The Future of Academic Research on Climate Solutions

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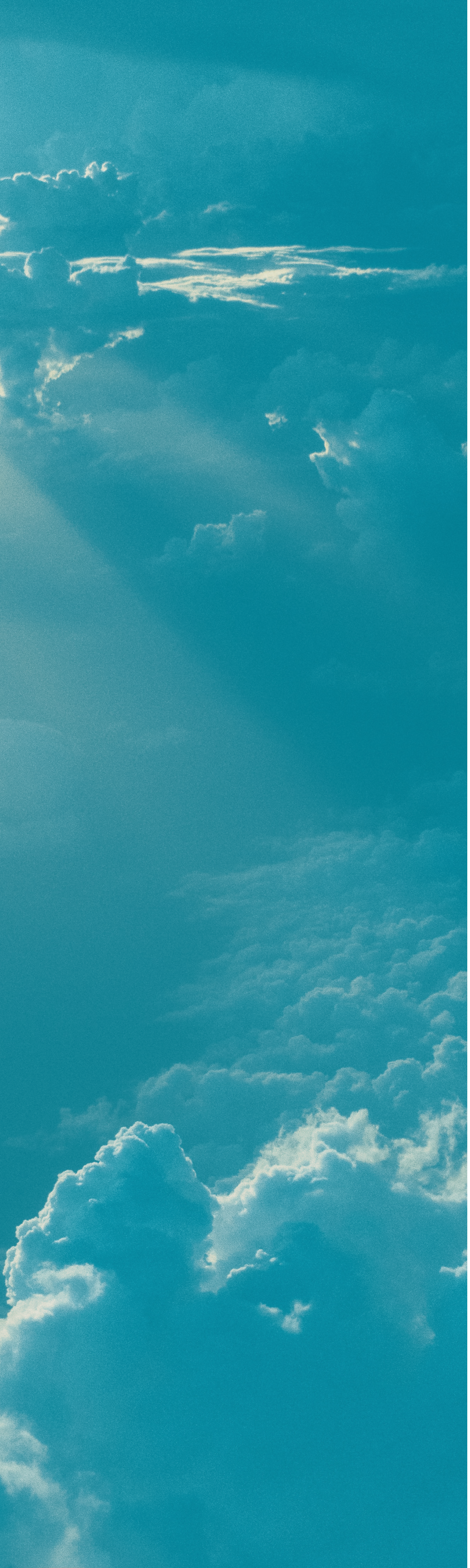

Executive summary

- Grantmaking toward academic research on climate solutions (ARCS) is distributed across multiple US federal agencies. We collected data from six agencies and interviewed key stakeholders to examine the current landscape of ARCS funding.

- We identified a sample of 1,829 federal ARCS grants related to clean energy, energy efficiency, and climate change initiated in FY 2019 and FY 2020, totaling $1.42 billion in funding. The large majority of these grants came from the US Department of Energy (DOE) and the National Science Foundation (NSF). **A centralized data repository is needed to capture the many disparate climate solutions research efforts across federal agencies.**

- Integration across disciplines is key to climate solutions. Geosciences were the dominant discipline for the NSF ARCS grants in our sample; engineering, computer science, and biology were the next most-funded areas. These four directorates combined received 85%of the funding total, while social science received only 5%. **Funders and institutions should prioritize social science and encourage collaborations between social science, natural science, and engineering fields.**

- Funding in our sample was heavily concentrated in institutions with "very high research activity" (R1), relative to "high research activity" (R2) schools or any other type. Hispanic-Serving Institutions were underrepresented, receiving only 8% of grant funds while serving 16% of enrolled students. **Funding should be inclusive across multiple types of institutions beyond R1 universities, including minority-serving institutions.**

- Community engagement is a missing piece across much of the ARCS landscape, despite being essential for considerations of equity and climate justice. In order to contribute to equitable climate solutions, **research should be planned and implemented in partnership with members of impacted communities.**

- Industry engagement is key to translating ARCS into actionable climate solutions. Additional funding opportunities for research translation are on the horizon, particularly at NSF, although allocation of these resources toward climate solutions is not guaranteed. **Research should be informed by and responsive to the capabilities of industry partners.**

- A new paradigm for funding ARCS can help academic institutions rise to the challenge of disastrous climate change, while bringing about social and economic success for all members of society. **All actors in the university research enterprise should consider how they can support the necessary tranformation.**

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1. Introduction

Discussions of energy transition, climate innovation, and climate justice are increasingly common across all segments of society, including higher education. There are opportunities to address climate change within the standard academic functions of teaching, outreach, and research. And yet these activities, as they are traditionally understood, do not represent the whole educational mission of higher education; they miss an important "fourth purpose," which is to mobilize the knowledge assets of the institution to solve real-world challenges happening in real time.[1] As we collectively push to address the climate crisis, alongside systemic racism and economic injustice, progress can be accelerated if we take a more expansive view of what higher education can accomplish toward climate action.

The topic of this report is how the US government can harness opportunities for more impactful academic research in climate solutions (ARCS). We take an expansive definition of ARCS, which includes a wide range of research disciplines across social sciences, natural sciences, and engineering, as well as a wide range of possible climate solutions, including social, political, and technological approaches to both climate change mitigation and adaptation.

Climate change touches practically every facet of society and so, not surprisingly, climate solutions research funding is distributed across many pockets of the federal government, with contributions from the Department of Energy (DOE), National Science Foundation (NSF), Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), Department of Agriculture (USDA), National Aeronautics and Space Administration (NASA), Department of Transportation (DOT), Department of Defense (DOD), and more. The National Labs oversee an extensive portfolio of climate solutions research, along with other intramural research funders. A full accounting of federally-funded climate solutions research would be immense and is out of scope of this report.

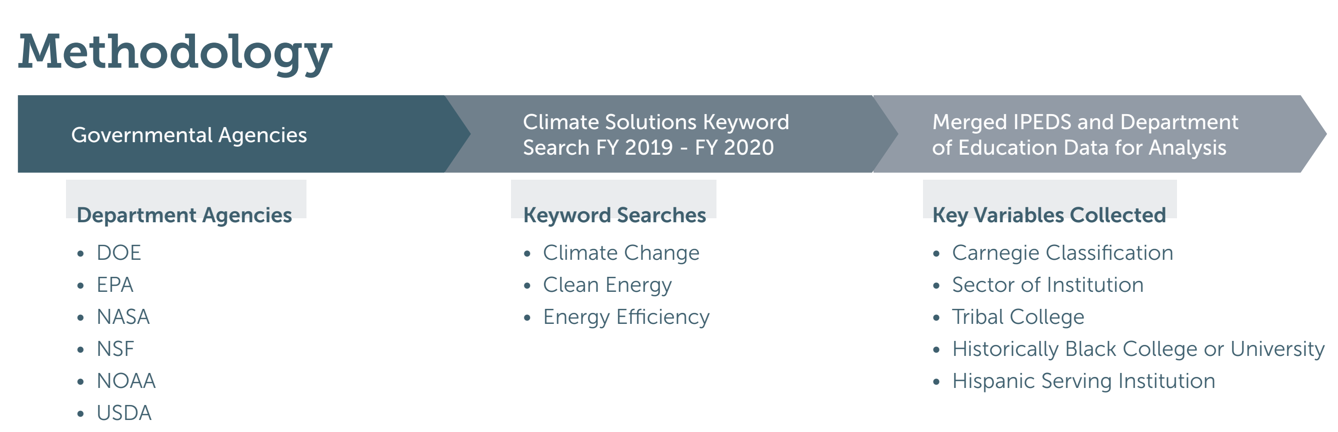
Our focus is on federal grantmaking to academic institutions. Specifically, we ask: *How can the academic research enterprise and federal funding programs ensure that ARCS investments contribute to equitable climate solutions?*

Using data on 1,829 recent federal ARCS grants and perspectives of various stakeholders, we arrived at several recommendations for improving the future of ARCS. The remainder of Section 1 explains the methodology and provides a snapshot of the ARCS data, which supports our recommendation for a centralized data repository of ARCS efforts across federal agencies. Next, we explain why participation of researchers in ARCS should be broadened, both by research field (Section 2.1) and institution type (Section 2.2). Finally, we argue that the most promising path to impact for ARCS lies in partnerships between academic and non-academic experts, including members of impacted communities (Section 3.1) and climate-relevant industries (Section 3.2).

1.1 Methodology

In this report, we examine the current landscape of federally-funded ARCS and explore potential pathways to greater impact. To support our analysis, we conducted interviews with various stakeholders

Figure 1: Flow Chart of Quantitative Data Collection Process



and gathered data on extramural research grants from federal agencies to higher education institutions for climate solutions topics, focusing only on the most recent funding in fiscal years 2019 and 2020.

Because climate solutions research is such a broad category, with contributions from many different agencies, there is no simple way to identify ARCS based on publicly available information. Rather than attempting to construct a comprehensive dataset of ARCS grants, we chose instead to generate a sample of grants that feature one or more key phrases in their title or description: "clean energy," "energy efficiency," and "climate change" (Figure 1). Two of the three keywords are energy-related, because of the importance of energy consumption as a driver of global emissions. The keyword search is an admittedly blunt instrument which excludes many grants that use alternative phrasing (e.g., "renewable energy" instead of "clean energy,"), or those that downplayed these motivations when a focus on climate was politically unfavorable. Our approach also misses many grants related to other ARCS concepts, such as climate resilience.

We searched for ARCS grants from six agencies that we knew to engage in extramural funding of climate-related research: DOE, EPA, NASA, NOAA, NSF, and USDA. For each agency, we identified a public web platform for downloading or searching past grants:

- DOE PAMS[2]
- DOE Energy Justice Dashboard[3]
- EPA[4]
- NSF & NASA[5]
- USDA (NIFA)[6]
- NOAA[7]

DOE does not provide a single grant search platform for the entire Department, so we combined two data sources: the Portfolio Award Management System (PAMS) from DOE's Office of Science, and the Beta Energy Justice Dashboard from DOE's Office of Economic Impact and Diversity. USDA similarly does not offer a search platform for all grants; instead, we used the public grant search platform for the National Institute for Food and Agriculture (NIFA). NASA and NSF share a combined grant search platform.

For each search platform, we completed keyword searches using the phrases "climate change," "clean energy," and "energy efficiency." In the case of DOE's Energy Justice Dashboard, we downloaded the full grants dataset, in which each grant was coded with one of nine categories of J40 relevance. We selected those grants that were coded as either "Climate Change" or "Clean Energy and Energy Efficiency," as well as those grants that were issued by the Advanced Research Projects Agency - Energy (ARPA-E) or the Office of Energy Efficiency and Renewable Energy (EERE). We limited the dataset to fiscal years 2019 and 2020 by requiring awards to be issued on or after October 1, 2018 but no later than Sept. 30, 2020.

We further limited our dataset to higher education organizations by requiring the awardee name to contain either "college", "university", or "school." We then manually reviewed the set of included institutions and removed awards to consortia or non-profit organizations supporting higher education institutions, including Thurgood Marshall College Fund and the University Corporation for Atmospheric Research.

This process generated a dataset of 1,829 ARCS grants awarded in FY 2019 and FY 2020. Next, we merged our grant data with data on higher education institutions from the Department of Education's Integrated Postsecondary Education Data System (IPEDS)[8], in order to analyze the types of universities and colleges receiving federal funding for ARCS. In the rare cases where the grantee listed was a university system, we assigned those grants to the flagship campus. The key variables collected from IPEDS were:

- *Basic Carnegie Classification* - Categorizes all degree-granting higher education institutions into classifications including Doctoral University: Very High Research Activity (R1), Doctoral University: High Research Activity (R2), and many others.[9]

- *Student Enrollment* - 12-month full-time equivalent enrollment, including undergraduate, graduate, and professional students

- *Geographic Region* - Eight categories defined by the Bureau of Economic Analysis: Far West, Great Lakes, Mideast, New England, Plains, Rocky Mountain, Southeast, or Southwest.

- *Tribal College and Universities* - Defined by the Higher Education Act of 1965, Tribal College and Universities are institutions that are operated by Native American tribes.

- *Historically Black College or University (HBCU)* - Institutions that were established prior to 1964 and who primarily serve the African American community.

Separately, we obtained data on Hispanic Serving Institutions (HSI) from the National Center for Education Statistics.[10] HSIs are institutions that have at least 25% enrollment of full-time equivalent undergraduate students who are Hispanic. We merged this dataset with other institutional characteristics obtained from IPEDS.

We also created a random sample of 100 NSF ARCS grants to examine the discipline associated with the research. We manually recorded the academic departments associated with each grant based on the faculty webpage of the lead PI, and we then assigned each department name to the most closely related NSF directorate; this sample of 100 grants was limited in size due to the time-intensive nature of the analysis.

Our qualitative data collection process consisted of two parts. First, we observed a breakout discussion among research university presidents at a June 2021 event for the Climate Action Pursuit, hosted virtually by Second Nature. The topic for this discussion was how the climate solutions research enterprise can be made more inclusive, collaborative, and effective. We also presented preliminary findings at an October 2021 Climate Action Pursuit event, during a breakout session about climate action in the research enterprise, which was open to all college and university presidents.

Second, we interviewed Congressional staff members and private sector workers involved in climate solutions research, in order to collect a range of views on ARCS. Interviews were conducted on background and responses will not be discussed in detail in this report. The interviews were semi-structured and included questions relevant to the interviewee's professional context, such as:

- What do you see as the most important ways for academic research to contribute to climate solutions?
- What kinds of research should be considered under the umbrella of "climate solutions"?
- What problems do you see with climate solutions research in academia?
- What are the most important changes coming for how climate solutions research in academia will be funded?
- What are the biggest barriers to commercialization of academic research on climate solutions?
- What are the most important issues around increasing diversity and broadening participation in the climate solutions research enterprise?

The interview data, combined with observations and feedback from academic administrators involved in the Climate Action Pursuit, provided us with a diverse set of perspectives on higher education and climate solutions research.

Table 1: ARCS grants from DOE and NSF in FY 2019 and 2020

	Department of Energy	National Science Foundation
Grants Identified	757	1036
Total Funding from Grants Identified	$693,228,456.30	$536,614,803.00
Average Funding per Grant	$915,757.54	$517,967.96
Example Grants	Title: Composite PEMs from Electrospun Crosslinkable Poly(Phenylene Sulfonic Acid)s Objective: To use electrospinning to create a novel membrane material for proton-exchange membrane (PEM) fuel cells[11] Institution: Vanderbilt University Award Amount: $536,014	Title: Marine Sky Brightening: Prospects and Consequences Objective: Explore marine sky brightening as a method of solar geoengineering wherein sea salt particles are injected into the marine boundary layer[12] Institution: Indiana University Award Amount: $299,994

1.2 Overview of the ARCS Landscape

The total grant amount awarded in our sample of ARCS grants was approximately $1.42 billion; DOE and NSF account for approximately 87% of this total. NOAA accounts for approximately 13% of the total grant amount, while the USDA accounts for less than 1%. No grants were identified from our keyword searches of NASA and EPA in this time period. Comparing DOE and NSF, DOE had a larger total funding amount and a higher average funding amount per grant, due to a small number of multi-million dollar grants (Table 1).

We note that our dataset does not provide a comprehensive view of all ARCS grants made by these six federal agencies, much less the whole of the federal government. Nonetheless, we believe this sample of recent ARCS grants can help to reach a better general understanding of how federal funds are distributed for this purpose.

Two example ARCS grants, one from DOE and one from NSF, are shown in Table 1. These grants represent research into two narrow segments of a diverse array of climate solutions: hydrogen-based fuel cells and solar geoengineering. The breadth of concepts and topics included in ARCS grantmaking is illustrated in Table 2.

A more precise picture of ARCS funding across agencies and over time would surely be informative, but is out of reach with existing data sources. This lack of data is more than just a nuisance to the authors. Without data, researchers cannot easily identify appropriate funding opportunities; the agencies themselves cannot easily understand their own programs in the context of others; and no one can assess the full landscape of funding for climate solutions research, academic or otherwise. A centralized data repository would allow observers to ask key policy questions, such as the one we ask in the next section: what types of disciplines and institutions receive ARCS funding?

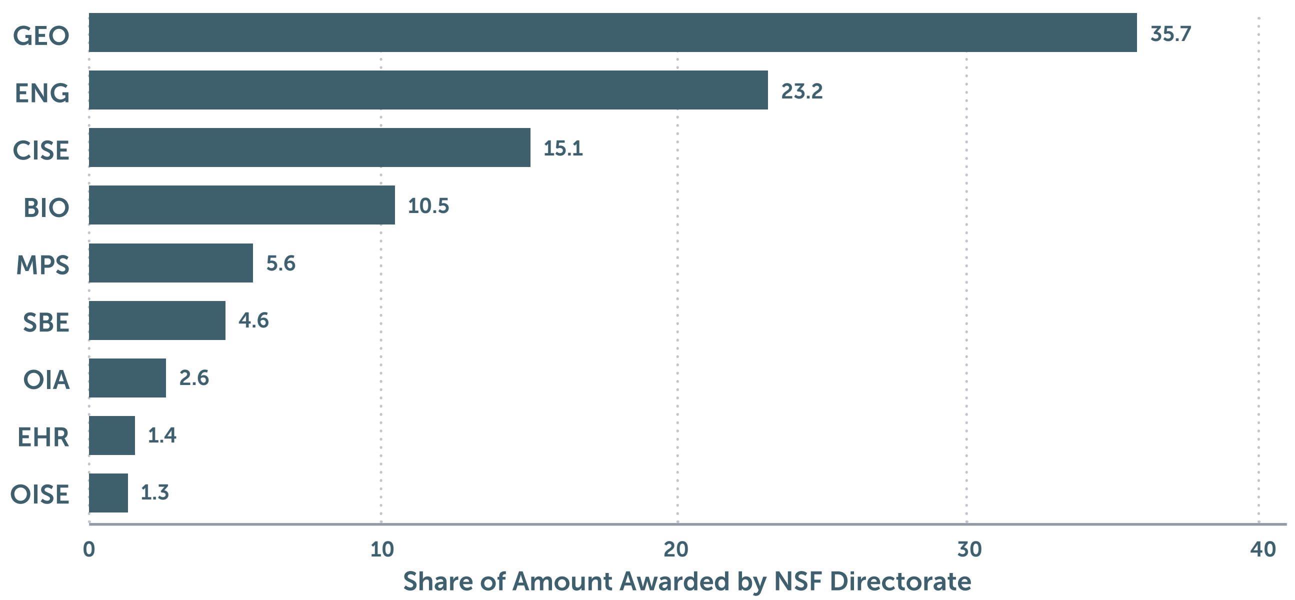
Table 2: Selected Words in Titles of Recent ARCS Grants (N = 25,468 words)

energy: 173	dynamics: 42	management: 34
climate: 121	hydrogen: 41	networks: 34
systems: 87	heat: 41	framework: 34
solar: 75	arctic: 40	marine: 33
power: 69	technology: 40	industrial: 33
efficient: 67	performance: 39	computing: 33
water: 66	fuel: 38	low-cost: 31
materials: 65	network: 37	manufacturing: 30
carbon: 57	thermal: 37	engineering: 29
modeling: 54	global: 36	devices: 29
environmental: 50	machine: 35	science: 28
design: 48	storage: 35	infrastructure: 28

2. Broadening Participation in ARCS

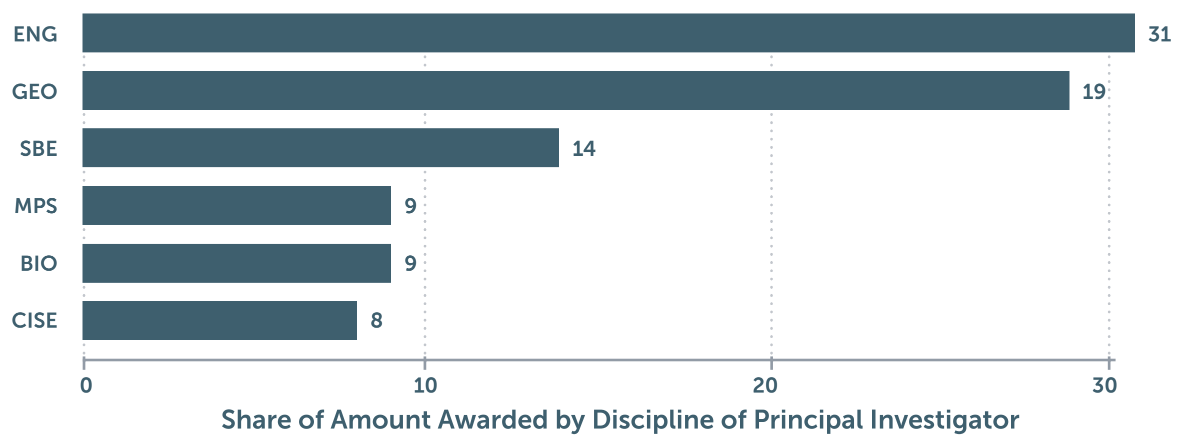
Solving climate change, or any set of complex, systemic problems, requires collaboration among individuals with different perspectives and problem-solving approaches.[13] Research indicates that functionally diverse teams are better at solving complex problems than high ability homogenous teams.[14] Scientific teams with greater ethnic diversity[15] and gender balance[16] have also been found to produce higher quality publications. In this section, we examine diversity in ARCS funding across multiple dimensions and find that broader participation is needed to achieve the greatest impact of ARCS investments.

Figure 3: Share of NSF ARCS Grant Funding in FY 2019 and 2020 by Directorate



Note: The seven primary directorates are biological sciences (BIO), computer and information science and engineering (CISE), engineering (ENG), geosciences (GEO), mathematical and physical sciences (MPS), social, behavioral and economic sciences (SBE), and education and human resources (EHR). Two other directorates are cross-cutting between research areas: Office of Integrative Activities (OIA) and Office of International Science and Engineering (OISE).

Figure 4: Share of Amount Awarded for Random Sample of 100 NSF ARCS Grants by Principal Investigator Discipline



BOX 1

Building Blocks

Convergence Research at NSF

Convergence research has been a priority of NSF since appearing as one of its 10 Big Ideas in 2016.[20] According to NSF, *"Convergence research is a means of solving vexing research problems, in particular, complex problems focusing on societal needs. It entails integrating knowledge, methods, and expertise from different disciplines and forming novel frameworks to catalyze scientific discovery and innovation."* Two key programs at NSF that support this mode of problem-based, deeply integrative research are the Convergence Accelerator[21] and Growing Convergence Research.[22]

Convergence is highly appropriate for ARCS, due to the complex interaction between human, technical, and environmental systems that constitute the climate challenge. However, there are no dedicated programs for funding this particular type of research. The NSF Research Traineeship (NRT) program formerly had a priority area called "Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS)"[23], but none of the current priorities relate to climate solutions.[24]

One example of INFEWS funding for convergence research is the ELEVATE program at the University of Massachusetts Amherst, in which this report's authors are currently participating.[25] ELEVATE's research focus is equity and resilience in the transition to a clean electricity system. Its mission is to train graduate researchers across geosciences, civil engineering, computer science, economics, and anthropology to work together on this complex set of challenges.

A dedicated funding program at NSF for convergence in ARCS would grow the community of researchers on these topics and ensure that diverse areas of expertise are being integrated in the search for climate solutions.

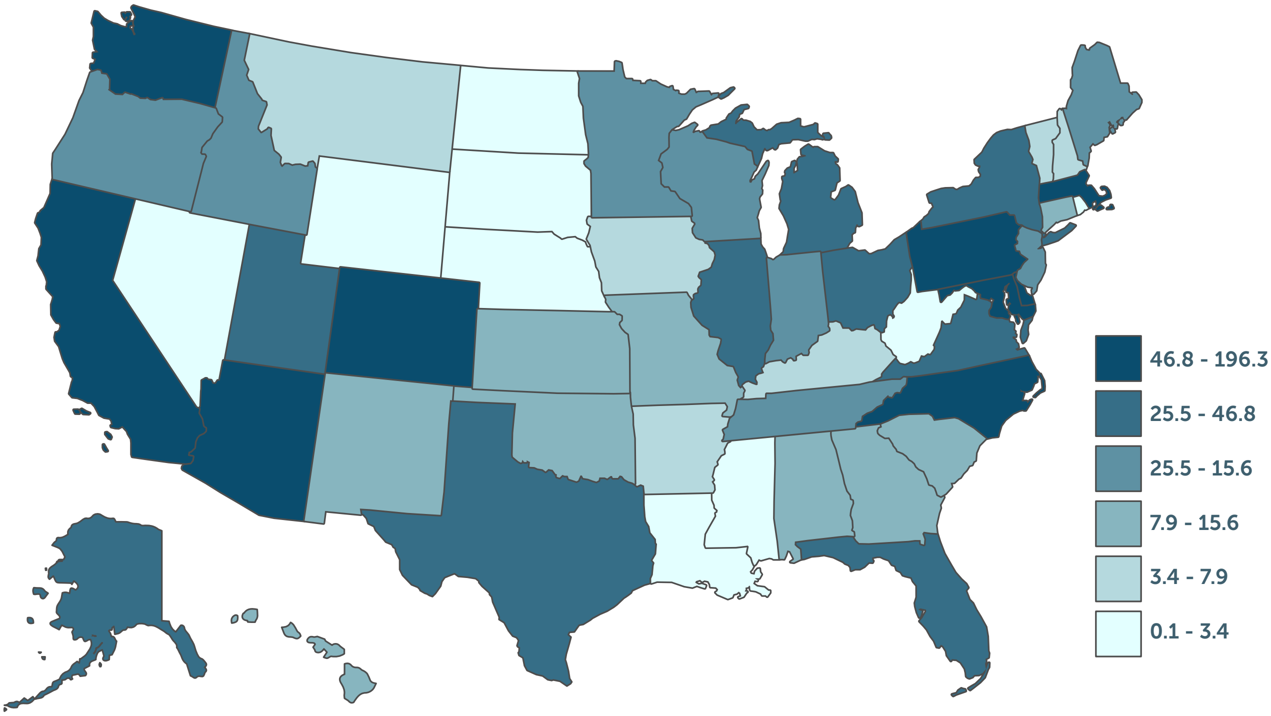
2.1 Participation of academic researchers across disciplines

The climate crisis is a multi-faceted problem that impacts society as a whole, requiring participation across a wide variety of academic disciplines. Solving climate problems requires a sophisticated understanding of the physical and biological processes of a changing climate, the social and behavioral dynamics of human societies, greenhouse gas emitting technologies, and their alternatives. And yet, in the current landscape of ARCS grantmaking, we find that research funds are not well-distributed across the relevant disciplines.

We examined the share of federally funded ARCS grants by academic discipline within NSF specifically, taking advantage of the fact that NSF organizes its grants under directorates of science and engineering that correspond roughly to research disciplines. The majority of NSF ARCS funding in our dataset was awarded to the "hard science" directorates (Figure 3): the largest group of grants was in geosciences (GEO, 35.7%), with a substantial amount in computer and information science and engineering (CISE), engineering (ENG), and biological sciences (BIO) as well. Only 4.6% of the funding in this dataset went to social, behavioral and economic sciences (SBE) grants.

Similarly, in the random sample of 100 NSF ARCS grants, we found that ENG and GEO are the most common specialties of lead PIs, with 31% and 29% of funding respectively. However, in this sample there is a higher proportion of lead PIs in SBE-related departments (14%) than the corresponding share of funding from the SBE Directorate (4.6%). This result could indicate some extent of social science participation in the "hard science" ARCS funding at NSF. And yet, the fact remains that geoscience topics

Figure 5: Map of ARCS Grant Funding Distribution in FY 2019 and 2020



Note: The total amount awarded by state in FY 2019 and FY 2020 is in millions of dollars.

appear to be the dominant focus for NSF in terms of climate solutions.

Perhaps the imbalance across disciplines and lack of focus on social sciences should come as no surprise, given prior research showing that natural and technical sciences receive far more funding than the social sciences for research on issues related to climate change. In one study, only 0.12% of climate research funding worldwide 1990-2018 was spent on the social science of climate mitigation.[17]

The paucity of social science focus in ARCS funding is concerning. Social science research is key to understanding human drivers of climate change and developing appropriate communication and policy strategies in response. The study of climate change mitigation measures based on consumer choices and behavior requires contributions from multiple social science disciplines.[18] Additionally, there is a long and growing list of ARCS efforts that risk missing critical information without the participation of social sciences, especially in terms of equity and the disproportionate impacts of climate change and climate change policies on low-income and other vulnerable demographic groups.[19]

No single discipline can effectively advance the complex set of strategies needed to combat the climate crisis. Deep understanding of these strategies will only come from transdisciplinary research approaches, such as convergence research (Box 1), that involve meaningful collaboration across disparate research fields. The impact of federal funding for ARCS research can be enhanced by investing heavily in the social sciences and actively encouraging transdisciplinary collaboration across social sciences, natural sciences and engineering research fields.

2.2 Participation across types of institutions

There has been significant public attention to the need to diversify the nation's science and technology workforce.[26] This effort is especially relevant to the energy transition, which will have a major jobs impact in the US and will require buy-in from labor coalitions and job training for skills needed in new energy industries.[27] And yet, the synergy between workforce development and ARCS grantmaking has been underappreciated. Discussions of job training and diversity are often siloed from discussions of climate solutions research, despite the important role of research in training the next generation of knowledge workers. This dynamic even played out in the Climate Action Pursuit breakout sessions in June 2021, with community college presidents discussing workforce development while leaders of research universities discussed ARCS funding.

One exception to this siloing is the recent policy debate over distribution of funds at NSF in the drafting of the Endless Frontier Act, which in 2021 became part of the US Innovation and Competition Act in the US Senate. Both the House and the Senate consider diversity in allocation of research funds in their draft legislation, but the two bodies have taken markedly different approaches. The Senate's legislation provides geographic diversity, by directing funds toward neglected geographic regions, such as those defined by the Established Program to Stimulate Competitive Research (EPSCoR).[28] The House version, in contrast, emphasizes diversity by funding emerging research institutions across all states; these include minority-serving institutions (MSIs) and others outside of the top 100 research institutions.[29]

In our analysis of ARCS grants for FY 19 and 20, we find that funding was distributed across much of the US (Figure 5). At least one ARCS grant was issued to institutions in each of the 50 states, plus the District of Columbia, Guam, and US Virgin Islands. The regions with the greatest portion of the ARCS funding total were the Far West (24%) and Mideast (19%), followed by Southeast (14%), New England (11%), and the Great Lakes (11%).

Although there was a wide geographic spread of federal ARCS funding, we find that funding was in fact highly concentrated within certain types of institutions. Funds were overwhelmingly distributed to research-intensive universities, with 95% of funds going to R1 and R2 institutions (Figure 6). Only 5% of ARCS funding went to any other type of institution, including all Master's Colleges and Universities, and all Baccalaureate Colleges. A similar disparity can be seen in the broader landscape of academic research, in which R1 institutions receive 90% of federal science and engineering research and development (R&D) funding overall.[30]

Some extent of concentration of research funds within research universities may seem appropriate, but consider how this affects students' access to opportunities. Among the institutions in our dataset, R2 schools only received 10% of ARCS grants but account for 20% of full time enrolled students. The racial inequity is dramatic; only 34% of students

Figure 6: ARCS Grants in FY 2019 and 2020 by Carnegie Classification

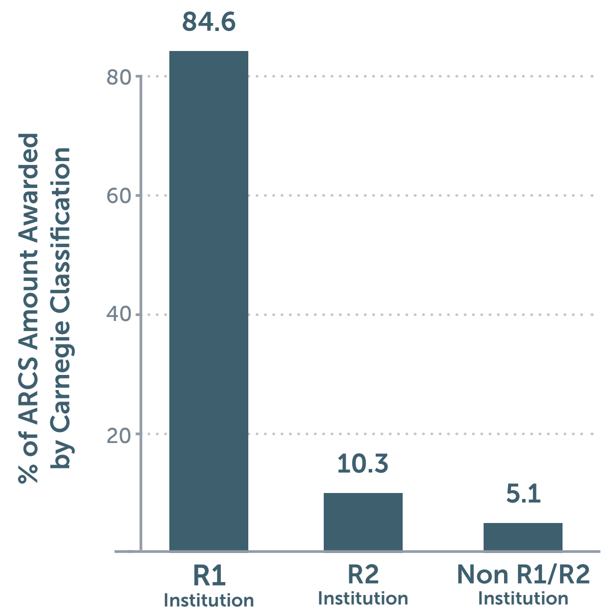
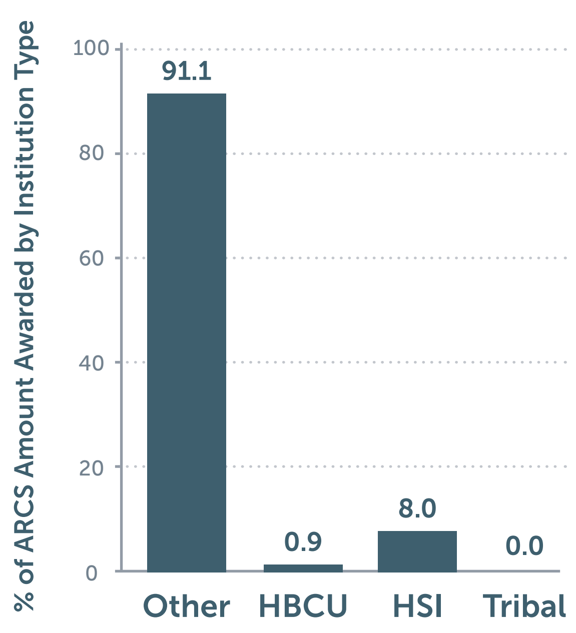


Figure 7: ARCS Grants in FY 2019 and 2020 by Institution Type



Note: The "Other" category is largely non-MSI but could include some MSIs beyond HBCU, HSI and Tribal College/University. Other types of MSIs are: Alaska Native-serving institutions, Native Hawaiian-serving institutions, Predominantly Black Institutions, Asian American and Native American Pacific Islander-serving institutions, and Native American-serving nontribal institutions of color in higher education are enrolled at R1 institutions.[31] As a result, the large majority of students of color are excluded from accessing the majority of climate solutions research opportunities.

ARCS funding appears similarly concentrated outside of MSIs. HSIs received 8% of ARCS grants despite having 16% of the student enrollment in our sample of ARCS-funded institutions (Figure 7). HBCUs received less than 1% of ARCS funding, and Tribal Colleges and Universities received only two of the grants in our dataset, for a total of $699,349 (0.1% of ARCS funding in FY 2019 and 2020). There are several categories of MSI not represented in IPEDS data; nonetheless, the low funding amounts for HBCUs and Tribal institutions, combined with the disproportionately low funding amount for HSI institutions, indicates that MSIs are not being prioritized for ARCS funding.

One opportunity for diversity in research funding to receive attention is through the Justice40 initiative. In President Biden's first month in office, he directed his administration to figure out how to direct 40 percent of the overall benefits of federal investments in clean energy and other environmental priorities to disadvantaged communities (Exec. Order No. 14,008, 2021).[32] So far, the focus has been on measuring benefits from tangible investments in demonstration and deployment of clean energy infrastructure, such as weatherization.[33] However, given that a large portion of DOE's budget is for clean energy research, it is reasonable to expect these research investments to also be brought into line with Justice40 goals.

> "We need to start with building capacity in different kinds of institutions, providing funding so they can acquire some **basic research instrumentation**, build out their physical infrastructure somewhat, but also **wrap-around capacity building**, like making sure the faculty have the support they need to develop their proposals, and scholarships and fellowships for students, in order to bring those institutions into a more competitive position for standard research grants."
>
> *- Anonymous interviewee*

BOX 2

Building Blocks

NSF FY 2022 Budget Request

The primary activity of the National Science Foundation (NSF) is to fund science and engineering research and education at higher education institutions; 80% of its award budget goes to this purpose.[35] All told, the NSF supplies 27% of all federal funding for basic research in higher education institutions.[36]

The proposed FY 2022 annual budget for NSF is $10.2 billion (20% greater than FY 2021).[37] Of this total, $440 million (4%) is devoted to clean energy technologies. This funding stream is dedicated to "fundamental clean energy research, research infrastructure enabling sustainable energy generation and distribution and allowing for the creation of more energy-efficient energy systems, the clean energy workforce, and the translation of fundamental discoveries in clean energy into technologies and systems."

The NSF is also proposing a 50% ($110 M) increase in funds dedicated to improving equity in science and engineering. Two programs in particular stand out for encouraging research collaborations across higher education institution types. Build and Broaden (B2), in the social sciences, aims to grow the STEM workforce and "encourages research collaborations between scholars at [MSIs] and scholars in other institutions or organizations."[38] Similarly, in computer science, the CISE Minority Serving Institution Research Expansion (CISE-MSI) program aims to "broaden participation by increasing the number of CISE-funded research projects from MSIs and to develop research capacity toward successful submissions to core CISE programs."[39]

Initiatives like B2 and CISE-MSI, if scaled up and made available across all NSF directorates, could increase ARCS participation for students of color and enhance the impact of ARCS funding.

The geographic approach to measuring benefits from ARCS grants would be the most straightforward, but perhaps the least informative. Funding research at colleges and universities located in disadvantaged communities may not in fact bring benefits to those communities. Other benefits accounting methods are needed to measure the benefits from science & technology research, which tend to be long-term and diffuse compared to benefits from real-world energy projects.

Participation of a broader set of academic institutions in ARCS would have multiple benefits. First, students and postdocs from underrepresented backgrounds trained by these grants would emerge as leaders of the next generation of climate and energy experts, thus providing much needed diversity to energy and cleantech-related industries.[34] Second, a diverse student body can help institutions build capacity for equitable community engagement, as students from disadvantaged communities will be better able to engage with members of those communities. Importantly, as we discuss in the next section, higher education institutions of all types must listen to members of impacted communities and work to build genuine relationships with them. Broader participation is a necessary, albeit insufficient, step toward supporting equitable climate solutions.

BOX 3

Future Possibilities

Parallels to Health Disparity Research at NIH

The climate crisis is not the only complex societal mission requiring broad research participation. We can look to other research areas for inspiration on how to encourage collaboration across different types of institutions. The National Institutes of Health (NIH) has been doing just that for research on health disparities for nearly 40 years, since Congress established the Research Centers in Minority Serving Institutions (RCMI) program in 1985 to diversify the biomedical research workforce.[40] Since its inception, RCMI has expanded its objectives to include development of infrastructure to increase clinical and community-based research capacity. The program supports health-related doctoral training in higher education institutions that serve underrepresented groups, and it funds institutions that provide health and clinical services to underserved communities.

The success of the RCMI program has led to other initiatives to encourage innovation and research collaborations within NIH. For one example, the RCMI Translational Research Network encourages collaborations and sharing of expertise across member RCMI institutions.[41] Another example is in NIH's National Center for Advancing Translational Science (NCATS)' Clinical and Translational Science Awards (CTSA) program, which has led to several notable partnerships between research-intensive medical schools and MSIs, to provide training for researchers and facilitate community participation in research:[42]

- Emory University & Morehouse School of Medicine[43]
- Georgetown University & Howard University[44]
- Vanderbilt University & Meharry Medical College[45]
- University of California, Los Angeles & Charles Drew University[46]
- Weill Cornell Medical College & Hunter College[47]

The lessons from RCMI and related programs can be usefully applied to climate solutions, given the strong parallels between health disparities and the disparities in harm done by climate change to underserved communities and people of color. Programs that fund research at MSIs on climate solutions—especially solutions that address inequities—are essential to build research capacity at these institutions. Funding for collaboration between MSIs and R1 schools can then further enhance the programs' impact by strengthening inter-university partnerships.

3. Engaging Non-Academic Partners

Climate solutions research is inherently problem-driven. But, as researchers seek climate solutions, whose problems in particular are these solutions addressing?

The processes of funding, planning, and implementing academic research is laden with value judgments, in terms of defining which problems are most important to solve and what approaches should be used to solve them. The academic research community itself has a great deal of agency in setting research agendas; funding programs often allocate resources in a way that mirrors the capacity of academic researchers. And although researchers have a wealth of expertise and training in their areas of specialization, they often lack knowledge of the real-world conditions in which climate solutions would be deployed.

Exchanging ideas with people outside of academia, therefore, holds the key to impactful ARCS. This applies both to industry professionals–with expertise in technology development and markets for climate solutions–and to members of disadvantaged communities–with expertise in the needs and capabilities of people who are most vulnerable to climate change impacts and often neglected by climate solutions discourse. In order for research to be usable by non-academic decision-makers, on critical subjects ranging from sea-level rise[48] to siting of wind turbines,[49] researchers must be able to engage with a diverse set of stakeholder groups.

"Generally, I find that academia has a hard **time listening to the other players** and being able to see their role in the context of the overall solution. The academics tend to say, 'We will be funded and we'll think of all these things and we'll bring solutions to the community,' and it's very much like, 'We'll invent stuff because we're the smart guys and we'll give you the answer.'

Academia can provide a lot of the enablers where a technology or a system that's being assembled runs into an issue. They could provide new insights and new answers, but **they have to actually be in the conversation.**"

- Anonymous interviewee

In this section, we examine the need for engagement with industry partners, which is a fairly well-known issue in science policy, as well as the need for engagement with communities, which is less widely understood, particularly in science and technology circles. Both forms of partnership for higher education institutions are critical for research on complex societal challenges.[50] Although the push to make academic research more responsive to societal need is not unique to ARCS,[51] it is of particular importance to developing equitable and impactful climate solutions.

3.1 Community Engagement

The Biden administration has sent strong signals connecting the fight against climate change to the fight for racial and economic justice. The climate crisis is anticipated to disproportionately impact underprivileged groups, due to increased exposure to environmental hazards. And yet, due to existing racial and class disparities, these same communities stand to miss out on much of the environmental and economic benefits of the transition.[52] Alternative paths to net zero emissions can have very different equity implications, both internationally and domestically across different racial, ethnic, and economic groups.[53] The social impact of new, clean technologies depends significantly on the details of how they are made, used, and disposed of.[54]

"Clean energy transition is great, but **are we going to leave behind a significant proportion of our population?** Can we make sure that clean energy jobs stay in the US and can be broad-based including underrepresented communities? Can we build research capacity at minority-serving institutions, HBCUs, tribal colleges? In certain cases there's going to be funding exclusively for MSIs; in other cases it's going to be required partnerships with an MSI or an HBCU that focus not just on climate science, but also **what are the impacts on communities and how do you build resilience in those communities?**"

- Anonymous interviewee

Grantmakers and institutions involved with ARCS must prioritize equity considerations and engage with disadvantaged communities to understand their unique challenges. And yet, this is easier said than done for the science and technology research enterprise. Much of what's written about public engagement with science is about outreach — informing the public about a research topic and making them aware of potential benefits.[55] Public engagement of this kind is often done with an eye toward legitimation of science, to secure public acceptance.[56]

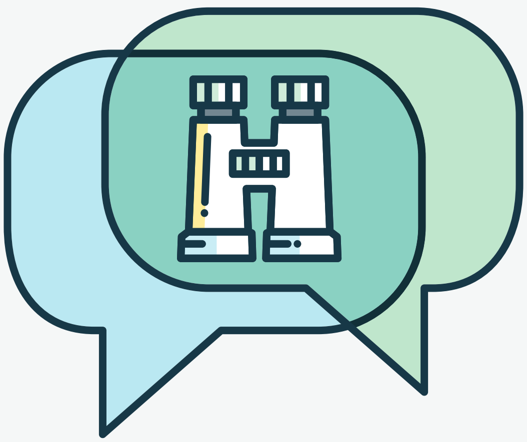
In order for ARCS to contribute to equitable climate solutions, a wholly different type of engagement is needed; the knowledge of disadvantaged community members must be elevated and inform the research processes that generate climate solutions. Academic research that engages members of impacted communities can have very different outcomes than more traditional academic research in which academic experts are siloed away from the people with lived experience of the phenomena of interest. The concept of community engagement is relevant to the full spectrum of ARCS, from energy justice research in social science[57] to natural science and technology research.[58]

BOX 4

Case Study

Responsible Innovation and Geoengineering Research

Research in science and technology has the potential to result in significant social impacts, both positive and negative. Public support for science is premised on the potential for positive impacts, and safeguards are needed to protect against potential negative impacts. Many negative impacts of science and innovation are unforeseen, and yet researchers have a responsibility to reflect on possible impacts and respond to early signs of harm.



One way to ensure responsible research that attends to possible harms is to open up inclusive public dialogue around decision-making in science and technology. A study by Stilgoe et al. examines one such dialogue in the UK in 2011 around research into geoengineering.[59]

The Stratospheric Particle Injection for Climate Engineering (SPICE) project was awarded public funding to investigate the possibility of injecting large quantities of reflective particles into the atmosphere to mitigate global warming. SPICE project researchers had proposed to deploy a field trial of a particle delivery system. Because of the significant controversy surrounding the concept of solar radiation management, the UK funders opted to put the project through review by an independent panel, based on principles of responsible innovation, before the trial began.

This additional review of the SPICE project was designed to be responsive to societal concerns, by encouraging the project leaders to anticipate possible impacts, reflect on the uncertainties involved in the project, and hold inclusive dialogues with the public and with stakeholders. The review process ultimately changed the project plan, leading to the field trial being cancelled.

Questions of responsible innovation (How will risks and benefits be distributed? How should risks and benefits be defined and measured?) can and should be asked of all ARCS research, not just hot-button issues like geoengineering. By engaging with communities to deliberate on these questions as part of the innovation process, ARCS researchers and funders can ensure that their work will bring societal benefit rather than disproportionate harm. In the words of Stilgoe et al., "Responsible innovation means taking care of the future through collective stewardship of science and innovation in the present."

Community-engaged research can take many forms and require different levels and types of participation, depending on the subject matter and community setting, ranging from highly participatory to more consultative approaches.

- Community-based participatory research (CBPR) and participatory action research (PAR) combine knowledge generation with social action on a topic of importance to a particular community. As the names suggest, these approaches entail highly active participation of community members at every stage of the research process.
- Ethnographic research approaches involve integration of the researcher into the community, in order to understand the lives of the participants before inductively forming research hypotheses.[60]
- Crowd-based science involves open data collection and data sharing by participants;[61] this approach can be applied to climate science to better understand local environmental changes.
- Quantitative data analysis can often gain critical context from complementary qualitative data, e.g. interviews with community participants.[62] Interviews can reveal insights such as barriers to technology adoption that are not evident in standard policy analyses.[63]
- Research on emerging technologies can be improved by engaging with communities on potential risks and benefits, especially during the design phase. Terms for this type of engagement include "participatory technology assessment" or "responsible innovation," as in the example in Box 4.
- Researchers can participate in community-based innovation efforts, which aim to empower marginalized communities and encourage local entrepreneurship.[64]
- Cooperative extension at land-grant universities, which has helped farmers develop "appropriate technology" in sustainable agriculture,[65] may provide insights on how to ensure broadly shared benefits from academic research. The extension model, despite its regrettable origin in the seizure of land from Indigenous Peoples, has the potential to enable more democratic engagement between academics and community members.[66]

No matter the flavor, community-engaged research must be done with equity as a priority and with a commitment to building ongoing relationships between the institution and the community. There is an inherent power imbalance between academic researchers and marginalized people, with academics often treating community members as an extractive data source rather than as a valued partner in knowledge creation.[67] Researchers, institutions, and funders must take proactive steps to be more inclusive and responsible in their approach to engaging communities in research, so that the resulting climate solutions are informed by dialogue with the people most affected.

Although community engagement, if done equitably, can bring benefits to participants and amplify the impact of the research, it can also come with some special challenges for researchers, as illustrated by the example in Box 5. The study by Reames et al. used relatively "small data" localized to a single county, so the results cannot be easily generalized to other locations. Compare this to a "big data" approach, which might have covered a wider geography but missed the deeper insights that come from interacting with people in a specific community. The local interactions involved in that study also required additional time and effort on the part of the researchers.

To encourage community-engaged research at a large scale requires patience and consideration on the part of institutional gatekeepers, such as journal editors and academic administrators, in order to appropriately evaluate and reward researchers who pursue it. Funders should also be clear on the value of research engagement and coordinate across agencies to share best practices.[68]

3.2 Industry Engagement

In order for ARCS to achieve maximum impact, research on emissions-reducing technologies or climate-relevant markets should be translated into new technologies or improved products or services. Academic-industry knowledge transfer is key to this process. Industry engagement also brings other benefits; students gain access to training and hiring opportunities, and knowledge flowing to local industry can lead to greater innovation, entrepreneurship, and growth within a region.[70]

The good news is that, in contrast to the situation with community engagement, academic researchers in science and technology disciplines interact relatively frequently with industry. For example, a survey of 1,528 academic physical scientists and engineers in the UK found that 71% of them had engaged in industry in some way.[71] Collaborative modes of interaction such as contract research and consulting, driven by the scientist's motivation to learn from industry and raise research funds, were much more

BOX 5

Case Study

Community-Engaged Research on LED Affordability

For an example of community-engaged climate solutions research, we look to the Urban Energy Justice Lab led by Tony Reames, Assistant Professor at University of Michigan and currently serving as Senior Advisor in the Office of Economic Impact and Diversity at DOE.

Lighting consumes a huge amount of home energy use and generates significant emissions and costs for consumers. A great deal of research attention has been paid to more efficient lighting in terms of the materials science of semiconductors, electrical engineering of devices, and policies to subsidize installation of efficient lighting, including light-emitting diodes (LED).

LEDs are far more efficient than incandescent light bulbs, making them a promising climate solution for those who can afford them. However, LEDs are not equally available and beneficial to everyone. In a 2018 study, Reames et al found that efficient lighting alternatives were generally less available and more expensive in poorer areas of Wayne County, MI.[69] Large retail stores, with cheap LEDs and plentiful advertising, were largely located in wealthier neighborhoods. Residents of high-poverty neighborhoods lacked personal vehicle access and thus were more likely to shop at small, local stores with higher prices and less information about the advantages of efficient lighting.

The Reames et al. study differs notably from a more siloed academic approach. The particular methodology of this study, which involved in-store survey data collection and qualitative observations about the lighting displays and the stores themselves, required researchers from the University of Michigan to get to know their surrounding community. These observations generated unique insights about the factors driving the statistical differences between neighborhoods and store types, thus exposing a barrier faced by poor people in accessing benefits from one particular climate solution.

common than formal technology transfer, such as patenting and founding spinoff companies.

Collaborations with industry scientists can be integrated relatively seamlessly into academic research activities.[72] There is also growing evidence that industry collaboration leads to added benefits in terms of scientific progress. In a study of 33 simultaneous discoveries from academic science teams, Bikard and Marx found that teams with industry collaborators produced more follow-on publications and fewer follow-on patents than their non-collaborating peers.[73] This suggests the possibility of a productive synergy between academic and industry researchers, in which each brings the different strengths of their organizational settings to bear on the interplay between research and effective use.

"The idea of creativity among constraints is a very uncomfortable topic for academics. In industry, you're not actually very useful if you can't invent inside the constraints. I'm not saying live with the constraints, but you have to **acknowledge the constraints and be thoughtful about solutions**. If academia thinks it's going to engage in multi-stakeholder problem solving, then I think they need to check their ego at the door about **who gets to define the problem**."

- Anonymous interviewee

There are differences in how academics engage with industry across various types of science and engineering. In academia, life scientists are more likely than their physical science colleagues to patent, and more likely to describe their research as "applied" rather than "basic", while in industry, life scientists are more likely to publish than physical scientists.[74] These findings suggest that the distinction between academic science and industry science is more blurred for life sciences than for physical science. It is especially important, therefore, for physical sciences and engineering to engage in and encourage collaborative research, to support the bridging of academic and industry knowledge.

At NSF, a new focus on research translation appears to be on the horizon. The creation of a new Technology, Innovation, and Partnerships (TIP) directorate has been proposed in the NSF FY22 budget request. TIP would create some new programs for research translation, while also absorbing a number of existing programs including I-Corps and Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR). An alternative proposal for coordinating research and innovation across academic and industry settings is described in Box 6.

It is unclear exactly how much of NSF's upcoming research translation efforts will be applied to ARCS topics. The Biden administration's American Jobs Plan in March 2021 proposed a $50 billion boost over 8 years to NSF, most of which would go to the TIP,[77] but this vision has since been dramatically scaled back. The NSF's FY22 budget request included $865 million for TIP,of which $52.5 million would be dedicated to research of clean energy technologies;[78] this amount is effectively flat funding for clean energy programs through TIP, based on the prior budget of the existing programs. Another $200 million in TIP is allocated to establishing the proposed Regional

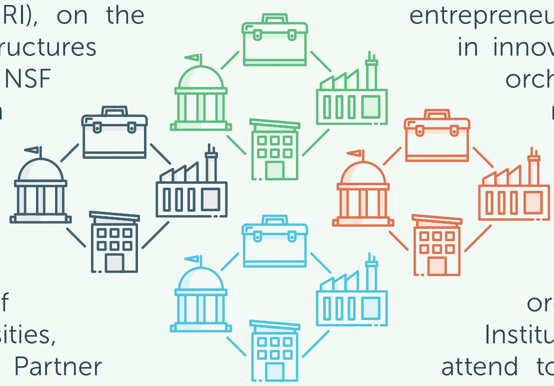
BOX 6

Future Possibilities

Proposal for the National Networks of Research Institutes

Some recent science policy discussions have focused on improving technology transfer outcomes from academic research through program design. A recent NSF-funded workshop examined a possible new approach to university-industry engagement on research and innovation, called the National Networks of Research Institutes (NNRI), on the premise that the typical structures for industry partnership at NSF generally don't deliver on their promise.[75]

The proposed NNRI would comprise a set of institutes, where each institute is a consortium of institutions, including universities, companies, and investors. Partner organizations within an institute would coordinate on use-inspired research and translation of that research into products and services, around a shared mission. Institutes would build on existing regional strengths and collaborations, and institutes operating in the same technology domain would be networked together to share knowledge and outcomes.



Some themes from the NNRI workshop report highlight how this model would differ from the standard NSF approach. In typical NSF centers, such as Engineering Research Centers (ERC) or Science and Technology Centers (STC), leaders are senior academics. In NNRI, leaders of each institute, and of each network, would be entrepreneurial figures with experience in innovation. These leaders would orchestrate across the different nodes, similar to an Advanced Research Projects Agency (ARPA) program manager who functions as a boundary spanner across organizational contexts.[76] Institutes would be required to attend to diversity and inclusion in terms of participation in research and training activities. The authors of the NNRI report note that flexibility is warranted when it comes to oversight and metrics for institute success; metrics may need to be customized for particular technology domains or geographic settings, and metrics may also need to adapt over time as the research progresses and the market environment changes.

Innovation Accelerators (RIA) program. RIA will fund 20 accelerators at $10m per year each, for 10 years, to advance use-inspired, solution-oriented research and innovation across all technology areas. Dedicated RIA funding for climate or clean energy would enhance NSF's ability to generate impactful climate solutions.

DOE, on the other hand, is focused squarely on the climate and energy mission, although its funding goes toward a much wider range of activities beyond academic research. In current policy discussions, much of the attention is on building up DOE support for later-stage innovation with a direct focus on industry. The Infrastructure Investment and Jobs Act has tens of billions going toward clean energy technology, most of which will be distributed through the new Office of Clean Energy Demonstrations.[79] Academic research on energy science will continue to be funded by DOE's Office of Science, although without the large budget increases seen by other DOE offices.

Meanwhile, DOE currently has several avenues for supporting translation of academic research. The National Labs serve as a conduit connecting universities to industry, and the Office of Technology Transitions is currently sponsoring an EnergyTech University Prize to get students involved in commercializing Lab technologies.[80] Many academics and industry professionals take advantage of DOE user facilities, and the Lab-Embedded Entrepreneurship Program helps early-career researchers transition from academia and create a cleantech startup,[81] through programs like Cyclotron Road at Lawrence Berkeley Lab.[82]

These DOE programs are steps in the right direction. Meeting the size and urgency of the climate challenge will require a department-wide focus on facilitating collaborations and integrating knowledge across all sectors. All applied R&D programs at DOE should offer competitive grant solicitations, so that academic researchers can contribute.[83] At the same time, the Office of Science should broaden their exclusive focus on "basic" research and be more supportive of academic awardees who engage with technology transfer and commercialization processes. This shift could yield greater research impact in terms of inventive outputs, without sacrificing scientific productivity.[84]

"One of the biggest changes that I've seen from this administration, and even Congress, is much more interest in deployment, demonstration, and commercialization. For a long time, innovation was the buzzword. The new terminology is that **we're facing a climate crisis**, we're seeing the consequences of climate change, and so, while innovation is great, and we want to maintain US leadership at STEM education, etc., it's really much more about deploying technologies that already exist now and getting ready for the ones that will be here in just a few years. **How do we translate our innovation into the market** and get private sector capital interested? This has always happened, but now it's on steroids."

- Anonymous interviewee

4. Conclusion

A new paradigm for funding ARCS can help colleges and universities rise to the challenge of disastrous climate change, while bringing about social and economic success for all members of society. In this report, we have highlighted one data challenge and four areas for improvement across the academic research enterprise that we expect to be particularly impactful toward climate solutions:

1. A centralized data repository is needed to capture the many disparate climate solutions research efforts across federal agencies.
2. Funders and institutions should prioritize social science and encourage collaborations between social science, natural science, and engineering fields.
3. Funding should be inclusive across multiple types of institutions beyond R1 universities, including minority-serving institutions.
4. Research should be planned and implemented in partnership with members of impacted communities.
5. Research should be informed by and responsive to the capabilities of industry partners.

These recommendations entail substantial change in ARCS funding and implementation. The need for change in ARCS echoes calls for change across all federally-funded research, to make it more effective at solving societal problems.[85] New investments in ARCS must not continue with the status quo funding approach, or even with small tweaks. They must break the mold, by including diverse researchers and institutions, prioritizing social science and transdisciplinary research, partnering with industry, and engaging with communities.

One connecting element between several of these takeaways is the importance of regional coordination. Climate change impacts are felt globally, but with unique adaptation needs in each region and unique features of each region's economy and demographics. Alliances between academic institutions in a given region would support more diverse participation, better partnerships with communities, and better coordination with industry across a range of climate solutions, perhaps building on the experience of USDA in organizing Climate Hubs.[86]

Ultimately, change is required for funders and higher education institutions alike. Although federal funding agencies and Congress set the priorities for resource allocation, they are informed in doing so by their perception of what is possible. As colleges and universities adjust their activities, coming more in line with the "fourth purpose," funders can make better use of the problem-solving capabilities in higher education. The need for impactful ARCS has never been more urgent, and so we call on all actors in the university research enterprise to consider how they can support the necessary transformation.

> "We need to double down on **connecting academic researchers to the ultimate users of the information** – these may be local policymakers, city, state-level officials, local communities, local businesses – to help **drive the research agenda to address local and regional needs**. In some areas, flooding is the biggest risk, and in other areas you're talking about drought. There's going to be a lot more regional focus and a lot more connection between the university, the local community, and local decision-makers to try to drive solutions to climate challenges in terms of both mitigation and adaptation."
>
> *- Anonymous interviewee*

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