been devoted to MMURF O&M since 2004. This longer term, gradual increase shown in Figure 6 is distinct from the increases for the other Divisions examined here. Based on out-year projections for EarthScope, EAR would require increases of 3.5 percent per year to stabilize at 20 percent of the Division's budget.



	2004	2005	2006	2007	2008	2009	2010	2011	2012 Estimate	2013 Request	2014	2015	2016	2017	2018
+5% / year	8%	10%	11%	15%	20%	16%	21%	21%	20%	19%	21%	20%	20%	19%	19%
Flat	8%	10%	11%	15%	20%	16%	21%	21%	20%	20%	23%	24%	24%	24%	25%
-5%/ year	8%	10%	11%	15%	20%	16%	21%	21%	20%	21%	26%	28%	29%	32%	34%

Figure B.6. Percentage of EAR budget spent on O&M for EarthScope and IRIS.

APPENDIX C: TABLE OF ABBREVIATIONS

AdvLIGO	Advanced Laser Interferometer Gravitational-Wave Observatory
AGS	Division of Atmospheric and Geospace Sciences
ALMA	Atacama Large Millimeter Array
AMISR	Advanced Modular Incoherent Scatter Radar
APR	Annual Portfolio Review
ARF	Academic Research Fleet
ARRA	American Recovery and Reinvestment Act of 2009
ARRV	Alaska Region Research Vessel
AST	Division of Astronomical Sciences
ATST	Advanced Technology Solar Telescope
BIO	Directorate for Biological Sciences
BSR	Business Systems Review
CA	Cooperative Agreement
CDR	Conceptual Design Review
CESR	Cornell Electron Storage Ring
CHESS	Cornell High Energy Synchrotron Source
CISE	Directorate for Computer and Information Science and Engineering
CSB	Committee on Strategy and Budget
CP	Current Plan
DBI	Division of Biological Infrastructure
DMR	Division of Materials Research
EAR	Division of Earth Sciences
EF	Emerging Frontiers Office
ENG	Directorate for Engineering
EVM	Earned Value Management
FDR	Final Design Review
FFRDC	Federally Funded Research and Development Center
GENI	Global Environment for Network Innovation
GEO	Directorate for Geosciences
HPC	High Performance Computing
IODP	Integrated Ocean Drilling Program
IRIS	Incorporated Research Institutions for Seismology
ITAR	International Traffic in Arms Regulations
LFO	Large Facilities Office
LHC	Large Hadron Collider
LIGO	Laser Interferometer Gravitational-Wave Observatory
LSST	Large Synoptic Survey Telescope
MMURF	Major Multi-User Research Facility
MPS	Directorate for Mathematical and Physical Sciences
MREFC	Major Research Equipment and Facilities Construction
NAIC	National Astronomy and Ionosphere Center
NCAR	National Center for Atmospheric Research
NEES	Network for Earthquake Engineering Simulation
NEON	National Ecological Observatory Network
NHMFL	National High Magnetic Field Laboratory

NNIN	National Nanotechnology Infrastructure Network
NOAO	National Optical Astronomy Observatories
NRAO	National Radio Astronomy Observatory
NSB	National Science Board
NSCL	National Superconducting Cyclotron Lab
NSF	National Science Foundation
NSO	National Solar Observatory
O&M	operation and maintenance
OCE	Division of Ocean Sciences
OISE	Office of International Science and Engineering
OCI	Office of Cyberinfrastructure
OOI	Ocean Observatories Initiative
OPP	Office of Polar Programs
PDP	Project Development Plan
PDR	Preliminary Design Review
PHY	Division of Physics
PI	principal investigator
R&RA	Research and Related Activities
RCRV	Regional Class Research Vessels
SCF	Subcommittee on Facilities
STEM	Science, Technology, Engineering and Mathematics
XSEDE	eXtreme Science and Engineering Discovery Environment

ENDNOTES

[1] The NSB-approved MREFC review process in is reproduced in Appendix A, Figure A.2.
[2] National Science Foundation, "Large Facilities Manual," NSF 10-12, March 31, 2011, http://www.nsf.gov/publications/pub_summ.jsp?ods_key=lfm.
[3] This analysis also generally includes ARRA funding, with the exception of several instances. For example, additional Research Fleet operations enabled by ARRA funds were excluded as atypical for trend analysis purposes.
[4] To account for the atypical ARRA budgets, an effective rate of average growth was computed by fitting a line to the end points.
[5] Inflation is based on the gross domestic product (chained) price index, following the Office of Management and Budget's approach to calculating constant dollar research and development outlays in its historical tables.
[6] NSB Report to Congress on Midscale Instrumentation, December 2011.
[7] Taken from NSF Facility Plan, 2012.
[8] Inflation is not considered in this assertion.