Executive Summary

This volume presents the main conclusions of the 2021 HEP Community Planning Exercise, also known as "Snowmass 2021" or just "Snowmass", the most recent of the planning exercises of the U.S. High Energy Physics (HEP) Community, which was sponsored by the Division of Particles and Fields (DPF) of the American Physical Society (APS). The objective of Snowmass 2021 was to examine the status and scientific goals of U.S. HEP and to propose essential scientific programs to pursue and thereby provide community input to the 2023 DOE/NSF "Particle Physics Project Prioritization Panel" (P5), a subpanel of the High Energy Physics Advisory Panel (HEPAP) charged with updating the strategic plan for U.S. HEP for the coming decade and beyond. In addition, the conclusions of Snowmass 2021, especially in the areas related to early career physicists and to community engagement, go beyond those that can be implemented solely by funding agencies — and will also require effort by individuals, universities, laboratories, and national scientific organizations, such as APS and DPF.

Several thousand people contributed to Snowmass 2021. Over five hundred contributed papers (also known as "white papers") were produced. The Snowmass planning process incorporated input from other national and international planning exercises, notably the European Strategy for Particle Physics. The final discussions of all the white papers and other materials developed for Snowmass took place at the Community Summer Study and Workshop at the University of Washington in Seattle, from July 17 – 26, 2022, with an in-person attendance of about 700 and about 650 remote participants.

Snowmass 2021 was organized into ten working groups, or "Frontiers": Accelerator (AF), Community Engagement (CEF), Computational (CompF), Cosmic (CF), Energy (EF), Instrumentation (IF), Neutrino (NF), Rare Processes and Precision Measurements (RPF), Theory (TF), and Underground Facilities and Infrastructure (UF). These Frontiers comprise a broad array of ground-breaking scientific research topics and the underlying technology and infrastructure needed to execute them, as well as, guided by the CEF, a forum to examine how the U.S. HEP community can become more representative of and responsive to all members of our community and can engage with society as a whole. Each Frontier divided its work among several subgroups, known as Topical Groups (TGs) and synthesized the input received from its TGs into a Frontier summary report. In addition, a Snowmass Early Career (SEC) organization was formed to assist young physicists in contributing to the Snowmass process and to bring their issues into the community study. The ten Frontier reports and the SEC Summary Report are included in the full Snowmass Report.

The High Energy Physics Landscape in 2022

After decades of pioneering explorations and milestone discoveries, the Standard Model (SM) of particle physics has been confirmed as the theory that describes electroweak and strong interactions up to energies of a few hundred GeV with great accuracy. However, the SM also leaves several fundamental questions unexplained such as the details of the evolution of the early universe, the origin of the matter-antimatter asymmetry of the universe, the nature of dark matter and dark energy, the origin of neutrino masses, the origin of the electroweak scale, and the origin of flavor dynamics. The answers to these questions must lie in physics beyond the SM (BSM physics). The quest for BSM physics, which has always been on the agenda, is now more than ever the motivating force in particle physics, leading to many proposals for experiments to directly search for new phenomena. Precision measurements of SM processes continue to have a strong place in the program, since these measurements can reveal discrepancies between theory and experiment that can indicate BSM physics, potentially at even higher mass or energy scales than can be observed directly.

A vast range of ideas was considered to probe the boundaries of the SM and to search for BSM physics during the Snowmass 2021 study. The framework for these considerations was provided by the five science

Drivers identified by P5 in 2014:

1. Use the Higgs Boson as a Tool for Discovery,
2. Pursue the Physics Associated with Neutrino Mass,
3. Identify the New Physics of Dark Matter,
4. Understand Cosmic Acceleration: Dark Energy and Inflation,
5. Explore the Unknown: New Particles, Interactions, and Physical Principles.

One important aspect of Snowmass 2021 was to evaluate, after nearly ten years, whether these Drivers continue to be appropriate and complete and can provide guidance for HEP for at least another decade.

The Frontiers Look to the Future

Here we present highlights from the discussions from each Frontier including the most significant projects and programs that each wants to carry out, or at least start, in the next two decades, and the most important conclusions reached concerning enabling technologies and infrastructure. *All* of the particle-physics-focused Frontiers (CF, EF, NF, RPF, and TF) are directly engaged in probing the boundaries of the SM and searching for BSM physics, and the contributions of *all* the enabling Frontiers (AF, CEF, CompF, IF, and UF) are crucial for them to succeed, as can be seen below.

The Cosmic Frontier (Science Drivers 2 – 5): The Cosmic Frontier is focused on understanding how elementary particle physics shapes the behavior and evolution of the universe, and how observations of the universe inform our understanding of physics beyond the Standard Model. In the moments just after the Big Bang, fundamental physics governs the production of the particles and energy fluctuations that give rise to the current universe. The properties of elementary particles also govern the behavior of the most energetic processes observed in the universe today, including supernovas.

A major thrust of the future Cosmic Frontier program is building the next generation of cosmological probes. Cosmic surveys "aim high" at observables spanning almost the entire 13.8 billion-year history of our Universe. The next big project in this arena is CMB-S4, a system of telescopes to study the cosmic microwave background with higher precision than has been achieved so far. CMB-S4, which is expected to operate through to at least 2036, will address many topics, including the mystery of cosmic inflation. Additional projects that would start after 2029 are Spec-S5, the follow-on spectroscopic device to DESI; a project to carry out line intensity mapping (LIM); and planning efforts to increase the sensitivity of gravitational wave detection by at least a factor of 10 (10^3 in sensitive volume) beyond what will be achieved by LIGO/Virgo and their planned upgrades.

A second thrust of the Cosmic Frontier is a suite of experiments to explore the physics of dark matter (DM). The space of DM models encompasses a dizzying array of possibilities representing many orders of magnitude in mass and couplings, making the DM program one of the most "interdisciplinary" investigations in high-energy and particle physics. The Cosmic Frontier's DM program will "delve deep, search wide" by employing a broad portfolio of small and medium-scale, direct and indirect, detection experiments, as is required to search optimally for each decade in dark matter mass. Furthermore, the expanded Cosmic Probes program described above will strive to identify the properties of dark matter via cosmic surveys, which is highly synergistic with the other science targeted by those surveys.

Yet another aspect of Cosmic Frontier science is the use of gravitational waves and very high energy neutrinos, cosmic rays, and gamma rays, produced by Nature in cataclysmic events, to probe BSM physics inaccessible in the laboratory.

The Cosmic Frontier strategy detailed in this report encompasses a science-rich program with small, medium, and large experiments which are planned on both near-term and long-term timescales. The community consensus is that this coming decade must feature strong support for this program in full to ensure that HEP will enjoy the new era of discovery and groundbreaking precision measurements.

The Energy Frontier (Science Drivers 1 – 3 & 5): The Energy Frontier currently has a top-notch program with the Large Hadron Collider (LHC) and its planned High Luminosity upgrade (HL-LHC) at CERN, which sets the basis for the Energy Frontier vision. The fundamental lessons learned from the LHC thus far are that a Higgs-like particle exists at 125 GeV and there is no obvious and unambiguous signal of BSM physics. This implies that new physics either occurs at scales higher than we have probed, must be weakly coupled to the SM, or is hidden in backgrounds at the LHC. The immediate goal for the Energy Frontier is to continue to take and analyze the data from LHC Run 3, which will go on for about three more years, and carry out the 2014 P5 recommendations to complete the HL-LHC Upgrade and execute its physics program. The HL-LHC will measure the properties of the Higgs Boson more precisely, probe the boundaries of the SM further, and possibly observe new physics or point us in a particular direction for discovery.

A new aspect of the proposed LHC program is the emergence of a variety of auxiliary experiments that can use the interactions already occurring in the existing collision regions during the normal LHC and HL-LHC running of the ATLAS, CMS, LHCb, and ALICE experiments to explore regions of discovery space that are not currently accessible. These typically involve observing particles in the far forward direction or long-lived particles produced at larger angles but decaying far outside the existing detectors. These are mid-scale detectors in their own right and provide room for additional innovation and leadership opportunities for younger physicists at the LHC. The EF supports continued strong U.S. participation in the success of the LHC, and the HL-LHC construction, operations, and physics programs, including auxiliary experiments.

New colliders are the ultimate tools to extend the EF program into the next two decades thanks to the broad and complementary set of measurements and searches they enable. With a combined strategy of precision measurements and high-energy exploration, future lepton colliders starting at energies as low as the Z-pole up to a few TeV can shed substantial light on some of these key questions. It will be crucial to find a way to carry out experiments at higher energy scales, directly probing new physics at the 10 TeV energy scale and beyond. The EF supports a fast start for the construction of an e^+e^- Higgs Factory (linear or circular), and a significant R&D program for multi-TeV colliders (hadron and muon). The realization of a Higgs Factory will require an immediate, vigorous, and targeted accelerator and detector R&D program, while the study towards multi-TeV colliders will need significant and long-term investments in a broad spectrum of R&D programs for accelerators and detectors.

Finally, the U.S. EF community has expressed renewed interest and ambition to develop options for an energy-frontier collider that could be sited in the U.S., while maintaining its international collaborative partnerships and obligations with, for example, CERN.

The Neutrino Frontier (Science Drivers 2, 3 & 5): Neutrinos, the neutral electroweak partners of the charged leptons, are predicted to be massless in the Standard Model. The demonstration that neutrinos oscillate and therefore have mass is currently the only laboratory observation of BSM physics. The study of neutrinos and their properties is, therefore, an essential component of the U.S. HEP program in the coming decades.

The Deep Underground Neutrino Experiment (DUNE) collaboration was formed to realize the 2014 P5 vision of a best-in-class long-baseline neutrino experiment based at Fermilab. The DUNE R&D program, propelled by the development of large-scale liquid-argon detectors in the U.S. and Europe, in particular through the CERN Neutrino Platform, has demonstrated the power and feasibility of this technique. DUNE will be built in two phases. Phase I includes the completion of the Long-Baseline Neutrino Facility (LBNF) at FNAL and construction at the Sanford Underground Research Facility (SURF) in Lead, South Dakota. This first phase includes far-site facilities at SURF to accommodate four far detector modules (FDs) at a depth of 1475 m (each with at least 10-kt fiducial mass) and installation of the first two FD modules; near-site facilities at FNAL to support the full (Phase II) near detector and installation of a basic suite of near detectors; and the construction of the PIP-II 1.2 MW source proton beam, also at FNAL, to produce a neutrino beam to SURF. The Phase I configuration is sufficient for early physics goals, including the determination of the neutrino mass ordering.

DUNE Phase II is required to achieve the precision neutrino oscillation physics goals laid out by P5 in 2014 and is the U.S. HEP neutrino community's highest priority project for 2030–2040. The Phase II project has three components: an upgrade or replacement of the Fermilab 8 GeV Booster to enable a more intense neutrino beam by delivering 2.4 MW to the DUNE target and possibly to provide beams for other experiments; the construction of an additional 20 kt (fiducial) of far detectors at SURF; and the full, highly capable, near-detector complex at FNAL to control the systematic uncertainties for the far-detector measurements. The full DUNE program will perform definitive studies of neutrino oscillations, test the three-flavor paradigm, search for new neutrino interactions, resolve the mass ordering question, have the ability to observe CP violation if it is present in neutrino oscillation, and observe astrophysical neutrinos.

A suite of small- and medium-scale neutrino experiments can address issues that are complementary to those studied by long-baseline experiments, such as measurements of the absolute neutrino mass and searches for neutrinoless double beta decay. All of these efforts have the potential to make paradigm-changing discoveries or innovations or provide necessary inputs to experiments that will make these discoveries, and they will work in synergy to address the science questions described above. A future neutrino program with a healthy breadth and balance of physics topics, experiment sizes, and timescales, supported via a dedicated, deliberate, and ongoing funding process, is highly desirable.

The Rare Processes and Precision Measurements Frontier (Science Drivers 3 & 5): The Rare Processes and Precision Measurements Frontier encompasses searches for extremely rare processes or tiny deviations from the SM that can be studied with intense sources and high-precision detectors. RPF is currently working on two mid-scale U.S. projects at Fermilab that were endorsed by P5 in 2014, the Muon $g-2$ experiment to measure the anomalous magnetic dipole moment of the muon, which has produced exciting results and is concluding its data-taking; and the Mu2e experiment, currently under construction, which will search for neutrino-less conversion of a negative muon into an electron in the field of a nucleus. The program also has important investments in b-quark, c-quark, and τ-lepton flavor physics through the support of the Belle II experiment at the SuperKEKB accelerator in Japan and the LHCb experiment at CERN. Priorities for the RPF community in the next few years are to complete the $g-2$ analysis; begin taking data with Mu2e; and to continue taking and analyzing data at Belle II and LHCb, and participate in their ongoing and future upgrades. It is worth noting that studies of baryon-number-violating decays of heavy flavors are uniquely being carried out in dedicated flavor experiments, such as LHCb and Belle II.

Two other central themes for the RPF that emerged from Snowmass are the quest to understand quark and lepton flavor and its violation, via precision measurements, and the search for dark-matter production in the mass range from sub-MeV to a few GeV in fixed-target proton and electron experiments. There is a proposal to study muon science in an "Advanced Muon Facility", AMF, at Fermilab, that would greatly improve the search for lepton flavor violation in $\mu \to e\gamma$, $\mu^- N \to e^- N$, and $\mu \to 3e$. This would require an intense proton beam with unique characteristics and modifications to the FNAL accelerator complex to manage the production of muon beams with different energies and time profiles.

Other experiments under consideration include the measurement of electric dipole moments (EDMs), in particular the proton EDM measurement in a storage ring, along with experiments exploiting techniques developed in the Atomic, Molecular, and Optical (AMO) community to examine fundamental symmetries; experiments probing rare light meson decays; and involvement of the U.S. experimental community in the vibrant international program studying rare kaon decays at both CERN and J-PARC.

As a result of the breadth of flavor physics, its potential for discovering BSM physics, and hints of possible new physics in the current data, the Rare Processes and Precision Measurement Frontier proposes that the upcoming P5 adds a new physics driver: *flavor physics as a tool for discovery.*

Theory Frontier (Science Drivers 1-5): Theoretical particle physics seeks to provide a predictive mathematical description of matter, energy, space, and time that synthesizes our knowledge of the universe, analyzes and interprets existing experimental results, and motivates future experimental investigation. Theory connects particle physics to other areas of physics and extends the boundaries of our understanding.

Fundamental theory seeks a deep understanding of the theoretical and mathematical structures that underlie our modern description of Nature and includes directions that are not, or at least not yet, directly connected to experimentally testable consequences. Recently the decades-long search for a theory of quantum gravity has been animated by new insights from string theory and quantum information theory. Progress in quantum field theory and quantum gravity has been tightly intertwined by the revelation of holography, the idea that quantum gravitational physics in a region of space is encoded by a quantum field theory living on its boundary. Promising avenues in the coming decade include the refinement of powerful new perturbative and non-perturbative approaches to quantum field theory, exploration of generalized symmetries and their implications, and a deeper understanding of the emergence of spacetime in the vicinity of black holes.

Particle phenomenology provides the connection between fundamental theory and the physical description of the real world, testable by experiments. The search for BSM physics has broadened considerably in the past decade with the advent of novel concepts like neutral naturalness and cosmological selection of the electroweak vacuum. Significant progress has been made in understanding inflation and properties of the early universe from the cosmic microwave background and large-scale structure. Dark matter theory is undergoing a renaissance with the exploration of the full range of dark matter masses, portals to dark sectors, and novel interaction mechanisms. Advances in precision collider theory, collider phenomenology, and flavor physics (including the calculation of many cross-sections to the next-to-next-to-leading order, the formulation of new collider observables, and advanced theoretical analyses of flavor data) are unlocking the door to unprecedented tests of the SM. And, finally, a theory-driven program combining nuclear theory, lattice and perturbative QCD, and event generation has been launched to quantify nuclear cross sections with the precision needed to realize the full potential of neutrino physics experiments.

Computational theory seeks to quantitatively test our theoretical descriptions of physical phenomena and gain new insights into fundamental aspects of the underlying theories, through developing and deploying computational methods. Over the last decade lattice QCD has become a powerful tool, which provides precise predictions for a broad range of observables relevant to experiment, while lattice methods also provide quantitative access to nonperturabtive properties of new QFTs. Event generators connect experimental measurements to theoretical predictions with increasing accuracy, directly enabling future experimental success. Recent innovations in the theory of machine learning (AI/ML), notable for their cross disciplinary impact, will be profitably utilized in a growing number of theoretical applications, while efforts to develop the methods and theoretical foundations for quantum simulations of quantum field theories offer great promise for computations of classically intractable problems in the decades to come.

Together, fundamental, phenomenological, and computational theories form a vibrant ecosystem whose health is essential to all aspects of the U.S. HEP program. The Theory Frontier recommends invigorated support for a broad program of theoretical research as part of a balanced HEP portfolio, an emphasis on targeted initiatives to connect theory to experiment, a focus on providing support and training for students and junior scientists, and strengthening the commitment to improve diversity, equity, inclusion and accessibility in HEP theory.

Accelerator Frontier: The Accelerator Frontier aims to prepare for the next generations of major accelerator-based particle physics projects to pursue the EF, NF, and RPF physics goals.

A multi-MW beam-power upgrade of the Fermilab proton accelerator complex is required for DUNE Phase II. Studies are required to understand what other requirements the beam complex needs to meet if the same upgrade is to be used for RPF-related experiments.

In EF, a global consensus for an e^+e^- Higgs Factory as the next collider has been reaffirmed. While some options (e.g. the ILC) have mature designs, other options require further R&D to understand if they are viable. In order to further explore the energy frontier, very high-energy circular hadron colliders and/or multi-TeV muon colliders will be needed, both of which require substantial study to see if construction is feasible in the decade starting in 2040 or beyond. A team of experts formed an “Implementation Task Force” that developed metrics and a process to facilitate a comparison among the many proposed accelerator concepts. Their findings are summarized in part in the Accelerator Frontier Report and are presented in detail in a white paper. It is proposed that the U.S. establish a national integrated R&D program on future colliders to carry out technology R&D and accelerator design studies for future collider concepts.

Community Engagement Frontier: The Community Engagement Frontier concentrated on seven topics: applications and industry; career pipeline and development; diversity, equity, and inclusion (DEI); physics education; public education and outreach; public policy and government engagement; and environmental and societal impacts. The inclusion of this broad array of issues as a “Frontier” was a novel aspect of Snowmass 2021 and led to the formulation of many proposals for consideration and implementation by the community as a whole. These issues impact the ability of all Frontiers to successfully complete their work, and some, such as the need to broaden representation in the U.S. HEP community, were highlighted by all other Frontiers as well. Two additional CEF themes that emerged during the Snowmass process were the need to make HEP activities broadly accessible and sustainable. While many recommendations apply directly to the DOE and NSF programs and could be considered by P5, many are directed to the HEP community as a whole. DPF should consider how best to pursue these issues within APS and with government agencies and other groups.

Computational Frontier: Software and computing are essential to all HEP experiments and many theoretical studies. However, computing has entered a new “post-Moore’s law” phase. Speed-ups in processing now come from the use of heterogeneous hardware, such as GPUs and FPGAs developed in the commercial sector, to accelerate calculations, with significant implications for the manner in which we develop and maintain software. We are also beginning to rely on community hardware resources such as

High-Performance Computing (HPC) centers and the Cloud rather than dedicated experiment resources. Finally, new machine-learning approaches are fundamentally changing the way we work.

This new computing environment requires substantial changes and novel approaches to address the long-term development, maintenance, and user support of essential software packages, and cross-cutting R&D efforts supported from proof of concept to prototyping and production. Additionally, strong investment in career development for HEP software and computing researchers is needed to ensure future success.

In order to help address these issues, the Computational Frontier recommends the creation of a standing Coordinating Panel for Software and Computing (CPSC) under the auspices of DPF, analogous to the Coordinating Panel for Advanced Detectors (CPAD) established in 2012.

Instrumentation Frontier: Improved instrumentation is key to experimental progress in CF, NF, EF, and RPF. Many aspects of the current instrumentation effort were hardly present in 2013/2014, including quantum sensors, machine learning, and precision timing. Funding for instrumentation in the U.S., however, is actually declining. Key conclusions about how to restore and preserve the instrumentation effort are: to develop and maintain a critical and diverse workforce, including physicists, engineers, and technicians at universities and national laboratories; double the U.S. Detector R&D budget over the next five years and modify existing funding models to enable R&D consortia; expand and sustain support for blue-sky, table-top R&D, and seed funding for pathfinder R&D, and establish a separate review process for these types of activities; and develop and maintain critical facilities, centers, and capabilities for the sharing of common knowledge and tools.

Most of the IF report is dedicated to a review of the status and plans for improving the capabilities of particle detectors and developing new technologies in the following key areas: quantum sensors, photon detectors, solid state detectors and precision tracking systems, triggering and data-acquisition systems, micropattern gaseous detectors, calorimetry, readout electronics and ASICs, noble element detectors, cross-cutting and system integration issues, and radio detection.

The Underground Facilities and Infrastructure Frontier: Experiments that require low backgrounds from cosmic radiation, typically needed by CF and NF experiments, often must be performed underground. Underground experiments address some of the most important questions of particle physics, including the study of dark matter, neutrino physics including neutrinoless double-beta decay and atmospheric neutrinos, cosmic ray physics, and proton decay experiments.

The UF concluded that new experiments and enabling R&D require more space than is currently available worldwide. They proposed a possible addition of the underground space at a depth of 4850 feet at SURF in South Dakota and possible additional space at a depth of 7400 feet. These would open up space to develop additional experiments and would provide the opportunity for SURF to host next-generation dark matter or $0\nu\beta\beta$ experiments.

As underground experiments become larger, they will increasingly have stricter radiation requirements and the need for larger and higher quality clean rooms, radon-reduction systems, and improved monitoring. These issues are discussed in the Underground Facilities Frontier report and information was presented on the needs of upcoming experiments.

Snowmass Early Career: The perspective on HEP in Snowmass 2021 reaches far enough into the future to surpass the timescale of a single career, making consideration of the next generation of physicists crucial. The

2021 Snowmass Early Career organization aimed to unite this group, consisting mainly of graduate students and post-doctoral research associates, with the purpose of educating the newest generation of physicists while informing the senior generation of their opinions, concerns, and needs.

One major activity of the SEC was the Snowmass Community Survey, which was designed by the SEC Survey Core Initiative team between April 2020 and June 2021 with the aim of collecting demographic, career, physics outlook, and workplace culture data on a large segment of the Snowmass community (both junior and senior). A high-level summary of the key findings and recommendations from the survey report can be found in the SEC Summary Report. Early career physicists took the lead in many other areas, including several successful events focused on industry careers, networking, and perspectives. They also hosted community discussions on mental health and invisible disabilities and participated in panel discussions on community topics such as COVID-19 and career development.

The SEC community was very active in the discussions of future directions in HEP and played a strong and influential role in advancing and advocating for recommendations in several areas.

The Path Forward

One of the most important goals of Snowmass 2021 was to develop a vision for the U.S. HEP community for the next decade, with an eye to the decade beyond that, and to identify the infrastructure, facilities, and experiments needed to achieve it. The aspirations of the U.S. HEP community as informed by the Snowmass 2021 process are succinctly summarized as follows:

> *Lead the exploration of the fundamental nature of matter, energy, space and time, by using ground-breaking theoretical, observational, and experimental methods; developing state-of-the-art technology for fundamental science and for the benefit of society; training and employing a diverse and world-class workforce of physicists, engineers, technicians, and computer scientists from universities and laboratories across the nation; collaborating closely with our global partners and with colleagues in adjacent areas of science; and probing the boundaries of the Standard Model of particle physics to illuminate the exciting terrain beyond, and to address the deepest mysteries in the Universe.*

There was broad agreement at Snowmass 2021 on the general principles needed to have a successful U.S. HEP program in the future:

- In 2014, P5 formulated five science Drivers that were meant to summarize and organize the scientific questions that HEP seeks to answer. These five Drivers have guided U.S. HEP for nearly a decade with great success. We have made tangible progress toward addressing them, and have used that progress to formulate the steps for the next decade that are outlined in this report. There was consensus in Snowmass 2021 that these Drivers were still appropriate for the next decade.
  - A proposal was made by the Rare Processes and Precision Measurements Frontier that the physics of flavor, currently included without explicit acknowledgment in the science Drivers, be specifically named, given its unique characteristics and opportunities. One way of accomplishing this would be for flavor physics to become a sixth Driver.
- The completion of existing experiments and the construction and operation of approved projects, including those prioritized by the 2014 P5 such as the HL-LHC, LBNF/DUNE, PIP-II, LSST/Rubin

Observatory, and Mu2e programs, along with our many midsize and small experiments, are critical for addressing the science Drivers for the near term and for much of the next two decades.

- As existing approved construction projects come to a completion, a broad and complementary set of new projects should be considered a high priority to maintain the continuity of our investigations and opportunities for new discoveries.
  - A list of the large-scale (estimated total project costs of approximately $500M or larger) new projects or programs discussed at Snowmass is shown in Table 1 of Chapter 1 of the full Report and is described in detail in section 1.2.1 and in the Frontier summaries that follow. The proposals are examined in detail in the Snowmass 2021 Frontier and Topical Group reports.
  - The portfolio of HEP projects should continue to include a healthy breadth and balance of physics topics, experiment sizes, and timescales, supported by a dedicated, robust, ongoing funding process. Medium- and smaller-scale projects are discussed more fully in section 1.2.2 of the full Report, and the corresponding Topical Group reports.
- Robust support for physics research programs at universities and national laboratories is essential to operate existing and planned experiments, analyze the data they collect, plan and construct upgrades and new experiments and projects, and educate the next generation of researchers and technical experts.
- Strong and continued support for all aspects of particle theory, comprising the interconnected themes of fundamental theory, phenomenology, and computational theory, is needed. As theoretical and experimental research are symbiotically entwined, stronger, targeted efforts connecting theory to experiment should also be supported.
- Greater support for the infrastructure and enabling technologies, namely accelerators, computation, detectors, and instrumentation, is essential. Both R&D directed to specific future projects and generic research should be supported in these critical enabling technologies, as well as in new areas such as quantum science and machine learning.
  - Some guidance to HEPAP and the funding agencies in how the work of the enabling Frontiers should be coordinated and advanced would be very valuable.
  - When R&D projects produce successful tools, where appropriate, plans should be developed to convert them to products and support them throughout their useful lives.
- HEP benefits from collaboration with adjacent scientific disciplines, such as nuclear physics, accelerator technology and beam physics, astronomy and astrophysics, gravitational physics, and atomic and molecular physics, and from interactions with industry, and contributes to them in return. Opportunities to strengthen and expand such collaborations are mutually beneficial and should be pursued, and new opportunities for collaboration are arising in other areas such as artificial intelligence and machine learning, and quantum information science and sensing.
- The HEP community should strengthen connections with its early career researchers, foster their professional success both within and outside of academia, and ensure their voices are well-represented in physics and community planning.
- HEP should take a cohesive and strategic approach to promote diversity, equity, and inclusion in high-energy physics, in collaboration with funding agencies, universities, adjacent scientific disciplines, APS/DPF, and others.
  - The community should institute a broad array of practices and programs to reach and retain the diverse talent pool needed for success in achieving our scientific vision and to address the persistent under-representation of women scientists, LGBT+ scientists, scientists who are Black, Indigenous, and people of color (BIPOC), and scientists with disabilities.

- The HEP community must engage in a coordinated way with five other interrelated communities: academia, the education communities providing instruction from kindergarten through postdoctoral training, private industry, government policymakers, and the broader society. A structure for formulating a coordinated approach to achieve these goals should be created and provided with the resources needed for success.

The Snowmass 2021 process highlighted the breadth, depth, and effectiveness of the U.S. HEP program in exploring the fundamental nature of matter, energy, space, and time. The remarkable progress that has been made in probing the boundaries of the Standard Model of particle physics since 2014 was analyzed, and different and complementary methods to move forward in uncovering the mysteries of nature were examined. Through the Snowmass process, the U.S. HEP community has created an integrated vision to make progress in the coming decades – a vision that is reported in detail in this volume, the Topical Group reports, the white papers, and the many references cited therein.