NSB-14-62
November 19, 2015

Annual Portfolio Review of Facilities
FY 2014

National Science Board
Committee on Strategy and Budget
Subcommittee on Facilities

NATIONAL SCIENCE BOARD

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National Science Board

November 19, 2015

MEMORANDUM FROM THE CHAIRMAN OF THE NATIONAL SCIENCE BOARD

SUBJECT: FY 2014 *Annual Portfolio Review of Facilities*

The National Science Board (Board, NSB) established the Subcommittee on Facilities of the Committee on Strategy and Budget in May 2009 to oversee the National Science Foundation's (NSF) portfolio of facilities and to provide guidance to the Board on strategic planning for NSF's research equipment and facilities portfolio. An important element of the Subcommittee's mission is to ensure that NSF's divisions and directorates have processes that evaluate tradeoffs between the concept and development work that seeds future projects and support provided for construction, operation, or transitioning of facilities.

The National Science Board is pleased to issue the FY 2014 Annual Portfolio Review of Facilities (APR). This report presents a broad overview of existing and planned research facilities and their projected long-term impact on budgets within the Foundation. This review differs in three notable ways from its predecessors. First, it provides less detail, relying instead on the Facilities Synopses that NSF produced in response to a recommendation in the previous APR. Second, it highlights community prioritization processes and stakeholder input as part of its presentation of lifecycle information.

Finally, this report does not include detailed assessment of the impact of specific projects or in-depth analysis of strategic issues. The Subcommittee has now separated those responsibilities from writing the APR, to allow more careful deliberation. For instance, the Subcommittee produced a whitepaper on the Regional Class Research Vessels (**NSB-CSB-SCF-2015-6**) that assessed that potential project's impact and made recommendations to the Committee on Strategy and Budget and the Board.

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

Dan E. Arvizu
Chairman

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EXECUTIVE SUMMARY

The Subcommittee on Facilities' (SCF) Annual Portfolio Review (APR) provides the National Science Board (Board, NSB) with a system-wide view of the National Science Foundation's (NSF) investments in research facilities. Complementing NSF's Annual Facilities Plan and Facility Synopses, the APR presents information about the composition of the research facilities portfolio and the budget impacts of existing, planned, and potential large facilities. It also includes data on how directorates and divisions balance the ongoing funding of such facilities with support for individual investigator grants.

Large research facilities are essential to conducting research in many of the sciences supported by NSF. As the Foundation grapples with an uncertain fiscal climate, soundly managing facilities, which often have fixed obligations, becomes ever more important. Persistent challenges include accommodating flat Operations &Maintenance (O&M) costs as new facilities enter operations; balancing, at the division and directorate levels, support for facilities with support for single investigator grants; and facilitating transitions at the end of the facility lifecycle.

NSF management has responded to these pressures by honing its strategic planning processes. Information in the Facility Synopses has provided a deeper understanding of lifecycle stages/decision points associated with each individual facility. Collectively, the information in the synopses has given both NSF and NSB a more robust portrait of the entire facility portfolio.

Community planning processes – long a feature of NSF's approach to facilities – have become more important as divisions and directorates seek community input to prioritize new facility ideas and determine the appropriate balance for that community between facility O&M and funding of research grants. The Subcommittee is pleased to note that several community-driven reports have directly considered budgetary tradeoffs in evaluating new Major Research Equipment and Facilities (MREFC) projects.

This report summarizes NSF's facility investments, projects associated budgets over the next five years, and outlines near-term challenges and pressures. The latter include new facilities coming online, ongoing discussions about transitioning facilities, and deliberations over new facilities. Section 3 of this report details these issues, notably including a summary of community-driven assessment and priority-setting processes and expressions of Congressional interest.

In considering these factors, Board Members may find Table 3 of particular use. Based on the NSF Budget Requests and Facility Synopses, this table summarizes high-level planning and financial characteristics of existing facilities. It shows that the Board will likely be considering renewals and recompetitions for several NSF facilities in the near-term.

Finally, Section 4 of this report details the ways in which NSF and NSB have collaboratively addressed most of the recommendations offered in the previous APR, as well as status reports for those recommendations not yet addressed.

SECTION 1: INTRODUCTION

Over the past decade, largely in response to Congress,[1,2,3] the National Science Board's (NSB) involvement in the oversight, planning, and assessment of the National Science Foundation's facilities portfolio has increased.[4] The Subcommittee on Facilities (SCF) was created in 2009 as a focal point on facilities issues and to address Operations and Maintenance (O&M) and pre-construction cost concerns raised in a 2008 NSB report.[5]

To partially fulfill its charge, SCF conducts an Annual Portfolio Review (APR) of National Science Foundation (NSF) facilities at all life-cycle stages. While this report may be useful for other audiences, it is primarily written for the Board, to support its strategic planning and statutory Major Research Equipment and Facilities Construction (MREFC) responsibilities. This report provides a high-level summary of NSF's facilities investments and projected changes to the portfolio. The APR complements the annual NSF Facility Plan and Budget Requests, both of which contain detailed information on individual facilities, including their scientific goals, status, budget, and management structure. To address other areas of its charge, such as analyzing and prioritizing MREFC projects that have completed a Conceptual Design Review,[6] SCF also produces white papers that build on this portfolio review.

Purpose

By offering a portrait of the current portfolio and upcoming changes, this report provides context for understanding how proposed facility developments would fit within NSF's present and future portfolio. The goal is to help the Board to evaluate candidate facilities and prioritize "their relative importance for further development, looking across the entire range of disciplines served by NSF within the constellation of other competing opportunities, existing facilities, and the balance of support for infrastructure, its utilization, and individual investigator-led research."[7] It pays special attention to budgetary impacts, opportunity costs, and future liabilities associated with facilities.

An important element of SCF's mission is to ensure that NSF's divisions and directorates have processes that evaluate the tradeoffs within Research & Related Activities (R&RA) that involve funding core research, operating and maintaining existing facilities, and investing in concept and development work. Likewise, SCF plays a role in examining the balance between the Major Research Equipment and Facilities Construction (MREFC) and R&RA accounts. Decisions about the facility portfolio should consider the opportunity costs to individual disciplines and the Foundation as a whole. Though the APR focuses on budgetary tradeoffs, it is important to note that facilities are usually intertwined with disciplinary research programs, and that scientists often need both grants and infrastructure to conduct their research.

Scope

The APR is built on two baseline questions about NSF's facilities portfolio:

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[1] See Appendix A.
[2] The America COMPETES Reauthorization Act of 2010, P.L. 111-478 § 507
[3] The America COMPETES Act, P.L. 110-69 § 7014
[4] See Appendix B.
[5] NSB-08-15.
[6] This helps fulfill the Board's statutory responsibility for project approval and prioritization of approved but not-yet-funded MREFC projects.
[7] Large Facilities Manual, p. 17, 2013.

1. What facilities comprise NSF's portfolio?
2. What changes to the portfolio are expected?

Definitions of several kinds of research infrastructure, along with an explanation of how they relate to the scope of the APR, can be found in Appendix B.

Inputs to the Review

The SCF Annual Portfolio Review relies on information from:

- NSF Budget Requests to Congress;
- the annual *NSF Facility Plan* (presented to the NSB in February);
- the public awards database; and
- The Facility Synopses prepared for SCF by NSF.

Overview of NSF's Portfolio of Facilities

The facility portfolio contributes primarily (but not exclusively) to the first part of NSF's mission — "to promote the progress of science" — and the Foundation's first Strategic Goal: *Transform the frontiers of science and engineering.*

As NSF's Strategic Plan for 2014-2018 states:

> *To fulfill our core mission of "promoting the progress of science," NSF must provide the research community with advanced and powerful tools and capabilities to keep the Nation's research enterprise at the global forefront. These tools and capabilities include major research facilities, mid-scale instrumentation … Large facilities hold the promise of major discoveries and revolutionary advances that can propel whole fields forward, thereby justifying significant investment costs. These facilities also are training grounds for the scientists and engineers of tomorrow. Smaller, so-called "mid-scale" instruments are increasingly critical for enabling fundamental research in the experimental sciences; there is an urgent need to adequately provide this category of instrumentation. … Balancing investments in the development and operation of these tools and capabilities with the rest of NSF's portfolio is a challenging management responsibility. Special challenges derive from life cycle planning … As with all NSF awards, infrastructure projects must meet extremely high standards of scientific merit and broader impacts, and comparable standards of project planning and execution.*[8]

[8] National Science Foundation Strategic Plan for 2014 – 2018

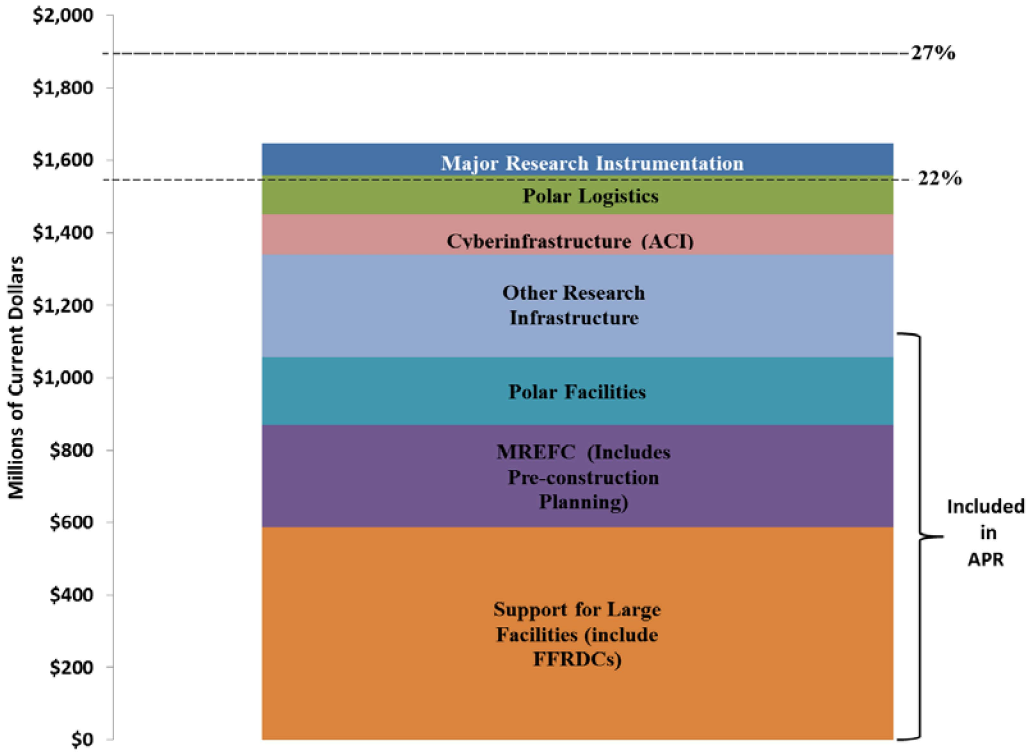

Figure 1. NSF funding of research infrastructure, FY 2014 as reported in NSF's FY 2015 budget request

Figure 1 shows how facilities discussed in this APR fit within NSF's full research infrastructure portfolio and NSB's 2003 guidance, which recommended maintaining infrastructure's share of NSF's budget toward the higher end of the 22-27% historical range. It is based on obligations, not replacement or construction cost, and does not show research infrastructure acquired under single-investigator grants.

Key Points:

- Facilities investments represent roughly 70 percent of Research Infrastructure spending.
- O&M and pre-construction planning for MREFC projects comes from the R&RA account. Only construction comes from the MREFC account.
- Although the APR includes mid-scale facilities, those are not completely represented in Figure 1, which shows the Research Infrastructure total reported in NSF's FY 2015 budget request. Some, but not all mid-scale facilities are included in "Other Research Infrastructure."

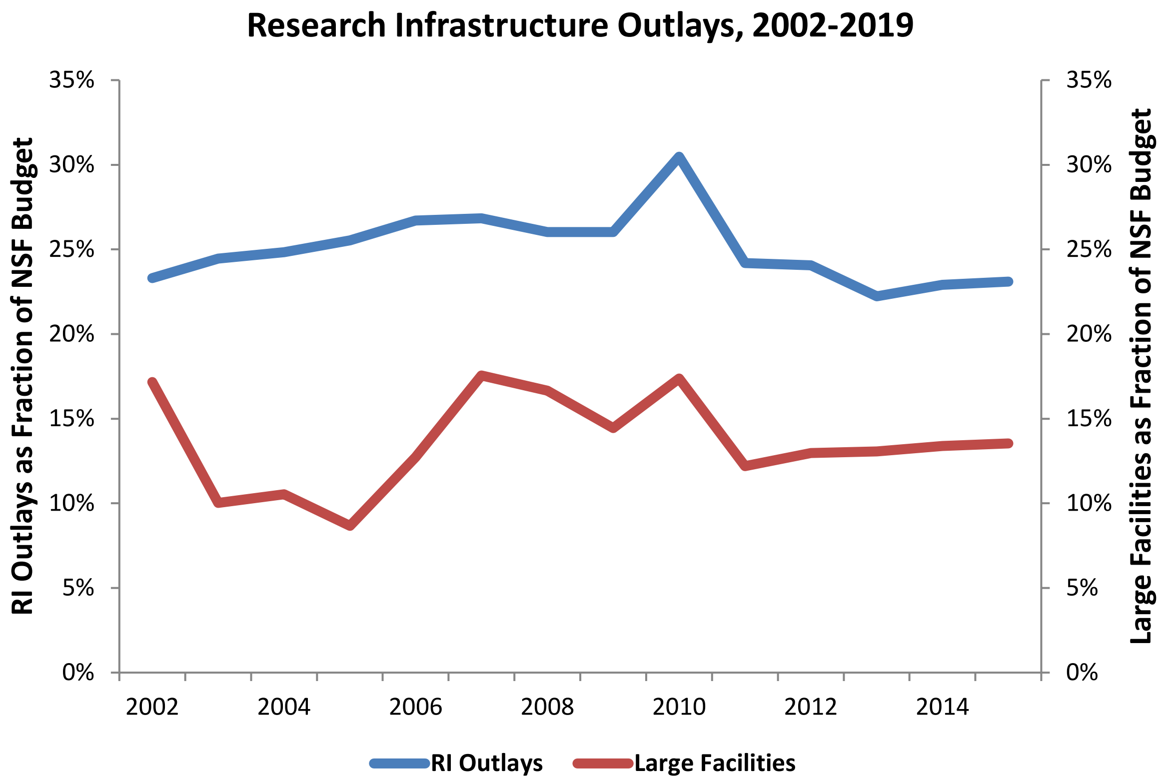

Figure 2. NSF investments in research infrastructure and large facilities

Figure 2 shows historical and projected investments in Research Infrastructure and large facilities as a percentage of the total NSF budget.

Key points:

- These data do not include potential new MREFC construction projects or concept and development work.
- With the exception of 2010, when the American Recovery and Reinvestment Act supported increased investment, NSF's support for research infrastructure has been within the NSB's recommended historical range of 22 – 27%.

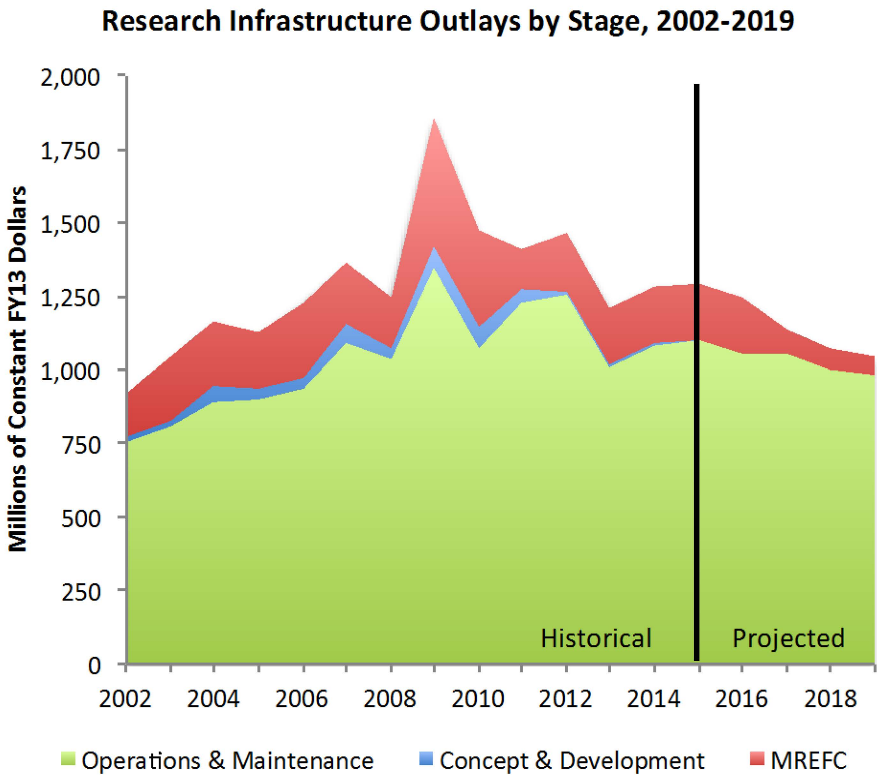

Figure 3. NSF research infrastructure investments by lifecycle stage.

Figure 3 shows historical and projected investments in large facilities by FY and lifecycle stage.

Key points:

- According to current plans, there will be fewer MREFC projects under construction in the coming years.
- Most facilities project their O&M costs as flat. This constant dollar decrease, together with a ramp up in O&M for the Daniel K. Inouye Solar Telescope (DKIST, formerly the Advanced Technology Solar Telescope), Ocean Observatories Initiative, and National Ecological Observatory Network, results in roughly constant total O&M outlays.
- This plot includes no future concept and development outlays, and only captures historical concept and development for completed MREFC facilities.
- Current MREFC construction projects imply additional future O&M obligations.

SECTION 2: CURRENT PORTFOLIO OF FACILITIES

Current Distribution

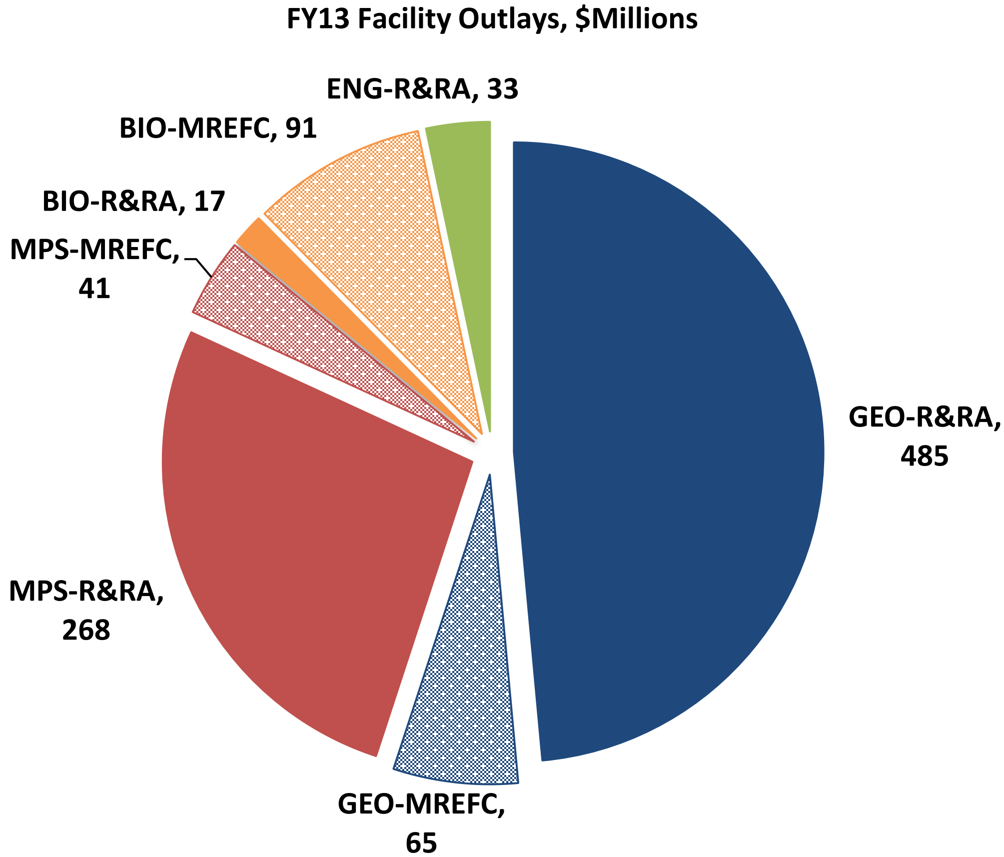

Figure 4. FY13 large facility outlays by Directorate and account.

Figure 4 shows the relative magnitude of each directorate's total large facilities investments from all accounts, including investments from the NSF MREFC account

Key points:

- The research infrastructure portfolio is dominated by GEO and MPS. Within those Directorates, the Divisions of PLR, OCE, AST, AGS, PHY, DMR, and EAR account for most of NSF's facilities investments.
- BIO's facility investments are almost entirely through support for NEON.

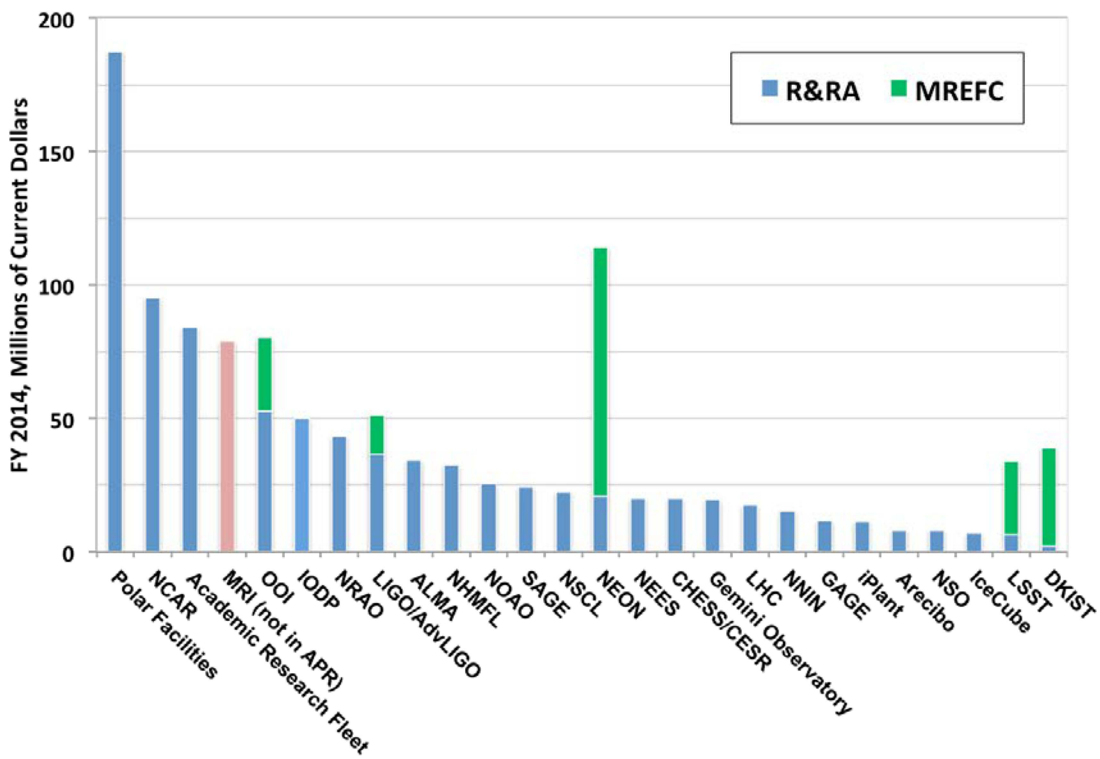

Figure 5. FY 2014 investments in facilities.

Figure 5 shows the relative magnitude of NSF's multi-user facility and cyberinfrastructure investments. It lists large facilities and shows those actively under construction using MREFC funding. For reference, it includes the total value of smaller tools funded by MRI awards. The majority of the R&RA costs are for O&M.

Key points:

- There is wide range in annual facility O&M costs.
- Mid-scale multi-user facilities in aggregate are comparable to the largest facilities (See **Figure 6**), as are total MRI awards.

The relative investment in facilities across NSF organizations reflects historical bases and different priorities in the science communities they serve. Some fields rely more heavily on facilities to perform their research.

Table 1: Large facility outlays from R&RA account in millions of constant FY 2013 dollars. See **Appendix D** for full facility names.

															2015	2016	2017			2002-
BIO	NEON	1	1	4	7	7	13	15	24	26	10	2	4	20	36	41	60	59	57	388
	iPlant	0	0	0	0	0	0	7	10	11	12	12	12	11	10	8	6	0	0	100
ENG	NEES	0	0	0	21	23	22	21	22	24	20	20	21	19	11	12	11	11	11	272
	NNIN	7	7	16	16	16	14	15	28	17	17	16	16	15	15	15	15	14	14	274
GEO	Polar Facilities	156	171	174	178	218	237	231	256	202	189	185	177	182	181	178	175	171	168	3,429
	NCAR	96	97	98	92	94	92	94	126	100	100	103	94	92	94	92	90	88	87	1,730
	ARF	76	79	98	95	85	95	81	112	81	83	93	83	82	83	80	78	77	75	1,534
	IODP	39	36	41	46	36	40	40	76	53	54	52	47	49	46	44	42	41	40	821
	OOI	14	6	4	4	5	7	8	19	17	16	27	36	51	52	52	51	50	49	465
	SAGE	0	0	0	0	0	0	0	0	0	0	26	24	24	23	23	22	22	21	186
	EarthScope	1	5	2	5	7	13	20	35	26	26	0	0	0	0	0	0	0	0	141
	IRIS	16	16	15	14	13	13	12	13	13	13	0	0	0	0	0	0	0	0	137
	GAGE	0	0	0	0	0	0	0	0	0	0	12	9	11	11	11	11	10	10	85
	IceCube	0	0	0	0	0	1	3	5	4	7	7	7	7	7	6	6	6	6	73
	R/V SIKULIAQ	0	0	0	0	0	0	0	0	0	0	0	0	4	8	8	8	8	8	44
	Wyoming HPC	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	17
MPS	NRAO	50	55	65	53	55	48	48	58	51	45	43	40	42	38	37	37	36	35	836
	LIGO/AdvLIGO	30	40	57	47	46	42	31	32	30	31	30	30	35	38	37	36	36	35	663
	NOAO	45	52	49	43	41	42	30	38	37	30	26	25	25	24	20	20	17	17	581
	NHMFL	31	30	29	29	29	29	29	33	58	33	27	31	32	32	32	33	32	32	581
	NSCL	18	19	18	20	19	20	20	24	22	22	22	21	22	21	21	21	20	18	368
	Gemini	15	16	16	18	20	22	20	20	20	20	22	18	19	20	20	20	19	19	343
	CHESS/CESR	24	24	21	19	16	16	21	30	10	14	20	20	19	19	19	18	18	18	346
	ALMA	0	0	0	1	2	4	8	12	19	24	29	32	33	38	38	37	36	35	348
	LHC	2	6	8	12	15	19	19	19	19	18	18	18	17	17	17	18	18	18	278
	Arecibo	14	15	15	14	13	11	13	13	11	9	9	8	8	8	8	8	7	7	193
	NSO	0	0	0	0	0	0	9	10	9	9	9	8	8	8	7	6	5	4	90
	DKIST	0	0	0	0	0	16	3	7	0	2	2	2	2	7	10	12	15	17	94
	LSST	0	2	2	2	6	5	6	6	7	6	5	7	6	0	0	0	0	1	61
		635	**677**	**734**	**738**	**764**	**822**	**803**	**1,023**	**868**	**828**	**815**	**792**	**835**	**848**	**836**	**840**	**816**	**800**	**14,475**
													HISTORICAL		**PROJECTED**					

Table 1 shows historical and projected outlays from the *R&RA account*. These include O&M and concept and development investments. The color coding loosely represents the magnitude of an investment, with red denoting a large investment and green a small one.

Key points:

- Excluding Polar facilities, the GEO Directorate's investments are concentrated in a few larger facilities: National Center for Atmospheric Research, Academic Research Fleet, the Integrated Ocean Drilling Program, and the Ocean Observatories Initiative. In contrast, MPS invests more uniformly across a greater number of facilities.
- Polar facilities receive the largest investments from the R&RA account.
- Large facilities can operate at roughly steady-state budgets for decades. Over time, as operating costs increase, flat budgets can present a serious management problem that requires active engagement with the user community. Section 3 describes some of the community processes that NSF has used to foster such a dialogue.

Notes:

- Two canceled projects, the Deep Underground Science and Engineering Laboratory and the Rare Symmetry Violating Processes experiment, are not shown. These total almost $100 million.
- The Wyoming Supercomputer Center is included in the National Center for Atmospheric Research budget line after FY 2011.
- Facilities that receive or received funding from multiple directorates are shown under the primary directorate. These include CHESS, Arecibo, National Nanotechnology Infrastructure Network, and IceCube. Though not shown, SBE contributes a small amount to the National Nanotechnology Infrastructure Network.

Table 2: Outlays for large facility construction from the MREFC account in millions of constant FY 2013 dollars

DIR		1994-																			1994-
MPS	ALMA	0	15	36	60	56	54	69	108	86	44	14	3	1	0	0	0	0	0	0	547
	LIGO	323	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	323
	DKIST	0	0	0	0	0	0	0	0	0	172	5	10	25	36	24	19	18	18	14	341
	LSST	0	0	0	0	0	0	0	0	0	0	0	0	0	27	76	93	62	50	42	350
	AdvLIGO	0	0	0	0	0	0	0	35	54	48	24	21	15	14	0	0	0	0	0	211
	LHC	70	21	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	103
	Gemini	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62
GEO	OOI	0	0	0	0	0	0	0	0	111	22	66	103	64	27	0	0	0	0	0	392
	IceCube	0	12	31	45	55	63	26	20	12	2	5	2	0	0	0	0	0	0	0	275
	EarthScope	0	0	36	51	51	55	28	4	0	0	0	0	0	0	0	0	0	0	0	227
	R/V SIKULIAQ	0	0	0	0	0	0	3	2	170	34	0	0	0	0	0	0	0	0	0	209
	SPSM	71	19	15	25	19	10	10	8	1	1	0	0	0	0	0	0	0	0	0	179
	SODV	0	0	0	0	7	73	46	0	0	0	0	0	0	0	0	0	0	0	0	127
	HIAPER	25	43	16	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99
BIO	NEON	0	0	0	0	0	0	0	0	0	0	13	60	89	90	92	76	0	0	0	420
ENG	NEES	46	30	16	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102
Grand Total		**598**	**141**	**163**	**206**	**189**	**255**	**183**	**177**	**434**	**324**	**128**	**198**	**194**	**194**	**192**	**188**	**80**	**68**	**57**	**3,966**

Table 2 shows historical and projected MREFC construction costs for large facilities.

Key points:

- In 2015, only the National Ecological Observatory Network, Daniel K. Inouye Solar Telescope (previously referred to as the Advanced Technology Solar Telescope or ATST), and the Large Synoptic Survey Telescope will be under construction.
- Assuming no new projects, the MREFC outlays will shrink in 2017.
- Relative to those in GEO, MPS facilities cost more to build but less to operate. In part this may be due to the nature of geological sciences and their dependence on transportation fuels.

Mid-Scale Facilities

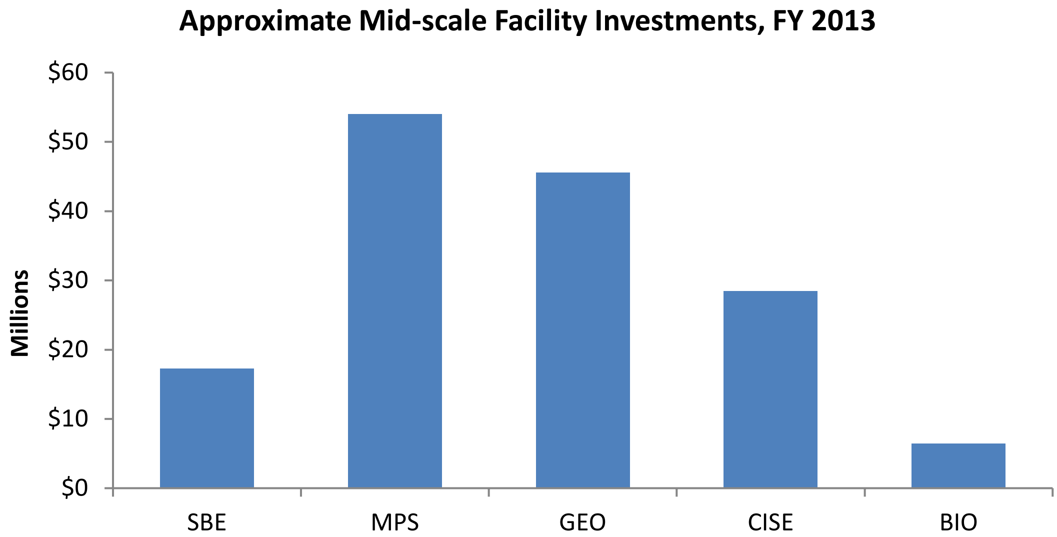

Figure 6. FY 2013 investments in mid-scale facilities by directorate.

Figure 6 shows how mid-scale facilities are distributed by directorate. For the purpose of generating this figure, NSBO staff relied on mid-scale facilities identified in prior NSB reports,[9] surveys of program officers, and facilities identified in the NSF awards database with a mid-scale or mid-size element or reference code. In total 40 mid-scale facilities were identified. Cyberinfrastructure funded from the Division of Advanced Computing Infrastructure, investments with a total award amount smaller than $4 million, or awards in excess of the NSB threshold were excluded. Of this group, only 11 facilities had an average annual award size greater than $4 million.

In the FY 2016 Budget Request, NSF described several new mid-scale infrastructure initiatives. These proposed initiatives that total $53 million in FY 2016 are included for the first time as a separate line in the Research Infrastructure table. MPS notes that its "mid-scale research infrastructure program, begun over the last few years to meet a critical research need, has received a strong response from the community"[10] and GEO describes its program as a "new activity that will enable GEO to invest in emerging infrastructure beyond the scope of the Major Research Instrumentation (MRI) program, but smaller than what is typically funded through NSF's MREFC account."[11]

SCF is encouraged by these programs, noting that they have been developed with extensive community engagement and are consistent with past Board recommendations.[12] The subcommittee also anticipates that the steps taken to aggregate Foundation-wide information about mid-scale infrastructure will enhance future discussion of this facet of the facilities portfolio.

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[9] **NSB-11-80, NSB-13-72**
[10] FY 2016 Budget Request to Congress
[11] FY 2016 Budget Request to Congress
[12] **NSB-11-80, NSB-02-190**

SECTION 3: PORTFOLIO CHANGES AND PLANNED FUTURE FACILITIES

Directorate-Level

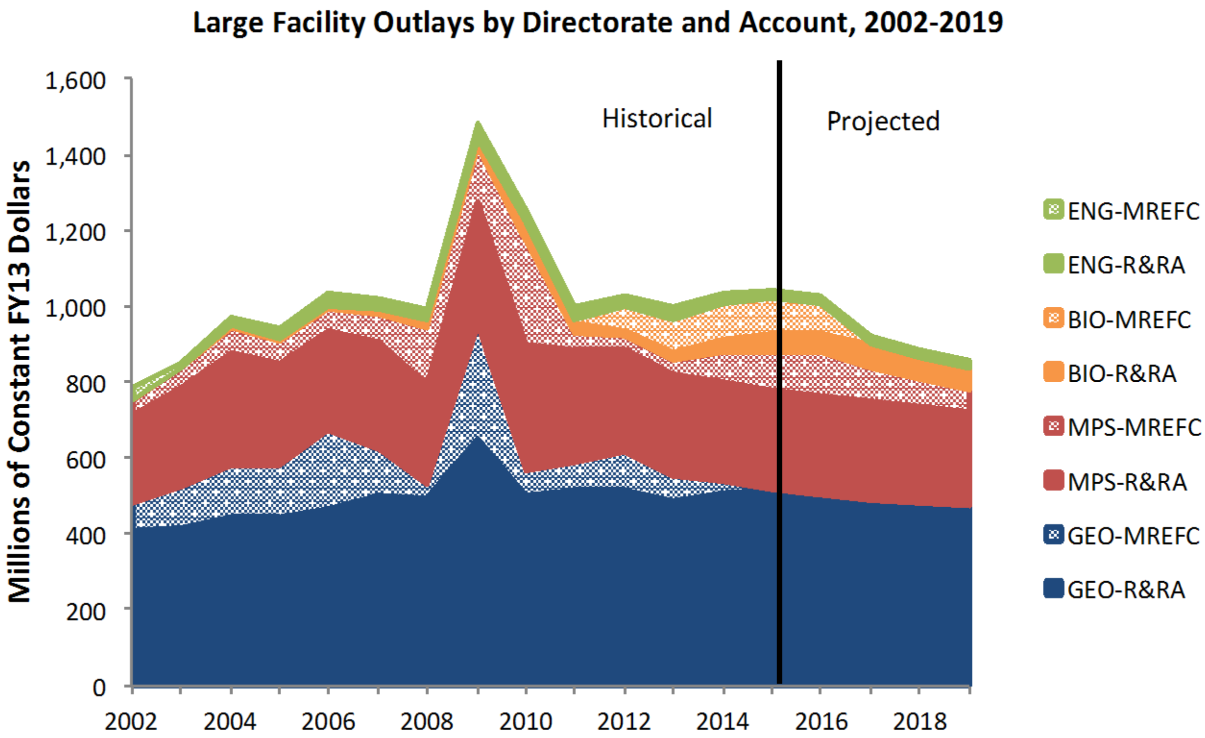

Figure 7. Historical and projected large facilities investments by Directorate and account.

Figure 7 shows historical and projected investments in large facilities grouped by Directorate and account (MREFC or R&RA). GEO includes PLR.

Key points:

- The impact of ARRA is pronounced in GEO. Some of this is due to investments in the maintenance of vessels and Polar facilities.
- Most directorates project essentially flat facilities outlays. BIO's increase reflects ramping up operations of the National Ecological Observatory Network. In other Directorates overall spending on facilities is roughly flat despite the ramping up of new facilities such as ALMA and OOI.
- Subsequent APRs will monitor these projections and anticipated O&M costs.
- Figure 4 showed that GEO and MPS account for the vast majority of NSF facilities investments in 2013. This holds true over time.

Directorates and Divisions with Near-term Large Changes

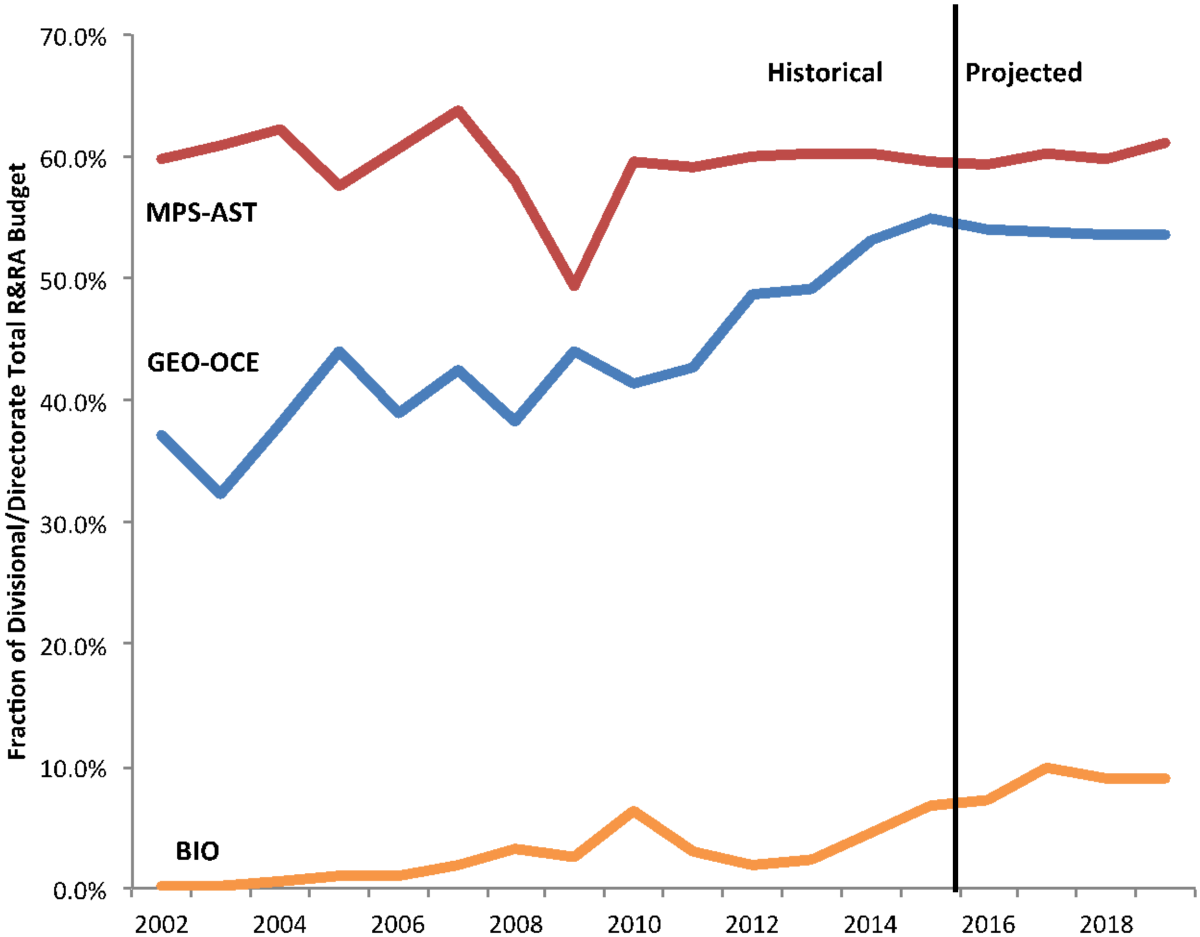

Figure 8. R&RA large facility investments for selected NSF units, as a percentage of total unit R&RA budget [13]

Figure 8 shows historical and projected investments in large facilities from the Research and Related Activities Account as a percentage of the total divisional or directorate budgets, for selected organizations expected to undergo significant changes in the near future. This figure does not include construction funding.

Key points:

OCE shows significant projected increases, largely due to OOI coming online. Aware of this challenge, OCE has started to rebalance its portfolio to bring outlays for core research into better equilibrium with its facility outlays. This is not shown here, as this figure is based on information provided in the FY 2016 Budget Request and earlier budgets, and does not include any more recent or planned changes.

AST and OCE appear stable in future years. This is because the projections assume flat Directorate funding baselines, and the relatively flat O&M budget for many facilities leads to relatively constant estimated outlays on a percentage basis.

[13] Sources: FY2004-FY2016 Budget Request to Congress

Strategic Planning

As Figures 3 and 7 show, the number of MREFC projects in construction will decrease unless the Board approves new ones. SCF is appreciative of the Director's efforts to better inform NSB of "Horizon Projects," potential large facilities in the early stages of planning. This subsection of the APR builds on the above-listed budgetary projections by providing a qualitative summary of these potential projects, community processes related to facilities, relevant Congressional report language, and planned renewals, recompetitions, and transitions.

The subcommittee is appreciative of the Director's efforts to support our discussions of the Regional Class Research Vessels, a post-CDR MREFC project that is the subject of a separate SCF white paper. In addition to this prospective project, SCF and the Board have been briefed on the potential Antarctic Infrastructure Modernization for Science (AIMS) Project. This grew out of the 2011 Academies' report "Future Science Opportunities in Antarctica and the Southern Ocean" and the 2012 Blue Ribbon Panel report "More and Better Science in Antarctica Through Increased Logistical Effectiveness." AIMS, which completed a conceptual design review in March of 2014, seeks to reduce the cost of Antarctic infrastructure by modernizing U.S. facilities in order to enable more efficient conduct of core science.

Community Processes

NSF has diverse mechanisms to solicit input from the relevant scientific communities on its facilities and instrumentation portfolio. These include NRC studies, decadal surveys, Directorate Advisory Committees and Committees of Visitors, panels, review of the number of NSF research proposals that involve certain facilities, Dear Colleague Letters, other types of studies and workshops to solicit input, and solicitations for conceptual and developmental research. As part of the Facility Synopses, every NSF-supported large facility provided SCF with information on "*the status of the facility with respect to the broad needs and priorities of the scientific community.*" While many facilities can be considered in a steady state, there are some for which scientific pressures and priorities are expected to have a more immediate impact on the facilities serving these communities.

There are several recent and ongoing community processes within the **Directorate for Mathematical and Physical Sciences** with near-term implications for the facility portfolio.

AST has been engaged in a planning and prioritization process for its facilities and instrumentation portfolio since the National Research Council (NRC) conducted its sixth decadal survey in astronomy and astrophysics in 2010. That report recommended key science questions and new initiatives for the current decade. To align science questions and priorities with budget constraints, AST subsequently conducted a community-based portfolio review through the Advisory Committee of the Directorate for Mathematical and Physical Sciences. The resulting report, *Advancing Astronomy in the Coming Decade: Opportunities and Challenges*, was released in August 2012. This report responded to the decadal survey science questions and included recommendations for all of the major telescope facilities funded by NSF as well as support for a Mid-scale Innovations Program (MSIP).

With an eye toward future facilities – in particular ALMA, DKIST, and LSST – the report recommended that AST transition the Mayall, the Wisconsin-Indiana-Yale-NOAO (WYIN), the

Robert C. Byrd Green Bank Telescope, the Very Long Baseline Array, the McMath-Pierce Solar Telescope, and the 2.1-meter telescopes at Kitt Peak National Observatory by FY 2017.

AST is currently considering multiple options as laid out in the December 2013 Dear Colleague Letter (NSF 14-022) and pursuing new partnership opportunities. In FY 2014 NSF hired a general engineering contractor to participate in engineering and environmental reviews. In FY 2015, that contractor is producing feasibility reports for transition options. Once NSF has identified viable options, it will embark on formal reviews (in FY 2015 and FY 2016) to evaluate the environmental impacts of these options.

DMR is currently engaged in similar processes for its facilities and instrumentation portfolio. At its August meeting in 2013, the Board received a presentation from MPS leadership on *Planning and Priority for Facilities in MPS*. Since then, the FY 13 MPS Advisory Committee (MPSAC) subcommittee advising DMR on facilities investments has completed its report "Closing the Loop: Report of the MPSAC Subcommittee on Materials Instrumentation". In addition, the 2013 NRC report "High Magnetic Field Science and Its Applications in the United States" provided several recommendations on scientific priorities and on the National High Magnetic Field Laboratory (NHMFL).

Two key points from these reports are:

1. The MPSAC subcommittee endorsed the NRC recommendation that "NSF continue to fund the National High Magnetic Field Laboratory for its contributions to advancing the frontiers of science."
2. The MPSAC report found that CHESS had not articulated a unique science case and that further work is needed to make a proposed upgrade persuasive.

Within the PHY Division, the Particle Physics Project Prioritization Panel (P5) was charged to develop an updated strategic plan for U.S. high energy physics involving both DOE and NSF. The resulting report, "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context" was released in May 2014. The Physics Division has convened an MPSAC subcommittee to provide advice on implementation of the P5 priorities for the next 5-10 years. The Board was briefed on this in November of 2014. The P5 report stated that "The LHC upgrades constitute our highest priority near-term large project," and the MPSAC subcommittee "strongly supports the NSF investment in the LHC phase-2 upgrades."

Finally, PHY's portfolio will change when the Department of Energy's Office of Science completes construction of the Facility for Rare Isotope Beams in 2020-2022.[14] At this time, NSF's National Superconducting Cyclotron Lab will merge into the Facility for Rare Isotope Beams.

Within the **Directorate for Geosciences,** OCE recently completed, through the National Research Council (NRC), a decadal survey of ocean sciences that considered resource constraints, analyzed tradeoffs between competing investments, and produced strategic guidance on science priorities and infrastructure needs. In conducting this survey, the Academies engaged extensively with the research community through physical and virtual town hall meetings,

[14] The project start is contingent on FY 2014 appropriations.

interviews, presentations from scientists in academic and government institutions, and consideration of prior reports generated with community input. The report called for rebalancing the OCE portfolio by reallocating 20 percent of OCE's infrastructure budget to core science. Since receiving the report in late January, OCE has similarly engaged the research community as it developed a plan to implement the report's recommendations.

The 2012 National Research Council report *New Research Opportunities in the Earth Sciences* highlighted for the Earth Sciences Division the important role EarthScope played in enabling cutting-edge research and in training the next generation of geoscientists. The report stated that, "The scientific rationale for following through on the EarthScope program in the next decade is compelling."

The **Directorate for Computing and Information Science and Engineering (CISE)**, has supported a National Academy of Science study of *Future Directions for NSF Advanced Computing Infrastructure to Support US Science in 2017-2020.* The interim report was released in October of 2014, with a final report expected in summer of 2015. When complete, this report will provide NSF with community priorities and recommendations for the Foundation's next generation of computational infrastructure.

The **Directorate for Engineering,** recently solicited input from the scientific community on the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) facility through a combined NIST/NSF report.[15] This input is intended to help NSF strategically support investments in natural hazards engineering research infrastructure beyond FY 2014. As a result of this report and other community efforts (described in **NSB/CPP-12-21**), ENG has released a solicitation (NSF 14-605 NHERI) to replace NEES and to "establish operations of the Natural Hazards Engineering Research Infrastructure (NHERI) for 2015 – 2019."

The science and engineering community has also been asked to offer input as the National Nanotechnology Infrastructure Network (NNIN) reached the end of its ten-year authorized award life at the end of FY 2013. To establish the successor program to NNIN and to continue support for valuable nanotechnology user facilities, NSF used a Dear Colleague Letter (DCL 14-068) in May 2014 to solicit community input on a possible future nanotechnology infrastructure support program. In August 2014, NSF convened a workshop that brought together recognized national experts to develop a vision of how to structure such a program and to discuss anticipated user community needs.

Congressional Interest

NSF's large facilities are of interest to both Houses of Congress, which used the report language accompanying FY 2014 and 2015 appropriations bills[16] to express infrastructure concerns and priorities. While not statutory, this language offers insights into Congressional priorities. In sum, appropriators support many ongoing investments in research infrastructure and facilities.

The Senate language states its expectation that NSF will sustain support for AST-funded scientific facilities, especially "those domestic instruments and facilities that produce U.S.

[15] "NIST GCR 14-973-13: Measurement Science R&D Roadmap for Windstorm and Coastal Inundation Impact Reduction,
[16] At time of writing. Appendix E contains the relevant language in full..

leadership in these fields."[17] FY 2015 Senate language also expresses support "for an interagency process to develop requirements for a new polar-class icebreaker"[18] and directs NSF to ensure that the Regional Class Research Vessels (RCRVs) "will soon be approved for inclusion in the MREFC account."[19] FY 2014 Senate language also called for shielding the facility portfolio from reductions in R&RA.

House report language expresses support for the International Ocean Discovery Program (IODP) and requests that NSF not transition AST infrastructure without first reporting such actions to the House Appropriations Committee's Commerce, Justice, Science, and Related Agencies subcommittee. 2014 report language also focuses on keeping the committee apprised of NSF procedural changes related to management, construction, and operations of large facilities.

Renewals and Recompetitions

Table 3 summarizes high-level financial and planning characteristics of current facilities. In particular, it shows that many of NSF's facilities are due for renewal or recompetition within the next five years. These decision points are opportunities for NSB to consider transitioning facilities, including those recommended by community processes.

[17] Senate Report 113-78
[18] Senate Report 113-181
[19] Senate Report 113-181. Senate language about RCRV predates the release of the *Decadal Survey of Ocean Sciences* in January 2015.

Table 3: Lifecycle summary for large facilities. See **Appendix D** for full names of facilities.

Name	DIR/DIV	C&D Period	C&D Cost (1994 - 2020)	MREFC Period	MREFC Cost (1994 - 2020)	O&M Start	R&RA Post-Construction Cost (2002-2014)	Planned Lifespan at Final Design (years)	Last	Next	Last	Next	Projected Project Cost 2015-20
									Renewal		Recompetition		
ARF	GEO/OCE, GEO/ICER			N/A	N/A	1971	$1,143				2012	2024	$471.9
AdvLIGO	MPS/PHY	?-2007	$47	2008-2014	$211	2007	Within LIGO	20	See LIGO				$0.0
Arecibo	MPS/AST, GEO/AGS			N/A	N/A	1962	$155				2011	2016	$44.8
ALMA	MPS/AST	1994-2001	$51	2002-2012	$547	2005	$163	30			~2009	~2015	$238.6
CHESS	MPS/PHY, MPS/DMR			N/A	N/A	1980	$254		2014	2019			$109.7
DKIST	MPS/AST	2007-2009	$25	2010-2017	$341	2011	$13	50					$175.9
DUSEL	MPS/PHY, MPS/OMA	2007-2011	$85	N/A	N/A	N/A	N/A		Terminated 2010				$0.0
EarthScope	GEO/EAR	1998-2003	$12	2003-2008	$227	2003	$136		See SAGE, GAGE				$0.0
Gemini	MPS/AST	?-1994	$17	1991-1998	$62	1999	$244	30			2006	2016	$112.9
GAGE	GEO/EAR			N/A	N/A	2012	$32	15			2013	2018	$66.0
HIAPER	GEO/AGS	1998-2001	$2	2000-2004	$99	2005	Within NCAR	25	See NCAR				
IceCube	GEO/PLR, MPS/PHY	2001-2001	$1	2002-2012	$275	2011	$41	25				2015	$37.8
IRIS	GEO/EAR			N/A	N/A	1984	$137		See GAGE				
LHC	MPS/PHY	1996-2002	$13	1999-2003	$103	2003	$188	20	2012	2017			$105.9
LSST	MPS/PHY	2003-2014	$60	2014-2021	$391	2020					2014		$368.8
LIGO	MPS/PHY	1992-1998	$12	1995-1998	$323	1998	$435		2014		2009	<= 2018	$216.3

Notes: Outlays are given in millions of constant FY 2012 dollars. C&D = “Concept and Development.” Planned Lifespan at Final Design is relative to start of facility operations (O&M Start). Projected cost includes both MREFC and R&RA. Projected cost includes both MREFC and R&RA.

Table 3 (continued)

Name	DIR/DIV	C&D Period	C&D Cost (1994 - 2020)	MREFC Period	MREFC Cost (1994 - 2020)	O&M Start	R&RA Post-Construction Cost (2002-2014)	Planned Lifespan at Final Design (years)	Renewal		Recompetition		Projected Project Cost 2015-20
									Last	Next	Last	Next	
NCAR	GEO/AGS			N/A	N/A	1950s	$1,279		2013			2018	$542.3
NEON	BIO/EF, BIO/DBI	1998-2014	$110	2011-2016	$420	2013	$21	30					$478.8
NHMFL	MPS/DMR, MPS/CHE			N/A	N/A	1990	$428		2013	2017			$184.0
NNIN	ENG/ECCS*			N/A	N/A	2002	$201		2015	2019			$84.8
NOAO	MPS/AST			N/A	N/A	1982	$484				2009	2015	$127.1
NRAO	MPS/AST			N/A	N/A	1956	$652				2011	2016	$200.5
NSO	MPS/AST			N/A	N/A	1950s	$62		2014			2019	$101.2
NSCL	MPS/PHY			N/A	N/A	1961	$267		Merge with FRIB (DOE 2020)				$121.2
NHERI	ENG/CMMI	1995-2001	$2	2000-2004	$102	2005	$215	10			2015	2019	$67.2
IODP	GEO/OCE			N/A	N/A	2003	$608	15			2014	2018	$263.3
OOI	GEO/OCE	2001-2009	$67	2009-2014	$392	2010	$143	25			2009	2017	$301.7
Polar Facilities	GEO/PLR			N/A	N/A	1982	$2,564		2012	2017			$1,066.5
RSVP	MPS/PHY	2001-2005	$15	N/A	N/A	N/A	N/A		Terminated 2005				#N/A
R/V SIKULIAQ	GEO/PLR	2000-2006	$3	2007-2010	$209	2014	Within ARF	30	See ARF				$0
SODV	GEO/OCE	2000-2005	$6	2005-2007	$127	2007	Within IODP	15	See IODP				
SAGE	GEO/EAR			N/A	N/A	2012	$74				2013	2018	$137.0
SPSM	GEO/PLR	?-1997	$23	1998-2010	$179	2007	Within Polar Facilities	25	See Polar Facilities				
Wyoming Super Computer	GEO/AGS		$0	N/A	N/A	2011	Within ACI		2010	2012			

SECTION 4: STATUS OF FY 2013 APR RECOMMENDATIONS

This section summarizes the status of the five Board-approved recommendations (**NSB-14-33**) that accompanied SCF's FY 2013 APR (**NSB-13-72**).

Recommendation 1: *SCF recommends that NSB and the Director discuss long-term strategies for optimal use of funds in the MREFC account and associated impacts on the R&RA account during a time of budgetary challenges.*

Status: The recommended strategic discussions occurred, initially as elements of conversations about specific facilities, and culminated in a dedicated agenda item at the Board's February, 2015 Plenary Closed session. SCF anticipates continued NSB discussions at future Board meetings.

Recommendation 2: *The Foundation should identify effective practices from current NSF and community-driven facilities portfolio planning activities, including those in the Division of Astronomical Sciences. SCF believes this may help NSF develop guidance for the termination or divestment of operating facilities. In order to promote constructive discussions of facilities life-cycle among all stakeholders, the Foundation should provide assessment criteria and performance expectations as part of the award development and approval process.*

Status: As detailed in Section 3, NSF is using community-driven prioritization processes in a number of areas. Several of these processes have included consideration of facility transitions. The Facilities Synopses also include summary lifecycle and facility health information that will improve future Board deliberations. While more remains to be done to enhance lifecycle planning, SCF applauds the progress to date.

Recommendation 3: *SCF concurs with the earlier Board finding (**NSB-08-15**) that enhanced understanding of the early phases of bringing MREFC facilities forward will help the Board fulfill its oversight and fiduciary responsibilities for the MREFC portfolio. To that end, NSF and SCF should jointly develop an effective means of informing NSB about potential MREFC projects, including discussion of community input about the prioritization of potential projects.*

Status: While this recommendation has not yet been acted on systematically, SCF is appreciative of early insights into several potential MREFC projects. This includes discussions of the Antarctic Infrastructure Modernization for Science (AIMS) Project and outcomes from community prioritization processes.

Recommendation 4: *SCF is concerned that NSB's 2003 guidance that the NSF spend 22-27% of its budget on research infrastructure may no longer be appropriate, as it is now more challenging for research directorates to assume the operational expenses associated with capital investments. The Subcommittee recommends that the Board review both the appropriateness of its guidance and the data used to capture the costs of research infrastructure.*

Status: While this recommendation has been an element of Board deliberations, there has not yet been a dedicated discussion.

<u>Recommendation 5</u>: *SCF believes that significant parts of the APR, NSF Facility Plan, and the information included in Budget Requests could be combined into a facility data-product that would facilitate the work of both NSF and NSB.*

> *The Subcommittee suggests that these data products should also help the Foundation better understand the evolution and health of a facility over time. While they may include, for instance, trends in facility demand, user-base, or scientific output, SCF notes that each of NSF's large facilities has a unique purpose, and thus requires individualized assessment at each lifecycle stage.*
>
> *The appropriate data products will vary with facility, but potentially include the following:*
>
> a. *Scientific purpose;*
> b. *Upgrades under formal discussion with associated timelines and projected costs;*
> c. *Information about funding partners, including governance structure and cost;*
> d. *A description of the discipline(s) served by the facility;*
> e. *Full lifecycle cost as determined at the last decision point;*
> f. *Projected costs for operations and maintenance;*
> g. *Construction status;*
> h. *Current timelines for award renewal, recompetition, termination, or divestment;*
> i. *Relationship to any Foundation or community prioritization processes;*
> j. *Trends in usage and users of the facility to determine how well the facility meets the needs of its intellectual community; and*
> k. *Analysis of the status of the facility with respect to the broad needs and priorities of the scientific community.*

<u>Status</u>: SCF is extremely pleased with the "Facility Synopses" that NSF's Budget Division and facility program officers produced in response to this recommendation. NSF leadership engaged iteratively with the Subcommittee over several months to produce a document that Board members found extremely helpful and that affords a high-level, consistent summary of NSF's large facility portfolio. SCF looks forward to annual updates to these Synopses.

APPENDIX A: TIMELINE OF NSB FACILITIES PROCESSES

2000: The Board created the Task Force on S&E Infrastructure (INF) to assess the state and direction of academic research infrastructure.

2001: Congress criticized[20] the co-mingling of R&RA and MREFC funds, stating that this "obscures the full cost of these projects," and specified that acquisition, construction, and commissioning should be funded from MREFC while planning, design, and O&M come out of R&RA. Congress also required a report on past MREFC full-lifecycle costs, stating that they took this "unusual step" because of concerns about NSF's "ability to adequately address this issue."

2002: The *NSF Authorization Act of 2002*[21] required NSB to "explicitly approve" MREFC account projects and their priorities and to report on the criteria used. Approval is required both for inclusion in budget requests and release of appropriated MREFC funds.

2003: The INF report[22] recommended increasing infrastructure's share of NSF's budget toward the higher end of the 22-27 percent historical range, improving planning and budgeting, and emphasizing midsize projects.

2003: Six senators, led by Chairman Barbara Mikulski, requested that the National Academy of Sciences (NAS) examine the MREFC account and its priorities. They cited "ad hoc and subjective" requests and "significant deficiencies in the Foundation's management and oversight."

2004: The requested NAS report[23] criticized a backlog of projects, unclear criteria for selecting and prioritizing projects, a lack of funding for generating and developing ideas, and a lack of transparency. The recommended solutions included increased NSB involvement and oversight.

2005: NSB and NSF jointly responded to the NAS report,[24] concurred with the findings (especially the need for a transparent process), and laid out a response strategy that included:

- increasing community involvement;
- developing an annual, public *Facility Plan* as part of a 10-20 year MREFC roadmap; and
- criteria and processes for developing, advancing, and overseeing projects.

NSB committed to reviewing the *Facility Plan* (including concurrence on a "Readiness List" of projects set for final design), approving and prioritizing "New Starts"[25], and transitioning projects. In a 2008 report to Congress, the Board later criticized concurrence on the Readiness

[20] Conference Report to accompany H.R. 107-272, p. 171-172, November 8, 2001.
[21] 42 USC §1862n–4
[22] *Science and Engineering Infrastructure for the 21st Century: The Role of the National Science Foundation*, 2003, NSB 02-190.
[23] *Setting Priorities for Large Research Facility Projects Supported by the National Science Foundation*, The National Academies Press, 2004. The report is sometimes called the "Brinkman report," after its Chair.
[24] *Setting Priorities for Large Research Facility Projects Supported by the National Science Foundation*, 2005, NSB-05-77.
[25] New Start projects were those approved for inclusion in Budget requests but which have not received MREFC funding.

List as not providing "an opportunity for meaningful analysis and oversight" of projects in the pre-construction phases and their readiness.[26]

2006: The National Academies released a second report[27] to Congress, focused on interdisciplinary research facilities and advanced instrumentation. This affirmed some recommendations of the 2005 NAS report and recommended expanding the MRI program.

2007: The America COMPETES Act[28] directed NSB to evaluate O&M and preconstruction costs for MREFC projects.

2008: In its response to Congress[29] NSB identified three major concerns with MREFC projects and recommended "an earlier and more thorough decision-making role for the Board." Specifically, it noted that "late and restricted involvement" limited NSB's ability to oversee the facilities portfolio and associated O&M costs. It identified the latter as "a priority issue" (cumulative O&M is the major lifecycle cost), and asked for "up-to-date inflation-adjusted O&M cost estimates."

The report also stated that NSB's statutory responsibilities require "significantly enhanced understanding" of all project phases and that NSB should be "significantly engaged in prioritizing which proposed MREFC projects receive funding for pre-construction planning and design." It documented the Director's "desire for the Board to become much more significantly engaged in setting … priorities, and to do this earlier in the MREFC process." Finally, it recommended that NSB obtain a system-wide view of all MREFC projects to ensure portfolio balance and sustainable budgets and to avoid forgoing opportunities.

2008: CPP deliberated NSB's promised follow-up report to Congress, including details on planning and design decision points, process modifications, and the NSB role. CPP sought[30] improved estimates for design and O&M costs, insight into planned MREFC projects, and better planning in the out years.

2008: NSB endorsed the policy that operations awards for major facilities should be recompeted.[31]

2009: To act on its 2008 report, NSB created[32] the *Subcommittee on Facilities* (SCF), and charged[33] it to holistically review the facilities portfolio, prioritize projects that have completed a Conceptual Design Review,[34] and assess the impact of facilities on long-term budgets. In

[26] *Report to Congress on Pre-construction Funding and Maintenance and Operations Costs Associated with Major Research Equipment and Facilities at NSF*, 2008, NSB-08-15.
[27] *Advanced Research Instrumentation and Facilities*, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 2006.
[28] P.L. 110-69 § 7014
[29] NSB-08-15.
[30] Meeting minutes from all 2008 meetings, NSB/CPP-08-44 and NSB/CPP-08-54.
[31] NSB-08-12.
[32] Testimony of SCF Chair Dr. José-Marie Griffiths to Congress, March 8, 2012.
[33] NSB-09-29.
[34] Note that this is distinct from prioritizing the pool of New Starts, which begins with CPP.

creating SCF, Board members stated that it would only include MREFC projects in its first year before broadening its efforts to consider other large and medium-size facilities.[35]

2010: NSB formalized its MREFC process and its integration into the annual budget process (NSB-10-65[36] and NSB-10-66). See Appendix B for further details.

2010: NSB declined[37] $19 million in further funding for the development of the Deep Underground Science and Engineering Laboratory (DUSEL). NSF had invested $80 million previously, with partners contributing over $220 million more.[38] This significant Board action reinforced the need to engage the Board earlier in MREFC projects. DUSEL was, in fact, specifically cited in the 2008 report that motivated NSB's new processes: "for DUSEL, over 7 years has passed since the initial concept was proposed within NSF, and the Board has yet to have substantive involvement."

2010: The *America COMPETES Reauthorization Act of 2010*[39] required NSB to evaluate the need for "mid-scale research instrumentation," and provide recommendations and options for its support.

2011: SCF led NSB's report[40] to Congress on mid-scale instrumentation. This report concluded that investments were "in alignment with the Board's earlier forecasts and recommendations on funding and prioritization," are in sound balance, and are funded by mechanisms that provide "flexibility and vigor." This report suggested that the APR might provide an appropriate forum for assessing mid-scale needs and incorporating them into NSF planning.

2012: SCF Chair Dr. Griffiths testified at a Congressional hearing titled *NSF Major Research Equipment and Facilities Management: Ensuring Fiscal Responsibility and Accountability*, explaining NSB's role in overseeing MREFC facilities. Dr. Marrett also testified: "The NSB provides oversight throughout the entire life-cycle process for planning, constructing, operating, and eventually transitioning NSF support for large facilities. It prioritizes among competing projects in preconstruction planning and relative to other opportunities, endorses project advancement from one preconstruction planning stage to the next, approves NSF's request to OMB to include a request for construction funding within a future NSF Budget Request to Congress, and approves the obligation of funds to commence construction following a Congressional appropriation."[41]

[35] Minutes, Plenary Session of the 408th NSB Meeting, February 23-24, 2008, NSB-09-28.
[36] Since replaced by NSB/CPP-12-18.
[37] Plenary Closed minutes, NSB-10-88.
[38] *Funding rejected for underground lab*, Nature, 2010.
[39] P.L. 111-358 § 507.
[40] *Report to Congress on Mid-scale Instrumentation at the National Science Foundation*, 2011, NSB-11-80.
[41] Testimony to the Research and Science Education Subcommittee of the House Committee on Science, Space, and Technology, March 8, 2012.

APPENDIX B: SCOPE AND DEFINITIONS

Definitions

"Research infrastructure," "facility," and related terms can be ambiguous and have indeterminate boundaries (Figure 9). For instance, facilities can be research projects in and of themselves, and "cyberinfrastructure" encompasses and supports all manner of research infrastructure. For its analyses, the APR examines a subset of facilities investments and follows the definitions used in the 2003 NSB report on research infrastructure:[42]

Tool: Anything used as a means of accomplishing a task or purpose.[43]

Infrastructure: An underlying foundation or basic framework.[44]

Instrument: A tool used for observation, measurement, or control.[45]

Research Infrastructure: The tools, services, and installations needed for science and engineering research. This includes:

1. Hardware (tools, equipment, instrumentation, platforms and facilities)
2. Software (enabling computer systems, libraries, databases, data analysis and data interpretation systems, and communication networks)
3. Technical support (human or automated) and services needed to operate the infrastructure and keep it working effectively
4. Special environments and installations (such as buildings and research space) necessary to effectively create, deploy, access, and use the research tools.[46]

Facility: Research-enabling equipment and systems that require special sites or buildings and a dedicated staff to effectively maintain it. It is typically large-scale, complex, and costly. Most NSF facilities are funded through cooperative agreements instead of grants.

Mid-scale: A cost-scale between the Major Research Instrumentation (MRI) program and MREFC account.[47,48] This term applies to both infrastructure and facilities.

Multi-user Facility: A facility used by multiple investigators and institutions.

Large Facility: A facility whose average annual award size has exceeded the NSB threshold (at least $7.1 million in FY 2012).[49] This category can include mid-scale facilities as defined above.

[42] *Science and Engineering Infrastructure for the 21st Century: The Role of the National Science Foundation*, 2003, NSB 02-190.
[43] Ibid.
[44] Ibid.
[45] Webster's Third New International Dictionary
[46] Following NSB's 2003 report, we omit consideration of the associated "human infrastructure."
[47] The MREFC threshold varies by Directorate. According to the NSF Large Facilities Manual, MREFC projects must have total construction and/or acquisition costs that exceed 10 percent of a Directorate or Office's Current Plan.
[48] This definition was given by Congress in the America COMPETES Reauthorization Act of 2010, P.L. 111-478 §507, and used in the resulting Board report.
[49] NSB approves awards where the average annual award amount is greater than either 0.1 percent of the prior year total NSF budget or 1 percent of the awarding Directorate or Office's prior year current plan (including funds transferred from other Federal agencies awarded through NSF actions). NSB also approves MREFC awards and sensitive awards.

MREFC Facility: A large facility whose construction is or was funded out of the MREFC account.

Cyberinfrastructure: A comprehensive infrastructure based upon distributed networks of computers, information resources, online instruments, data analysis and interpretation tools, relevant computerized tutorials for the use of such technology, and human interfaces. The term provides a way to discuss the infrastructure enabled by distributed computer-communications technology in contrast to the more traditional physical infrastructure.

Networking and Computational Resources Infrastructure and Services (NCRIS): A NSF budget category in the Division of Advanced Cyberinfrastructure (ACI) that includes mid and large-scale cyberinfrastructure.

Major Multi-User Research Facilities: An NSF budget category that includes MREFC facilities, multi-user Federally Funded R&D Centers (FFRDCs), and polar facilities.

Many other acronyms are used in this report and at NSF. These are defined in Appendix D.

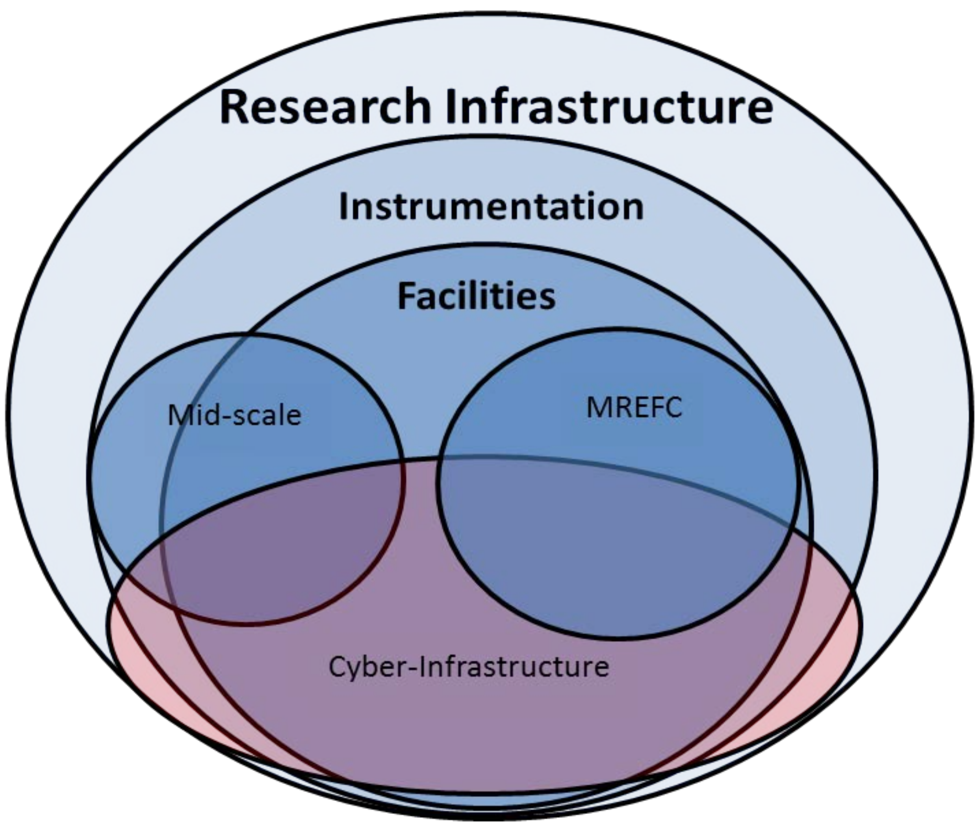

Figure 9. Venn diagram showing the relationships between some of the terms defined in this subsection. Areas are not to scale. Cyberinfrastructure can be stand-alone research infrastructure or embedded in a facility.

Scope

The APR examines ***multi-user facilities that are mid-scale or larger***, presenting them in the context of the broader research infrastructure portfolio. These facilities represent significant, long-lasting investments by the Foundation, and have more complicated technical, oversight, management, and partnership characteristics than smaller instruments.

Note that the scope and definitions used in the APR do not align with the "Research Infrastructure" and Major Multi-User Research Facilities categories used in the NSF budgets. For example, "Research Resources" within the budget's Research Infrastructure roll-up includes investments that are not infrastructure as defined in this report. Conversely, that roll-up does not include all mid-scale multi-user facilities considered here.

While larger multi-user facilities, such as MREFC projects, are readily identifiable, differentiating midscale facilities from other infrastructure can be difficult. The APR relies on input from directorates and program officers, solicitations, and the recent NSB mid-scale instrumentation study to identify mid-scale projects that are multi-user facilities.[50] Only facilities with a total active award value in excess of $4 million are included in this review.

The full list of facilities considered in this APR is given in Appendix D**.**

[50] Specifically, Directorates were asked to submit such projects that were a) "bricks and mortar" ground-based physical sites; b) multi-user cyberinfrastructure systems; c) mobile assets such as ships, aircraft, satellites; d) multi-user data or simulation systems including large-scale models, model- and data-serving facilities; or e) instruments, instrument clusters, and networks of observing instruments/systems supported as one activity.

APPENDIX C: CURRENT NSB MREFC PROCESS

The creation of SCF and goals of the APR are intertwined with the evolution of the Board's internal processes for approving MREFC projects. Appendix A relates the history of those processes. This appendix explains them as they currently exist and how they relate to SCF. Note that some earlier Board documents, such as its 2005 response to Congress and the NAS (NSB-05-77) reference deprecated terms, e.g. the "Readiness list" and "New Starts Pool."[51] The current process is summarized in Figure 10.

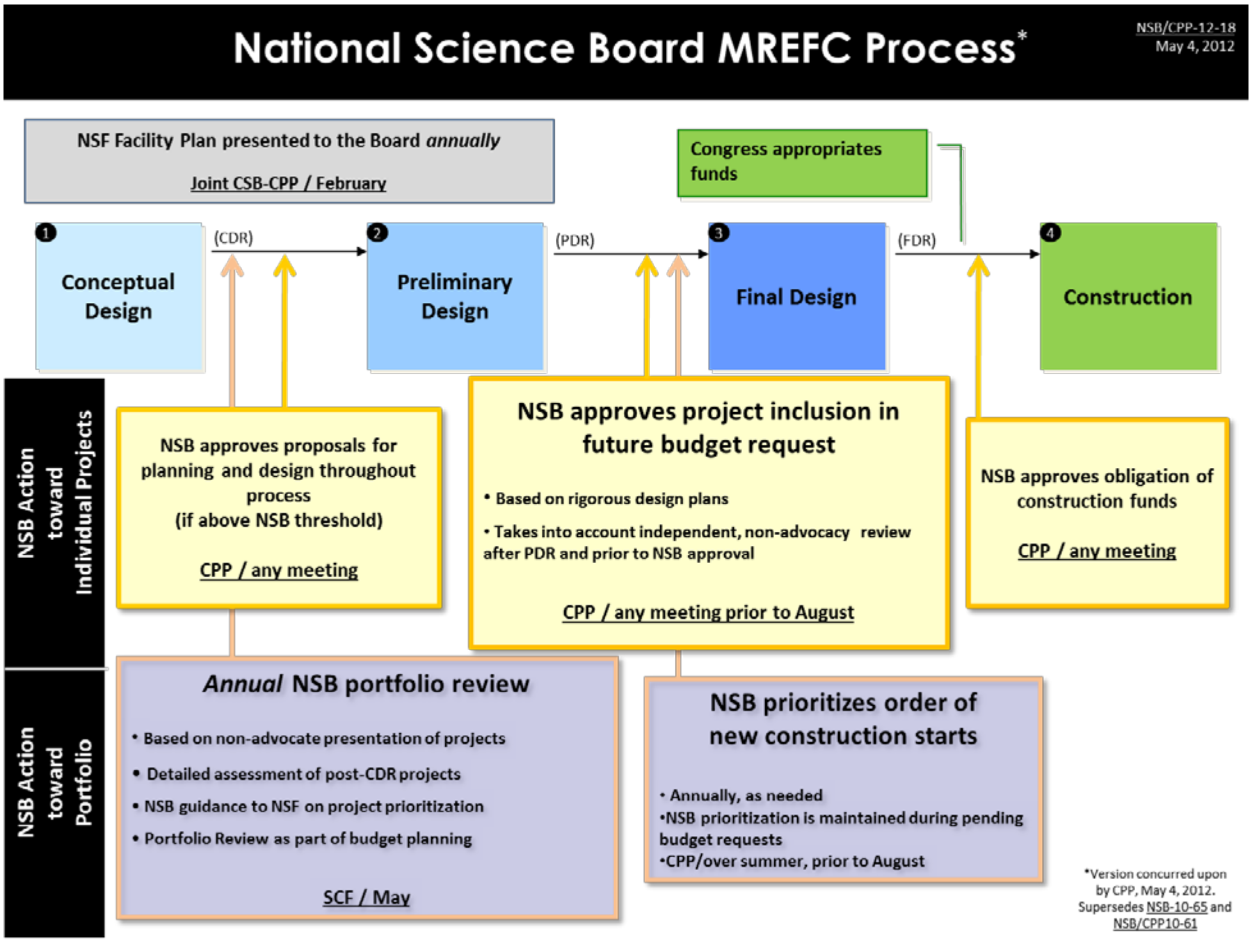

Figure 10. NSB process for review and approval of MREFC projects

1. The first element of this process is the NSF *Facility Plan* that is presented to a joint CPP/CSB session each February. While this plan has evolved in recent years, it remains rooted in the 2005 joint NSF/NSB report,[52] with components summarized in the Large Facility Manual.[53] It provides a 10-20 year roadmap for MREFC projects (including those in development) and explains their scientific objectives, context, need, and prioritization. It is expected to be reviewed by NSB, to include decision criteria, and to be made public.

[51] The "Readiness List" refers to projects that have completed a CDR and which are expected to go to the Board for approval within one year. The "New Starts Pool" is now termed the "Final Design" or "Board Approved" stage.

[52] *Setting Priorities for Large Research Facility Projects Supported by the National Science Foundation*, 2005, NSB-05-77.

[53] Large Facilities Manual, Appendix 4, pg. 64, 2013.

2. Next is SCF's annual portfolio review, which occurs each May. The review considers horizon projects, potential new projects that have completed Conceptual Design Review (CDR), projects under design or construction, and facilities that are in operation. It was specifically intended to be a vehicle for Board review of projects that have completed a CDR. Ideally[54] it considers several of them simultaneously, sets priorities, and evaluates them in the context of their discipline and the overall portfolio. By reviewing and prioritizing projects at the CDR stage, when a preliminary baseline budget and initial risk assessment have been developed, NSB intends to address the O&M cost oversight, portfolio balance, statutory,[55] and out year budget concerns raised in its 2008 report to Congress. At the September 2008 NSB meeting, Director Bement also "noted that a major purpose in developing the current MREFC process was transparency and that [it] is important in major investments to have reviews. An NSB review at the end of CDR is important as NSF and the NSB need to make a commitment to the project at this point; to wait until after preliminary design review is too late."[56]

3. If an award for planning and design exceeds the NSB threshold, CPP needs to approve it. In principle this could occur at any time. In practice, such an award is most likely to occur during preliminary design. In that scenario, CPP action will be most congruous with other Board processes if CPP acts after SCF has considered the project in its May APR.

4. After a project has successfully completed Preliminary Design Review and prior to inclusion in a budget request, NSB reviews the project based on information provided in an independent assessment by an impartial team (not selected from the proposing directorate). Based on this and preliminary design plans, CPP makes a recommendation on including the project in a future budget request. This Board action is a statutory responsibility for proposed MREFC projects.[57] Projects completing this step are termed "NSB Approved" or "Final Design" stage projects.

5. Each summer, before considering a budget request in August, CPP prioritizes all MREFC "new construction starts." These are projects which have been approved by NSB but which have not previously received construction funding from the MREFC account.[58] This statutory requirement[59] derives from a backlog of such projects that currently does not exist.

6. NSB (through CPP) must[60] explicitly approve of the obligation of MREFC construction funds. This can occur at any meeting after Congress has appropriated funds.

7. After construction is completed, operations awards typically require NSB/CPP approval. While drawn from the R&RA account (and therefore not subject to MREFC account requirements), these awards usually exceed the NSB threshold.

[54] It was originally envisioned by both NSB and NSF management that SCF would consider 1-3 projects in a group as they completed CDR; in recent years there has only been a single project.
[55] The Board has specific statutory responsibilities for projects within the MREFC account.
[56] NSB/CPP-08-52, CPP minutes from September 22, 2008.
[57] 42 USC §1862n–4(a)
[58] Ongoing construction projects, as a matter of policy, are always prioritized over new proposals.
[59] 42 USC §1862n–4(a)
[60] 42 USC §1862n–4(d)

APPENDIX D: TABLE OF ABBREVIATIONS

ACI	Division of Advanced Cyberinfrastructure (CISE)
AD	Assistant Director
AdvLIGO	Advanced Laser Interferometer Gravitational-Wave Observatory
AGS	Division of Atmospheric and Geospace Sciences (GEO)
ALMA	Atacama Large Millimeter Array
AMISR	Advanced Modular Incoherent Scatter Radar
APR	Annual Portfolio Review (SCF)
ARF	Academic Research Fleet
ARRA	American Recovery and Reinvestment Act
ARRV	Alaska Region Research Vessel
AST	Division of Astronomical Sciences (MPS)
ATST	Advanced Technology Solar Telescope, now known as the Daniel K. Inouye Solar Telescope (DKIST)
BIO	Directorate for Biological Sciences
BFA	Office of Budget, Finance and Award Management
BSR	Business System Review
C&D	Concept and Development
CA	Cooperative Agreement
CBO	Congressional Budget Office
CDR	Conceptual Design Review
CFO	Chief Financial Officer
CHESS	Cornell High Energy Synchrotron Source
CI	Cyberinfrastructure
CIF21	Cyberinfrastructure Framework for 21st Century Science and Engineering
CISE	Directorate for Computer and Information Science and Engineering (NSF)
CMMI	Division of Civil, Mechanical and Manufacturing Innovation (ENG)
CPP	Committee on Programs and Plans (NSB)
CSB	Committee on Strategy and Budget (NSB)
DBI	Division of Biological Infrastructure (BIO)
DDLFP	Deputy Director for Large Facility Projects
DKIST	Daniel K. Inouye Solar Telescope (DKIST), formerly Advanced Technology Solar Telescope (ATST)
DMR	Division of Materials Research (MPS)
DRB	Director's Review Board
DUSEL	Deep Underground Science and Engineering Laboratory
EAR	Division of Earth Sciences (GEO)
ECCS	Division of Electrical, Communications and Cyber Systems (ENG)
EF	Emerging Frontiers Office (BIO or ENG)
EIS	Enterprise Information System

ENG	Directorate for Engineering (NSF)
EVM	Earned Value Management
FDR	Final Design Review
FFRDC	Federally Funded R&D Center
FRIB	Facility for Rare Isotope Beams (DOE)
GAGE	Geodetic Facilities for Advancement of Geoscience & EarthScope
GDP	Gross Domestic Product
GENI	Global Environment for Network Innovation
GEO	Directorate for Geosciences (NSF)
GPRA	Government Performance and Results Act
HIAPER	High-performance Instrumented Airborne Platform for Environmental Research
HPC	High Performance Computing
ICER	Integrative and Collaborative Education and Research (GEO)
IMP	Internal Management Plan
INF	Task Force on S&E Infrastructure (NSB)
IODP	Integrated Ocean Drilling Program
IRIS	Incorporated Research Institutions for Seismology
LFO	Large Facilities Office (NSF)
LHC	Large Hadron Collider
LIGO	Laser Interferometer Gravitational-Wave Observatory
LSST	Large Synoptic Survey Telescope
MMURF	Major Multi-User Research Facilities
MPS	Directorate for Mathematical and Physical Sciences
MREFC	Major Research Equipment and Facilities Construction
MRI	Major Research Instrumentation
NAIC	National Astronomy and Ionosphere Center
NAS	National Academy of Sciences
NCAR	National Center for Atmospheric Research
NCRIS	Networking and Computational Resources Infrastructure and Services
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
NRC	National Research Council
NSB	National Science Board
NSCL	National Superconducting Cyclotron Lab
NSF	National Science Foundation
NSO	National Solar Observatory

O&M	Operations and Maintenance
OCE	Division of Ocean Sciences (GEO)
OIG	Office of the Inspector General
OMB	Office of Management and Budget
OOI	Ocean Observatories Initiative
PEP	Project Execution Plan
PDP	Project Development Plan
PDR	Preliminary Design Review
PHY	Division of Physics (MPS)
PI	Principal Investigator
PLR	Division of Polar Programs (GEO)
PO	Program Officer
R&RA	Research and Related Activities
RCRV	Regional Class Research Vessels
RI	Research Infrastructure
RSVP	Rare Symmetry Violating Processes
SAGE	Seismological Facilities for Advancement of Geosciences and EarthScope
SBE	Directorate for Social, Behavioral and Economic Sciences
SCF	Subcommittee on Facilities (NSB)
SODV	Scientific Ocean Drilling Vessel
SPSM	South Pole Station Modernization
STPI	Science and Technology Policy Institute
TCS	Terascale Computing System
USAP	United States Antarctic Program
WIYN	Wisconsin Indiana Yale NOAO
XSEDE	eXtreme Science and Engineering Discovery Environment

APPENDIX E: FY14 AND FY15 CONGRESSIONAL REPORT LANGUAGE

This appendix contains all excerpts from FY 15 and FY 14 NSF appropriations report language relevant to the APR.

House:

House Report 113-448 - **COMMERCE, JUSTICE, SCIENCE, AND RELATED AGENCIES APPROPRIATIONS BILL, 2015**

> *Astronomical Sciences Portfolio Review*--NSF shall not implement any final divestment of infrastructure tied to the findings of its 2012 Astronomical Sciences Portfolio Review without first reporting such actions to the Committee and ensuring that they are carried out in accordance with any relevant reprogramming requirements.
>
> *International Ocean Discovery Program (IODP*)--The recommendation provides the requested level for IODP.

House Report 113-171 **- COMMERCE, JUSTICE, SCIENCE, AND RELATED AGENCIES APPROPRIATIONS BILL, 2014**

> *United States Antarctic Program (USAP)*--The Committee supports NSF's decision to temporarily reduce funding for Antarctic science in order to provide funds for the implementation of important safety-related and efficiency-promoting recommendations of the USAP Blue Ribbon Panel.
>
> *International Ocean Discovery Program (IODP)*--The Committee encourages NSF to continue funding the IODP at no less than the level contained in the agency's fiscal year 2013 current plan.
>
> *Management of large research facility projects*--NSF recently undertook a major review of its policies and processes for managing the construction and operation of large facilities. This review, although broader in scope, will assess many of the practices previously identified as problematic by the OIG in its examinations of construction contingency funding and cost surveillance for cooperative agreements. NSF shall provide a copy of the results of this review and any associated recommendations for action to the Committee as soon as possible.
>
> *Management of large research facility projects*--The OIG is directed to assess and report to the Committee on the efficacy and completeness of any policy or procedural changes proposed by NSF pursuant to its review of its management of large research facilities.

Senate:

[Senate Report 113-181], **DEPARTMENTS OF COMMERCE AND JUSTICE, AND SCIENCE, AND RELATED AGENCIES APPROPRIATIONS BILL, 2015**

> *Scientific Facilities and Instrumentation*--A critical component of the Nation's scientific enterprise is the infrastructure that supports researchers in discovery science. Investments to advance the frontiers of research and education in science and engineering are critical to the Nation's innovation enterprise. The Committee expects the NSF to fully fund world-class U.S. scientific research facilities and instruments to adequately support scientists and students engaged in research to maximize sustained investments in science.
>
> *Astronomy*--U.S.-based astronomy facilities continue to make groundbreaking discoveries and maintain excellent world- class scientific research even as operating budgets have been continually constrained. The Committee expects NSF to sustain support for the scientific facilities funded by the Astronomical Sciences division, including the National Radio Astronomy Observatory, which shall be funded at no less than the fiscal year 2014 level of $43,140,000.
>
> *Ocean Science Infrastructure*--The Committee supports the requested increase in funding for the planning and design of the regional class research vessels. The Committee directs NSF to ensure that these vessels will soon be approved for inclusion in the Major Research Equipment and Facilities Construction account.
>
> *Icebreakers*--The Committee supports the interagency process to develop requirements for a new polar-class icebreaker, recognizing the strategic importance of Arctic operations to our Nation's future security and prosperity and the critical support that such a vessel will provide to NSF's research and logistics in Antarctica. NSF is encouraged to work with its interagency partners to support this effort, which should result in an operational requirements document no later than 180 days after the date of enactment of this act.

Senate Report 113-78 **DEPARTMENTS OF COMMERCE AND JUSTICE, AND SCIENCE, AND RELATED AGENCIES APPROPRIATIONS BILL, 2014**

> The Committee's fiscal year 2014 recommendation renews its support for Federal long-term basic research that has the potential to be transformative to our economy and our way of life in the context of a stagnant Federal budget. However, the Foundation continues to prioritize new initiatives while cutting support for core, merit-based science grants and for scientific infrastructure like ships and facilities … The Committee once again directs that the $194,000,000 reduction below the fiscal year 2014 budget request level for R&RA be taken from the proposed increases in OneNSF initiatives and not from core NSF program or infrastructure funding. The Committee urges NSF to reconsider cuts

to key scientific infrastructure when delivering its spending plan by further reducing proposed increases for OneNSF initiatives.

Scientific Facilities and Instrumentation.--A critical component of the Nation's scientific enterprise is the infrastructure that supports researchers in discovery science. Investments to advance the frontiers of research and education in science and engineering are critical to the Nation's innovation enterprise. The Committee expects the NSF to fully fund world-class U.S. scientific research facilities and instruments to adequately support scientists and students engaged in ground-breaking research to maximize sustained investments in research.

CHESS-- The Committee support's the budget request for NSF's Cornell High Energy Synchrotron Source [CHESS], which is a unique multi-disciplinary user facility that supports research in medicine, physics, materials science, chemistry, biology, and engineering.

Astronomy-- The Committee remains concerned about the continued erosion of support for NSF's domestic national astronomy facilities, including facilities such as the National Radio Astronomy Observatory [NRAO], that have been at the forefront of science for more than 50 years. The Committee expects NSF to fully support the scientific and educational activities at the Division of Astronomical Sciences in the context of a strong NSF astronomy program with NRAO funding at fiscal 2012 levels, and fully supporting the domestic instruments and facilities that produce U.S. leadership in these fields.

Furthermore, the Committee is aware that NSF is preparing to make a final decision on the Astronomy Portfolio Review Commission's recommendation. At least 60 days before issuing a final decision, the Committee directs NSF to submit a report to the Committees on Appropriations and the authorizing committees of jurisdiction outlining the legal authorities the agency has to dispose of real property and providing a full accounting of the multi-year costs that will be required to close these operations if efforts to identify new tenants are unsuccessful.

The Committee welcomes the line item identification of pre-construction funds for future major MREFC projects, including the Large Synoptic Survey Telescope, the astrophysics decadal survey's top ranked ground-based priority in the coming decade. This joint NSF-Department of Energy project will provide unprecedented views of the changing sky and will drive key advances in cyber-infrastructure and large-volume data management. The Committee provides funding at the request level in order to make progress toward a potential new start in a subsequent year, subject to the project meeting the necessary conditions for such action.

Ocean Science Infrastructure--The Committee is supportive of improved funding for Ocean Science infrastructure items including the International Ocean Discovery Program and the Ocean Observing Initiative, and directs NSF to fund these items at the budget request level. However, the Committee is disappointed with the proposed funding cuts to the Academic Research Fleet and planning for the regional-class research vessels. The Committee is concerned that this budget request will mean that current research ships will either not be properly maintained or will not be adequately utilized. Both scenarios are unacceptable. The Committee directs NSF to fund the Academic Research Fleet at no less than the fiscal year 2012 level from proposed budget request increases to OneNSF initiatives. Furthermore, as these current vessels continue to age, planning for their replacements--which includes regional-class vessels--must not be derailed. The Committee directs NSF to ensure that the design and planning for these vessels will soon make them viable candidates for approval for inclusion in the Major Research Equipment and Facilities Construction account.