Appendix I: Summaries of the National Science Foundation's Major Facilities Projects under Construction

Accessible Version

This appendix provides individual summaries of the National Science Foundation's (NSF) five major facilities projects under construction: (1) the Daniel K. Inouye Solar Telescope, (2) the Vera C. Rubin Observatory, (3) the Regional Class Research Vessels, (4) the Antarctic Infrastructure Modernization for Science, and (5) Large Hadron Collider High Luminosity Upgrade Program.

Each project's summary is based on project documents and other information that NSF officials provided and includes the following:

- an overview of the project and its purpose;
- a timeline identifying key project dates, including the date of the original construction award, which we report as the start of construction;
- project information, such as the project's scheduled completion date for construction (including schedule contingency), the type and latest amounts of the awards for construction,[1] the responsible NSF directorate, project partners, and expected duration of operations;
- tables summarizing the project's current status and its cost and any cost[2] or schedule[3] increases or scope reductions made under NSF's no cost overrun policy and changes since our April 2020 report;[4]
- a summary of the project's cost and schedule performance history;

[1]Costs are reported in then-year dollars, which means that NSF or the recipient converted base-year dollars by applying an inflation index. According to NSF policy, inflation is a part of NSF's budgeting and project planning.

[2]NSF measures cost increases against the not-to-exceed cost that the National Science Board authorized under the agency's no cost overrun policy. Therefore, we define cost increases since starting construction as increases to the not-to-exceed cost that the Board authorized.

[3]We identified schedule increases by comparing the project's scheduled completion date in the construction award as of December 2020 with the scheduled completion date in the original construction award. When a project's scheduled completion date was not identified in the award, we used the expiration date of the award.

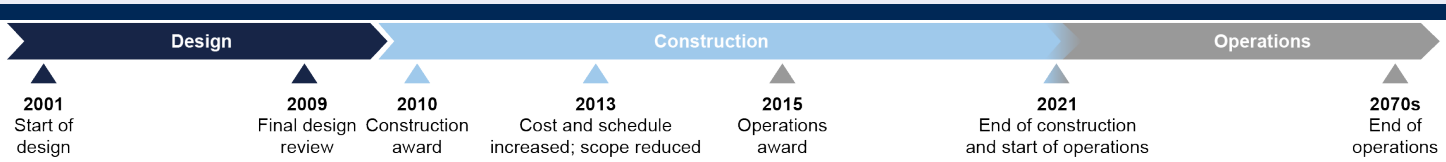
[4]GAO, *National Science Foundation: Cost and Schedule Performance of Major Facilities Construction Projects and Progress on Prior GAO Recommendations,* GAO-20-268 (Washington D.C.: April 3, 2020).

- a chart depicting the latest construction award's total project cost for construction, including the performance measurement baseline and budget contingency;
- if applicable, a chart showing the increase in the construction award's total project cost since the original construction award; and
- information on remaining project risks and potential for cost or schedule increases, including the amount of remaining contingency and scope reduction options.[5]

[5]We report each project's estimate of remaining risk exposure as weighted by the recipients for the probability of the risks occurring. According to NSF's *Major Facility Guide*, risk exposure is the quantitative impact of risks. We report the risk exposure as determined by the Monte Carlo method when available.

DANIEL K. INOUYE SOLAR TELESCOPE

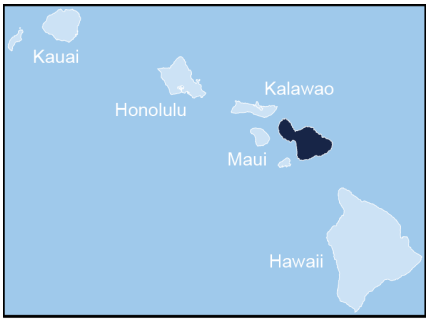
Source: Claire Raftery/Association of Universities for Research in Astronomy, Inc./National Solar Observatory. | GAO-21-417



Source: GAO analysis of NSF information. | GAO-21-417

Project Information

Location: Maui, Hawaii.



Source: GAO. | GAO-21-417

Expected construction completion date, including schedule contingency:

December 2021.

Construction award:

Cooperative support agreements with the Association of Universities for Research in Astronomy, Inc., consisting of 42 U.S. institutional members and five international affiliates.

Responsible NSF directorate:

Mathematical and Physical Sciences.

Project partners:

More than 20 U.S. and international organizations. Leibniz-Institut für Sonnenphysik (Germany) and Queens University Belfast (Northern Ireland) are supplying additional equipment for the project.

Expected duration of operations:

50 years.

Source: NSF documents and officials. | GAO-21-417

Project Summary

Construction of NSF's DKIST project was 98 percent complete, as of December 2020. The project was in its 11th year of construction and in the process of testing and commissioning the facility. Since our April 2020 report, which included data from September 2019, the project installed and aligned a key component of the telescope's optics. However, the Coronavirus Disease 2019 (COVID-19) pandemic and extreme weather events in Hawaii in early 2020 delayed the project. As of December 2020, the estimated end date for construction was June 2021, but in May 2021 NSF staff said they expect the end of construction in December 2021. As of February 2021, the National Science Board approved a total management reserve of $18.9 million to cover expenses related to the pandemic, such as increased labor due to delays or inefficiencies. NSF applied $6.7 million of this reserve to the project in December 2020 and $2.7 million in March 2021.

Construction Status of the Daniel K. Inouye Solar Telescope, as of March 2021 (Percentage complete – 98)

Category	Dollars in millions
Not-to-exceed cost that the National Science Board authorized	363.0
Total project cost in latest construction awards[a]	353.4
National Science Foundation (NSF) funding obligated to date	353.4

Changes in Cost, Schedule, and Scope (Dollars in millions)

Category	Cumulative changes since original construction award	Changes since April 2020
Not-to-exceed cost that the National Science Board authorized	+65.1(cost or schedule increase)	+18.9 (cost or schedule increase)
Total project cost	+55.5 (cost or schedule increase)	+9.3 (cost or schedule increase)
Scheduled completion date (months)	+42 (cost or schedule increase)	+12 (cost or schedule increase)
Scope[b]	-5.9 (scope reduction)	None

Legend: ▲ = cost or schedule increase; ▼ = scope reduction.

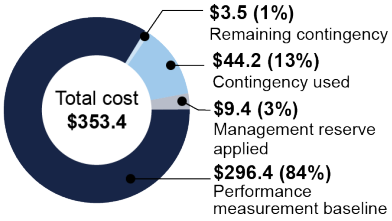
Source: GAO analysis of NSF documents and information from NSF officials. | GAO-21-417

[a]Includes an award funded by appropriations under the American Recovery and Reinvestment Act of 2009 and an award funded by NSF's Major Research Equipment and Facilities Construction account.

[b]Scope changes included are reductions in response to NSF's policy on cost overruns or as part of a cost increase.

Latest Construction Award[a]

Total Project Cost, in millions, as of March 2021



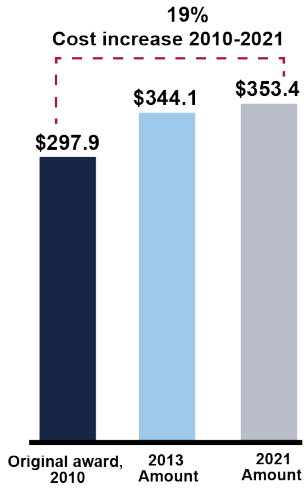
Accessible Data for Latest Construction Award[a] (Total Project Cost, in millions, as of March 2021)

Category	Total Project Cost, in millions
Remaining contingency	$3.5 (1%)
Contingency used	$44.2 (13%)
Management reserve applied	$9.4 (3%)
Performance measurement baseline	$296.3 (84%)
Total cost	$353.4

Note: Percentages do not sum to 100 percent due to rounding.

Increase in Construction Award[a]

Total project cost, in millions, as of March 2021



Source: NSF documents and officals. | GAO 21-417

Accessible Data for Increase in Construction Award[a] (Total project cost, in millions, as of March 2021)

Category	Total project cost, in millions
Original award 2010	$297.9
2013 increase	$344.1
2021 increase	$353.4
Cost increase 2010-2021	19%

[a]Includes an award funded by appropriations under the American Recovery and Reinvestment Act of 2009 and an award funded by NSF's Major Research Equipment and Facilities Construction account.

Remaining Contingency and Scope Reduction Options

As of December 2020 with construction 98 percent complete.

NSF Management Reserve:

$18.9 million

Budget contingency:

$3.5 million of budget contingency remaining ($1.1 million more than the estimated remaining risk exposure of about $2.4 million).

Schedule contingency:

One month.

Estimated value of remaining scope reduction options:

$21,000

Source: NSF documents and officials. | GAO-21-417

Cost and Schedule Performance History

DKIST was delayed for pandemic and non-pandemic related reasons. In February 2020, there was an ice storm which caused a power outage at the construction site, and a subsequent 2-week slow down. Then the construction site was shut down again from March 17 to June 4, because of the COVID-19 pandemic. The project began a phased reentry to the site on June 4, 2020. The project requested, and NSF approved, a no cost extension to the project's end date from June 30, 2020 to December 31, 2020. However, the project was unable to meet this deadline because, among other things, personnel needed for testing were located on the U.S. mainland and unable to reach Hawaii until it reopened to travel in October 2020. To address costs and delays related to the pandemic, NSF initially increased the not-to-exceed cost of the project to include a management reserve of $9.4 million using authority delegated to NSF by the National Science Board to adjust costs by up to $10 million. In February 2021, the National Science Board approved an additional increase in management reserve of $9.5 million for a total reserve of $18.9 million. As of March 2021, NSF applied $9.4 million of the reserve to the award and delayed end of construction to June 2021.

Remaining Project Risks and Potential for Cost or Schedule Increases

As of December 2020, the DKIST project had $3.5 million of budget contingency remaining—$1.1 million more than the estimated remaining risk exposure of about $2.4 million when weighted for the risks' probability. The project also had 1 month of schedule contingency remaining to offset any potential delays in completing construction. However, NSF had to extend the award due to commissioning challenges and the pandemic which will require further use of management reserve within the $18.9 million currently authorized.

According to the project documentation, the largest remaining non-pandemic risk category is project completion and closeout, which includes risks related to staff retention and performance and quality issues. As of December 2020, this category included seven risks with about $1.4 million in probability weighted risk exposure. The project maintains a list of scope reduction options, which, as of December 2020, included approximately $21,000 in total possible project scope reduction options. However, the ability of these remaining scope reduction options to reduce costs will continue to decrease as the project approaches completion.

Source: W O'Mullane/LSST Project/ NSF/AURA | GAO-21-417

VERA C. RUBIN OBSERVATORY

The National Science Foundation's (NSF) Vera C. Rubin Observatory (Rubin), an 8.4-meter, wide-field optical telescope, will initially be used to image the entire visible southern sky—every 3 days for a decade—using the world's largest digital camera (3 billion pixels). Built on a mountaintop in Chile, a location with pristine skies, the telescope will collect data and images to chart billions of galaxies and increase knowledge about potentially hazardous asteroids, dark matter, and energy. Rubin has the potential to advance every field of astronomical study, from the inner solar system to the large-scale structure of the universe. Its former name was the Large Synoptic Survey Telescope (LSST).

Source: GAO analysis of NSF information. | GAO-21-417

Project Information

Location: Cerro Pachón, Chile.

Source: GAO. | GAO-21-417

Scheduled construction completion date, including schedule contingency:

October 2022.

Construction award:

Cooperative support agreement with the Association of Universities for Research in Astronomy, Inc., consisting of 42 U.S. institutional members and five international affiliates.

Responsible NSF directorate:

Mathematical and Physical Sciences.

Project partners:

The LSST Corporation, Department of Energy.

Expected duration of operations:

50 years.

Source: NSF documents and officials. | GAO-21-417

Project Summary

As of December 2020, the Rubin project was 86 percent complete and in its 7th year of construction. Since our April 2020 report, the project made progress on the observatory's dome and telescope mount assembly. However, construction was halted in Chile due to the pandemic in March and the site remained closed until late September 2020. The project is no longer operating on schedule because of pandemic-related delays. NSF expects the end of construction will occur in early 2024, but no formal changes have yet been made to the project schedule. NSF increased the not-to-exceed cost by $10 million to include a management reserve for costs due to the COVID-19 pandemic, such as increased labor due to delays or inefficiencies.

Construction Status of the Vera C. Rubin Observatory, as of December 2020 (Percentage complete – 86)

Category	Dollars in millions
Not-to-exceed cost that the National Science Board authorized	483.0
Total project cost in latest construction award	471.2[a]
National Science Foundation (NSF) funding obligated to date	459.4

Changes in Cost, Schedule, and Scope (Dollars in millions)

Category	Cumulative changes since original construction award	Changes since April 2020
Not-to-exceed cost that the National Science Board authorized	+10 (cost or schedule increase)	+10 (cost or schedule increase)
Total project cost[b]	+3.4 (cost or schedule increase)	None
Scope[c]	-9.5 (scope reduction)	-8.1 (scope reduction)
Scheduled completion date (months)[d]	None	None

Legend: ▲ = cost or schedule increase; ▼= scope reduction.

Source: GAO analysis of NSF documents and information from NSF officials. | GAO-21-417

[a]Excludes fee of $1.1 million in total provided to date to stimulate efficient performance since award.

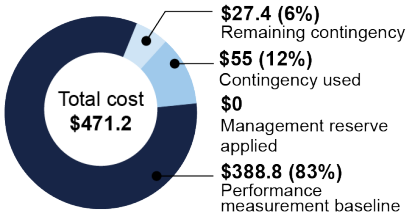
[b]This cost change was anticipated at the time of the original construction award, according to NSF officials, in order to accommodate evolving NSF policies on budget contingency.

[c]Scope changes included are reductions in response to NSF's policy on no cost overruns at initial award ($1.4 million) or to increase the available budget contingency ($8.1 million).

[d]Schedule does not yet incorporate COVID-19 pandemic impacts.

Latest Construction Award

Total project cost, in millions, as of December 2020



Notes: Excludes fee of $1.1 million provided to the recipient to stimulate efficient performance. Percentages do not sum to 100 percent due to rounding.

Accessible Data for Latest Construction Award (Total project cost, in millions, as of December 2020)

Category	Total project cost, in millions
Remaining contingency	$27.4 (6%)
Contingency used	$55 (12%)
Management reserve applied	$0
Performance measurement baseline	$388.8 (83%)
Total cost	$471.2

Remaining Contingency and Scope Reduction Options

As of December 2020 with construction 86 percent complete.

NSF Management Reserve:

$10 million

Budget contingency:

$27.4 million ($2.8 million more than the probability-weighted risk exposure of $24.6 million)

Schedule contingency:

4.8 months.

Estimated value of remaining scope reduction options:

$9 million.

Source: NSF documents and officials. | GAO-21-417

Contributions of Project Partners

The U.S. Department of Energy (DOE), a cosponsor of the Vera C. Rubin Observatory is responsible for delivering the camera at a cost of $168 million. SLAC National Accelerator Laboratory manages a collaboration of DOE national laboratories and universities to develop, fabricate, and deliver the camera. The COVID-19 pandemic also impacted camera construction, but as of January 2021 NSF did not expect camera construction would further delay the project.

Source: GAO analysis of NSF and DOE information.

Cost and Schedule Performance History

In June 2020, NSF increased the not-to-exceed cost for Rubin by $10 million to $483 million to include a management reserve to address pandemic-related costs. According to NSF and project documents, the added costs are primarily due to schedule delays as well as direct costs associated with office and construction site closures. As of March 2021, NSF had not yet applied any of this reserve to the award, thus the total project cost has not changed since our April 2020 report. However, NSF and the project anticipate that additional funding beyond the $10 million will be needed for pandemic-related costs. Further, increasing the cost of the project will require authorization from the National Science Board.

The project will not finish by its current construction completion date of October 2022. Prior to the pandemic, the project had experienced delays related to the construction of the dome enclosure and telescope mount assembly. According to NSF, significant progress was made on these items in early 2020. However, they remain unfinished as the project halted construction in March 2020 in response to the COVID-19 pandemic and the Chilean government-imposed quarantine throughout the country in July 2020. Limited construction activities at the site began again in late September 2020. Dome construction resumed in November and mount assembly construction resumed in January 2021. NSF expects a re-baselining of the project in late 2021 to establish a new schedule and total project cost. According to project documents, the pandemic will delay completion by at least 10 months. The project measurement baseline currently has 4.8 months of schedule contingency for non-pandemic-related delays, however pandemic impacts and the planned re-baselining will alter the project's schedule.

Remaining Project Risks and Potential for Cost or Schedule Increases

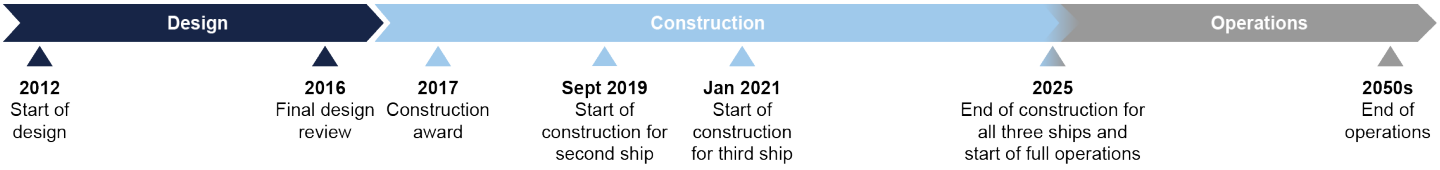
As of December 2020, the project had an estimated remaining risk exposure of $24.6 million for non-pandemic-related risks, which is $2.8 million less than the remaining budget contingency of $27.4 million. According to project documents, factoring in actions to mitigate these risks lowers the expected risk exposure to just $12.4 million. The largest non-pandemic-related risks include late delivery or integration of the dome enclosure or mount assembly and late delivery of the DOE-funded camera.

In accordance with NSF policy, the project maintains a list of scope reduction options. As of December 2020, there was approximately $9 million in total possible project scope reduction options remaining. As the project moves towards completion, fewer scope reduction options will be available.

Source: Artist Rendering by Glosten. | GAO-GAO-21-417

REGIONAL CLASS RESEARCH VESSELS

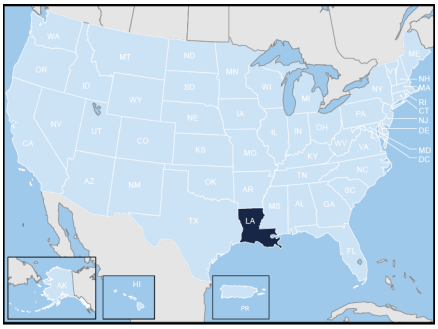
The National Science Foundation's (NSF) Regional Class Research Vessels (RCRV) project will construct three 199-foot vessels to support the nation's ability to conduct fundamental scientific research in the coastal zone and continental shelf, including from the ocean's surface through the water column to the sea floor and subsea floor environment. These vessels will provide enhanced capabilities beyond those of the retiring vessels they will replace. The three vessels' research locations will depend on where the science demand is greatest, but NSF plans to operate the first vessel along the west coast of the U.S.



Source: GAO analysis of NSF information. | GAO-21-417

Project Information

Location: Construction site is in Louisiana.



Source: GAO. | GAO-21-417

Scheduled construction completion date, including schedule contingency:

January 2025 for three vessels.

Construction award:

Cooperative support agreement with Oregon State University, which contracted with Gulf Island Shipyards, LLC.

Responsible NSF directorate:

Geosciences.

Project partners:

The U.S. Navy supported initial design oversight for the vessels.

Expected duration of operations:

30 years.

Source: NSF documents and officials. | GAO-21-417

Project Summary

As of December 2020, construction of NSF's RCRV project was 35 percent complete and the project was in its 4th year of construction. Since our April 2020 report, the RCRV project has made progress on vessel construction and 3D modeling, but has fallen behind schedule. The project continued construction on vessel 1 and vessel 2. They also performed a keel laying ceremony for vessel 3 in March 2020 but delayed start of construction until January 2021. NSF increased the not-to-exceed cost by $10 million in December 2020 and designated a management reserve of about $14.1 million held by NSF for COVID-19 related costs, such as increased labor costs due to delays or inefficiencies. NSF authorized the project to use $5.5 million of this reserve to address COVID-19 costs to date, but NSF has not yet applied any reserve since the current obligations cover these increases.

Construction Status of the Regional Class Research Vessels, as of March 2021 (Percentage complete, based on construction of three vessels, - 35)

Category	Dollars in millions
Not-to-exceed cost that the National Science Board authorized	375.0
Total project cost in latest construction award	359.5
National Science Foundation (NSF) funding obligated to date	343.0

Changes in Cost, Schedule, and Scope (dollars in millions)

Category	Cumulative changes since original construction award	Changes since April 2020 report
Not-to-exceed cost that the National Science Board authorized	+10 (cost or schedule increase)	+10 (cost or schedule increase)
Total project cost	+5.5 (cost or schedule increase)	+5.5 (cost or schedule increase)
Scope[a]	None	None
Scheduled completion date (months)	+6 (cost or schedule increase)	+6 (cost or schedule increase)

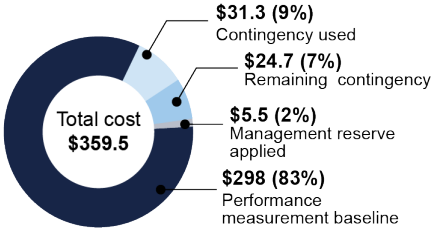
Legend: ▲ = cost or schedule increase.

Source: GAO analysis of NSF documents and information from NSF officials. | GAO-21-417

[a]Scope changes included are reductions in response to NSF's policy on cost overruns or as part of a cost increase.

Latest Construction Award

Total project cost, in millions, as of March 2021



Note: Percentages do not sum to 100 percent due to rounding.

Accessible Data for Latest Construction Award (Total project cost, in millions, as of March 2021)

Category	Total project cost, in millions
Contingency used	$31.3 (9%)
Remaining contingency	$24.7 (7%)
Management reserve applied	$5.5 (2%)
Performance measurement baseline	$298 (83%)
Total cost	$359.5

Remaining Contingency and Scope Reduction Options

As of December 2020 with construction of three vessels 35 percent complete.

NSF Management Reserve:

$14.1 million

Budget contingency:

$24.7 million ($4.5 million more than the probability-weighted risk exposure of $20.2 million).

Schedule contingency:

None.

Estimated value of remaining scope reduction options:

$4.9 million

Source: NSF documents and officials. | GAO-21-417

Cost and Schedule Performance History

As of December 2020, the RCRV project had no schedule contingency remaining and NSF anticipated additional schedule delays due to the pandemic. The project also increased its total project cost and delayed project completion, but had not implemented any scope reductions.

The RCRV project has fallen behind schedule, in part due to shipyard delays in developing the 3D models and technical drawings needed for construction. As we reported in April 2020, the project recipient, Oregon State University, had concerns regarding the project management and subcontractors of the Gulf Island Shipyards that led to a partial work suspension in early 2019. In November 2019, Oregon State University implemented the contract's dispute resolution process and assumed responsibility for the project's modelling. In May 2020, the project implemented a change to its baseline to address the impacts of the dispute. This change used $18 million of budget contingency, including a $12.2 million increase in the contract to the shipyard. The change also led to about a 9-month delay in delivery of the three vessels and exhausted the 180 days of schedule contingency available at the time.

In addition, the project has continued to fall behind schedule due to the COVID-19 pandemic. The shipyard lacked sufficient staff to complete RCRV construction as planned and labor inefficiencies led to delays in technical drawings used by the shipyard. In December 2020, NSF authorized about $14.1 million in management reserve to cover costs associated with the pandemic by increasing the project's not-to-exceed cost by $10 million and using additional funds available because the total project cost in the construction award was less than the prior not-to-exceed cost. No additional funds have yet been obligated to the construction award, but NSF subsequently authorized Oregon State University to modify its contract with the shipyard by $5.5 million to address the increased labor costs in 2020. This modification also delayed delivery of the first two vessels by 4 months, delivery of the third vessel by 3 months, and project completion by 6 months.

Since we reported in April 2020, vessel delivery has slipped from August 2021 to September 2022 for the first vessel; from January 2022 to March 2023 for the second vessel; and from July 2022 to August 2023 for the third vessel.

Remaining Project Risks and Potential for Cost or Schedule Increases

As of December 2020, the project had an estimated risk exposure of $20.2 million and a remaining contingency of $24.7 million. Inadequate shipyard performance remains a major risk, but has decreased due to the project's re-planning efforts. Nonetheless, hull delivery delays remain a risk to completing the project on time and budget.

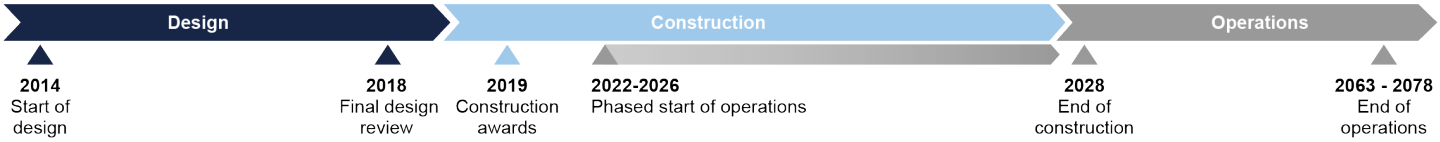
The project has implemented no scope reductions. Fourteen scope reduction options remain totaling $4.9 million in cost reduction. The largest remaining option was to reduce the 18-month timeframe currently devoted to transitioning from construction to full operations. Such a reduction could save $1.5 million in staff costs, but would incur risks to transitioning activities that could impact operations. Other scope reduction options included eliminating certain pieces of equipment, such as the inspection vehicle or cold storage space, to support longer term operations.

Source: Leidos. | GAO-21-417

Note: Rendering of McMurdo Station's core facility.

ANTARCTIC INFRASTRUCTURE MODERNIZATION FOR SCIENCE

The National Science Foundation's (NSF) Antarctic Infrastructure Modernization for Science (AIMS) project will modernize the core infrastructure of McMurdo Station in Antarctica, the largest of three stations operated by NSF's United States Antarctic Program and used by multiple agencies. McMurdo Station serves as a logistics hub for remote field sites and for the Amundsen-Scott South Pole Station. The AIMS project is expected to make environmental and safety upgrades to McMurdo Station and redevelop it into a more compact, operationally and energy-efficient core facility to support research. The planned core facility will consolidate critical buildings, such as medical facilities and field science support.



Source: GAO analysis of NSF information. | GAO-21-417

Project Information

Location: McMurdo Station, Antarctica

Source: GAO. | GAO-21-417

Expected construction completion date, including schedule contingency:

January 2028

Construction award:

February and April 2019 modifications to the existing Antarctic support contract with Leidos Innovations Corporation.

Responsible NSF directorate:

Geosciences.

Project stakeholders:

Other federal agencies—such as the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, and the Department of Energy.

Expected duration of operations:

35 to 50 years.

Source: GAO analysis of NSF information. | GAO-21-417

Project Status

Construction of the AIMS project was about 24 percent complete as of December 2020. In March 2020, work at the project site was suspended to avoid the possibility of introducing COVID-19 to Antarctica. As of December 2020, AIMS remains behind schedule with all construction work at McMurdo paused. The site has been placed in a safe and stable condition until pandemic and longer-term logistical impacts are better understood. NSF and the awardee continue to discuss how to reprioritize work and maintain forward momentum given the considerable uncertainties of the global logistics chain and construction feasibility due to COVID-19. Materials for the Vehicle Equipment and Operation Center and Lodging facilities are still being procured and delivered to the project's shipping staging site in Port Hueneme, California. Prior to the suspension of work, production of the stone material needed for new structures at the site had begun as had the demolition of retired structures.

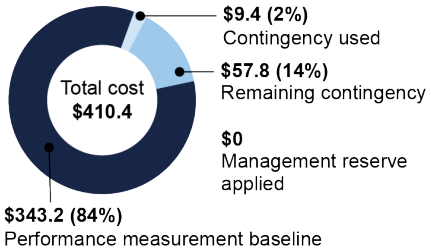
Construction Status of the Antarctic Infrastructure Modernization for Science, as of December 2020 (Percentage complete – 24)

Category	Dollars in millions
Not-to-exceed cost that the National Science Board authorized	410.4
Total project cost in latest construction awards	410.4
National Science Foundation (NSF) funding obligated to date	151.7

Source: GAO analysis of NSF information. | GAO-21-417

Latest Construction Award

Total project cost, in millions, as of December 2020



Note: .The baseline includes fees and on-site oversight costs.

Accessible Data for Latest Construction Award (Total project cost, in millions, as of December 2020)

Category	Total project cost, in millions
Contingency used	$9.4 (2%)
Remaining contingency	$57.8 (14%)
Management reserve applied	$0
Performance measurement baseline	$343.2 (84%)
Total cost	$410.4

Independent Cost Estimate

In November 2018, the U.S. Army Corps of Engineers completed an independent cost estimate (ICE) report for the AIMS project. According to NSF officials, the ICE was critical for negotiations with the contractor as NSF utilized data within the ICE, such as labor rates and cost of materials, to verify costs. Specifically, the ICE assisted NSF in determining the reasonableness of the contractor's proposed cost estimate and schedule for the project and associated risks. According to NSF officials, NSF and the contractor resolved all recommendations from the ICE report to NSF's satisfaction prior to setting the not-to-exceed cost.

Remaining Contingency and Scope Reduction Options

As of December 2020 with construction about 24 percent complete.

Budget contingency:

$57.8 million ($5.7 million more than the probability-weighted risk exposure of $52.1 million).

Schedule contingency:

15.2 months (included in the 2028 scheduled completion date).

Source: GAO analysis of NSF information. | GAO-21-417

Cost and Schedule Performance History

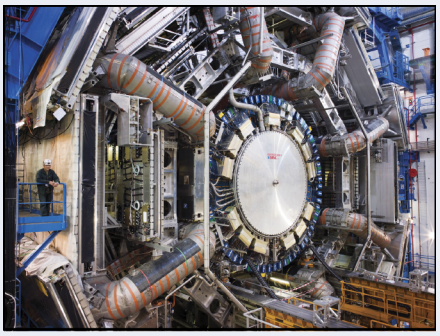
Due to the pandemic, AIMS remains behind schedule with all construction work at McMurdo Station paused. With the loss of a second construction season likely, NSF officials expect that the project will be re-baselined by the end of 2021. In accordance with NSF policy, this could include reductions in project scope, a return to the National Science Board for an increased total project cost, or both. As of December 2020, the impacts of the pandemic were not yet reflected as construction cost increases, formal changes to its scheduled completion date, or scope reductions. The project's not-to-exceed cost of $410.4 million, which included $67.2 million in budget contingency, was set by the National Science Board in February 2019. On April 30, 2021, NSF determined that it would not be funding additional components of AIMS due to the significant impacts of the pandemic. Current components of AIMS include the Vehicle Equipment and Operations Center, the first lodging unit, and associated utilities.

Remaining Project Risks and Potential for Cost or Schedule Increases

As of December 2020, the AIMS project had a risk exposure of $52.1 million and $57.8 million in remaining contingency, and 15.2 months of schedule contingency remained available. The project had cumulatively used $9.4 million in budget contingency. Of this, $7.3 million was used for contract modifications for initial construction, with the remainder used for other realized risks, including additional equipment purchases and leases.

As of December 2020, the AIMS project had $17.0 million in major risks monitored by NSF. Given the level of uncertainty and high potential impact on Antarctic operations associated with the COVID-19 pandemic, a meaningful risk profile will not be available until the project is re-baselined. Other major previously-known risks being monitored include proposals exceeding estimates with an estimated value of $15.2 million, and design and value engineering delays with an estimated value of $1.4 million, and their associated impacts have been overtaken by the pandemic. Environmental conditions at McMurdo during the 2020/2021 season prevented the construction of a safe ice pier for cargo unloading, but this did not impact AIMS since no on-site construction was planned due to the pandemic. Domestic production of AIMS components was able to continue.

In accordance with NSF policy, the project maintains a list of scope reduction options, which as of April 2019 included approximately $34.0 million to $43.1 million in total possible project scope reduction options. For example, the largest scope reduction option, with an estimated value of up to $19.1 million, is to remove the new trades shop from the AIMS scope and instead continue to use the current facility. Another option, with an estimated value of up to $4.0 million, is to remove the gymnasium from the emergency operations facility and instead continue to use and maintain the existing gymnasium.



Source: © 2007 CERN. | GAO-21-417

Note: photograph above depicts the A Toroidal Large Hadron Collider Apparatus detector.

LARGE HADRON COLLIDER HIGH LUMINOSITY UPGRADE

The Large Hadron Collider (LHC) is the world's most powerful particle accelerator. The facility's four detectors observe new particles that are produced when high-energy protons are accelerated and collided, providing insight into fundamental forces of nature and the condition of the early universe. Through the National Science Foundation's (NSF) Large Hadron Collider High Luminosity Upgrade (HL-LHC) program, the agency will fund a portion of a larger international effort to upgrade the facility's accelerator and detectors. Specifically, NSF plans to fund the design and implementation of certain parts of the upgrades as two separate projects for the facility's detectors, the A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) detectors. The Department of Energy (DOE) is also contributing to upgrades to the LHC's accelerator and to the ATLAS and CMS detectors.

Source: GAO analysis of NSF information. | GAO-21-417

Project Information

Location: Geneva, Switzerland.

Source: GAO. | GAO-21-417

Expected construction completion date, including schedule contingency:

December 2026.

Construction awards:

Cooperative agreements with Columbia University (ATLAS detector) and Cornell University (CMS detector).

Responsible NSF directorate:

Mathematical and Physical Sciences.

Project partners:

European Organization for Nuclear Research (CERN) and the Department of Energy.

Expected duration of operations:

12 years.

Source: GAO analysis of NSF information. | GAO-21-417

Project Summary

As of December 2020, NSF's HL-LHC program was in its 1st year of construction. In February 2020, the National Science Board authorized an award to Columbia University for the ATLAS detector not to exceed $75 million and a second award to Cornell University for the CMS detector not to exceed $78 million. NSF awarded construction awards to the two universities in March 2020. While the upgrades involve separate cooperative agreements for each detector, NSF considers them one program consisting of two distinct projects. The COVID-19 pandemic has delayed construction of the detectors, including an estimated 7-month delay for ATLAS from its baseline schedule, and impacted other aspects of the LHC upgrade. Excluding impacts of the pandemic, the detectors' baseline schedule estimates end of construction in 2025, not including schedule contingency, or 2026 including it.

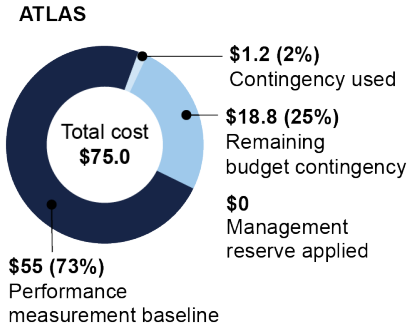
Construction Status of the Large Hadron Collider High Luminosity Upgrade, as of December 2020 (Dollars in millions)

Category	ATLAS	CMS	Program Total
Percentage complete	8.2	9.4	not applicable
Not-to-exceed cost that the National Science Board authorized	75	78	153
Total project cost in latest construction awards	75	77.2	152.2
National Science Foundation (NSF) funding obligated to date	22	27.9	49.9

Source: GAO analysis of documents and information from NSF. | GAO-21-417

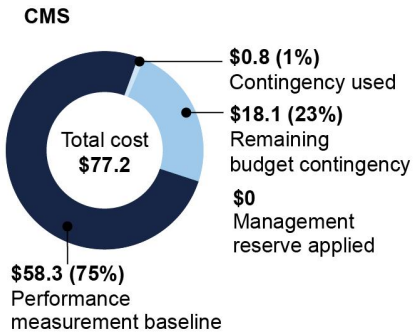
Latest Construction Award

Total Project Cost, in millions, as of December 2020



Accessible Data for Latest Construction Award (Total Project Cost, in millions, as of December 2020) - ATLAS

Category	Total Project Cost, in millions
Contingency used	$1.2 (2%)
Remaining budget contingency	$18.8 (25%)
Management reserve applied	$0
Performance measurement baseline	$55 (73%)
Total cost	$75.0



Accessible Data for Latest Construction Award (Total Project Cost, in millions, as of December 2020) – CMS

Category	Total Project Cost, in millions
Contingency used	$0.8 (1%)
Remaining budget contingency	$18.1 (23%)
Management reserve applied	$0
Performance measurement baseline	$58.3 (75%)
Total cost	$77.2

Remaining Contingency and Scope Reduction Options

As of December 2020.

Budget contingency:

$36.9 million as follows

- $18.8 million for the ATLAS detector.
- $18.1 million for the CMS detector.

Schedule contingency:

- 13.5 months for the ATLAS detector.
- 10.2 months for the CMS detector.

Estimated value of scope reduction options:

$15.1 million as follows

- $8.4 million for the ATLAS detector.
- $6.7 million for the CMS detector.

Source: GAO analysis of NSF information. | GAO-21-417

DOE's Contributions to Upgrading the Large Hadron Collider

The estimated cost range of DOE's contributions is $149 million to $181 million for the ATLAS detector and $144 million to $183 million for the CMS detector. DOE's work on the detectors is led by the department's national labs, whereas NSF's work is led by university researchers.

Source: DOE fiscal year 2021 budget information. | GAO-21-417

Cost and Schedule Performance History

NSF has obligated $22 million for construction of ATLAS and $27.9 million for CMS, as of December 2020. The project's initial awards estimated total project costs of $75 million for ATLAS and $77.2 million for CMS. The National Science Board's not-to-exceed cost is $75 million for ATLAS and $78 million for CMS. In addition, according to NSF officials, NSF invested a total of $23.7 million for the design of the detector upgrades. Funding for the design came from NSF's Research and Related Activities account. Funding for construction will come from the Major Research Equipment and Facilities Construction account.

Remote work conditions and social distancing protocols due to the COVID-19 pandemic have led to delays to both detectors as compared to the baseline schedule. Both projects are assessing the impacts of the pandemic, and neither has completed changes to their baseline schedules as the impacts of the pandemic are ongoing.

Remaining Project Risks and Potential for Cost or Schedule Increases

Neither the ATLAS team nor the CMS team has fully assessed the impact of COVID-19 on their projects. Both project teams are developing change requests to their baseline to address these impacts. NSF plans to use management reserve, not the projects' contingency, to cover expenses related to the pandemic but has not yet established reserve amounts for these projects. According to NSF, the estimated cumulative costs currently range from $2 million to $3 million, due to labor inefficiencies and re-planning costs, among others. As of December 2020, the project teams estimate schedule delays from the pandemic of 7 and 2 months for ATLAS and CMS, respectively.

According to project documentation, as of December 2020, the ATLAS project team had $18.8 million in budget contingency remaining after using $1.2 million of its initial $20 million contingency fund. The highest impact risks managed by the project team include volatility of commodity prices, delays due to other ongoing projects at CERN, and loss of key personnel. The project team plans to update its risk exposure in late fiscal year 2021.

As of December 2020, the CMS project had $18.1 million in budget contingency remaining after using $840 thousand of its initial $18.9 million contingency budget. In October 2020, the CMS project team estimated its risk exposure was $17.5 million. The highest impact risks managed by the project include uncertainty regarding foreign currency exchange rates, unavailability of scientific labor, and quality problems. Risks regarding COVID-19 were not included in the project team's analysis.

NSF policy also directs a project's design to include prioritized, time-phased options for reducing its scope during construction if needed. As of the final design review, the project teams had identified a total of $15.1 million of potential scope reduction options for the projects, which are subject to change throughout the design and construction of a project.

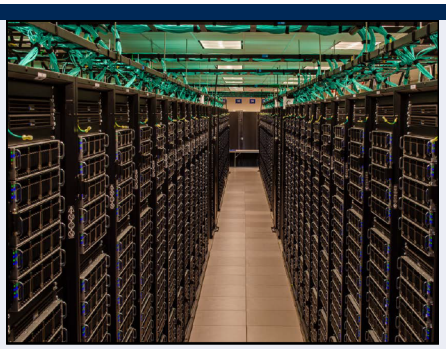
Appendix II: Summary of the National Science Foundation's Future Major Facilities Project in Design

This appendix provides an individual summary of the National Science Foundation (NSF) project that is in design and planned for construction as a major facilities project: the Leadership Class Computing Facility. As of December 2020, no construction funds had been awarded for this project and all cost, schedule, scope, and design information was subject to change.

The project's summary is based on project documents and other information that NSF officials provided and includes the following:

- an overview of the project and its purpose;
- a timeline identifying key project dates;
- project information, such as the expected date for completion of construction; the anticipated type of awards for construction; the responsible NSF directorate; project partners; and expected duration of operations;
- a summary of the project's current status;
- a summary of the project's design and construction costs, if available, and the budget account NSF planned to use for construction of the project;[1] and
- information on potential project risks.

[1]Costs are reported in then-year dollars, which means that NSF or the recipient converted base-year dollars by applying an inflation index. According to NSF policy, inflation is a part of NSF's budgeting and project planning.



Source: NSF. | GAO-21-417

Note: Photograph above depicts NSF's most advanced computing system currently in operation, known as Frontera.

LEADERSHIP-CLASS COMPUTING FACILITY

The National Science Foundation's (NSF) Leadership-Class Computing Facility (LCCF) project is intended to provide advanced computational capabilities to enable transformative research in all areas of science and engineering that would not be possible by theory or experiment alone. According to NSF officials, future research using LCCF might include extremely detailed simulations ranging from biological molecules to supernovae and analyses of very large data streams such as satellite images to create high-resolution Earth maps.

Source: GAO analysis of NSF information. | GAO-21-417

Project Information

Location: Texas Advanced Computing Center, University of Texas at Austin

Source: GAO. | GAO-21-417

Expected construction completion date, not including schedule contingency:

Fiscal Year 2026.

Construction award:

Planned for 2024.

Responsible NSF directorate:

Directorate for Computer & Information Science & Engineering.

Project partners:

None.

Expected duration of operations:

10 years.

Source: GAO analysis of NSF information. | GAO-21-417

Project Status

As of December 2020, the LCCF project was in its second year of design; consequently, all cost, schedule, scope, and design information for the project was subject to change. In March 2019, the NSF Director approved the project to enter the design stage as a candidate major facilities project. NSF approved advancing the project to the preliminary design phase in September 2020, following the recommendation of the conceptual design review and facilities readiness panels. A preliminary design phase award of $3.5 million was made on September 17, 2020. The project represents the final phase of a two-phase deployment of high-performance computing systems. The first phase—known as the Frontera project at the Texas Advanced Computing Center at the University of Texas at Austin—was completed in September 2019. According to NSF, at that time, Frontera was the largest high-performance computing system deployed on a U.S. academic campus. The LCCF project will support the design and construction of an upgrade to the Frontera system as well as to the physical facility that will host it.

Design and Construction Costs

As of December 2020, NSF had not yet established the construction cost and scope for the LCCF project. The final cost will be subject to the outcomes of further design reviews, NSF approval, and eventual National Science Board authorization. In fiscal years 2019 and 2020, NSF obligated $5.5 million from its Research and Related Activities account for the design of LCCF. Based on a recommendation from the Conceptual Design Review Panel, NSF is also planning to fund 15 to 20 science teams ($4.5 million to $6.0 million) in fiscal year 2021 to help define the benchmark suite of science applications that will be used to measure the performance improvements of the LCCF system. According to the project's cooperative agreement, NSF may provide $2.5 million additional funding in fiscal year 2022 to advance the design of LCCF following successful completion of the preliminary design review, subject to availability of appropriations. The preliminary design review is tentatively scheduled for October 2021.

NSF's Support for High-Performance Computing Systems

NSF has supported high-performance computing capabilities for nearly 4 decades. In 2007, NSF awarded $226.6 million for the Blue Waters high-performance computing system through a cooperative agreement to the University of Illinois at Urbana-Champaign. According to NSF, at the time of its deployment in 2013, Blue Waters was one of the most powerful supercomputers in the world and was one of the fastest on a university campus. Scientists and engineers across the country used the computing and data power of Blue Waters to tackle a wide range of problems, including predicting the behavior of complex biological systems and simulating the evolution of the cosmos.

Because of the rapid evolution of computer technology, by 2019, NSF no longer considered Blue Waters to be the leadership computing system for fundamental science and engineering research. Anticipating these technological advances, in August 2018, NSF awarded about $60 million to the University of Texas at Austin for the follow-on project to Blue Waters. Frontera was intended to provide three to five times the computing capability and twice the storage capacity to support the increased computational requirements for science and engineering research. NSF also anticipated that Frontera would help inform science requirements and reduce risks for LCCF, which is planned to provide substantially more computational capabilities than both Blue Waters and Frontera.

Source: GAO analysis of NSF information. | GAO-21-417

Project Risks

As of December 2020, NSF had not yet formally identified risks for the LCCF project because the project is early in the design stage. The project team identified 25 significant risks during the conceptual design, such as failing to meet performance specifications. However, the conceptual design review panel found that there were immediate, identifiable risks that were absent or insufficiently delineated in the design and recommended that the project team expand their consideration of risks early in the preliminary design phase.

According to NSF officials, one anticipated challenge for the LCCF project is the rapid pace of technological change in the field of high-performance computing. The officials stated that forecasting the technology marketplace in the future can be challenging as technology can change radically because of external market forces. Conversely, the rapid pace of change can also be an opportunity if the LCCF project can incorporate the latest technological advances that result in the most advanced computing capabilities. According to NSF officials, taking advantage of such opportunities as late in the design or construction stage as possible will be important for the success of the project.