



Earth to Economy: Accelerating Innovation for Climate Change Solutions

Presented by the Geological Society of America

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The responses received to the Geological Society of America's (GSA) initiatives to crowdsource climate change solutions illustrate the fundamental role of geoscience in understanding climate change and its impacts, sourcing needed materials for solutions, and designing effective mitigation, geoengineering, and adaptation measures. Geoscience will be critical to understanding the changing conditions that affect communities, such as water resources, agriculture, and extreme events, and developing mitigation measures, such as low-carbon energy sources and carbon capture and storage. Equitable partnerships and engagement with communities, particularly those most vulnerable to climate impacts, are needed. These efforts must be prioritized, valued, and funded, which requires a change in the culture and funding structure to be effective.

Our approach to collecting information was crowdsourcing through a series of targeted brainstorming sessions, online questionnaires, and soliciting comments by directed

outreach to leaders in the geoscience community. We presented four questions to participants. The questions were intended to help responders focus their answers in ways appropriate to the charge of this effort as outlined in communications with NSF. Results are given below as well as a brief description of our methodology. We also include the full complement of responses in an appendix to this document.

We take this opportunity to recognize that no one scientific discipline has all the solutions or the expertise to innovate and change. We also know that non-scientists have tremendous knowledge and critical context to contribute. We at GSA are already working with other organizations and societies to share and collaborate, as are our members and leaders. We welcome further discussions with the broad NSF community and representatives of the sciences and the public to work together on the climate change solutions needed for a robust world.

Q1: What do you view as the most transformative climate change challenge(s) that can be addressed with actionable solutions in a two to three-year timeframe?

The responses to this question were quite extensive and covered a large range of topics. The responses and summary below focus on adaptation and dealing with the production and sequestration of atmospheric carbon by human activities such as transportation.

1. Adapt to inevitable climate changes by:
 - incentivizing climate-susceptible communities to (re) locations that are intrinsically more resilient and/or less susceptible to climate impacts (e.g., higher elevation);
 - building resilient and adaptive infrastructure (e.g., underground power lines, public transit, heat-repelling building materials, waterworks);
 - monitoring environmental hazards, particularly in low-income communities most susceptible to climate impacts (e.g., tidally influenced groundwater mobilizing hazardous materials, changing groundwater resources);
 - focusing on protecting communities from extreme events and more extreme weather (e.g., heat islands, hurricanes, tornadoes, forest fires); and
 - applying climate adaptation and risk management research (e.g., food security, human health and well-being, infrastructure, security, cultural heritage, resilience, monitoring networks) to communities that are owned/managed by Indigenous nations, African-Americans, and Latinx peoples.
2. Promote low/no-carbon energy and storage by:
 - improving nuclear energy, particularly modular/small footprint, advanced reactors, storage of waste;
 - reducing or eliminating greenhouse gas emissions from fossil fuels (e.g., switch from coal to natural gas, end fossil-fuel use, enhance carbon capture) via incentives to convert to renewable sources;
 - developing and promoting wind, solar, hydropower, and geothermal development, including low-pressure hydro without dams and deep-well geothermal;
 - funding the development of battery storage along with improving materials and compounds for batteries; and
 - researching the sourcing and recycling of critical minerals and materials needed for battery production in environmentally responsible ways.
3. Reduce the carbon footprint of transportation and infrastructure through:
 - reducing human activities that create climate-changing emissions. Allow work from home as a permanent option to reduce combustion engine vehicle use;
 - building the infrastructure needed to make walking and biking societally viable and rewarding people for not using their cars;
 - supporting the digital infrastructure to make virtual conferences as or more compelling and valuable than in-person; and
 - providing the incentives for building climate-mitigating structures (e.g., reflective/green roofs) and cities (e.g., reduce impervious surfaces).
4. Expand research on carbon sequestration and geoengineering by:
 - modifying agricultural, forestry, and ocean practices to enhance carbon sequestration;
 - exploring Indigenous knowledge-based ecosystem services, soil organic carbon storage, tree-planting, blue carbon, and regenerative agriculture;
 - incentivize inexpensive ways for citizens to sequester carbon to offset their emissions;
 - identifying and promoting carbon-sequestering technologies such as green cement;
 - researching and implementing geological processes for enhanced weathering and carbon mineralization; and
 - using geoscience research to realize the promise of blue carbon sequestration in the oceans.

Q2: How would you reach that climate change goal? What stakeholders, technology, and/or partnerships are needed to effect change?

Ideas offered here may take longer than three years to implement, but all must be started today to have any hope of implementing in the future. Responses concentrated on the stakeholders of climate change. Because this group is all of society, there are necessary changes in participation, political processes, and focused research.

1. Involve the communities of stakeholders and researchers whose work impacts the solutions for climate change by:
 - directly funding opportunities for affected communities to mitigate climate change by working with universities as secondary partners;
 - involving the communities most impacted, particularly marginalized communities, in identifying and solving problems;
 - involving local governments more in the decision-making process, particularly for communities most affected by climate change and those without financial or political power, such as Indigenous, Black, Latinx, and rural groups;
 - funding tribal governments and Indigenous STEM scholars to co-create place-based climate change solutions; and
 - incentivizing geoscientists who possess a deep understanding of subsurface processes, hydrology, morphology, deep time, and climate drivers and those with deep knowledge of minerals, critical minerals, and climate-friendly extraction techniques to conduct research focused mainly on climate change mitigation and adaptation.
2. Promote behavioral and political solutions for climate change by:
 - requiring product labels to describe the product's climate footprint;
 - scoring legislation with a long-term cost-benefit ratio for humans and communities with respect to impact on climate change; and
 - fostering equitable interaction among impacted communities, governments, utilities, countries, and the fossil-fuel industry.
3. Invest in targeted cutting-edge research for:
 - mineralization and bacteriological carbon-dioxide sequestration technologies;
 - cloud formation/dissipation technology;
 - modular, small-scale, and non-uranium nuclear energy technologies (e.g., thorium salt bed reactors);
 - electrical vehicle charging technology;
 - creative surface morphology engineering that makes regions more climate-resilient;
 - critical mineral recycling and non-traditional mining;
 - shallow marine mapping and paleo-morphology for off-shore wind energy production;
 - a centralized online, publicly navigable database of location- and time-specific water conservation actions based on geosciences research about past and future water availability; and
 - awarding grants and holding workshops for students that focus on climate change impacts such as landslides, permafrost thaw, drought, and increasing wildfires.

Q3: How do we effectively communicate the critical role of geoscience to the public and decision makers in providing solutions, tools, utilities, and technologies to help address identified challenges in climate change?

A primary missed avenue to working on solving climate change is the knowledge base of the public and public officials. Responses here are aimed at much better communication and education. Although we all live the reality of climate change, there is no consistent and crystal-clear message that is being communicated.

1. Involve professional communicators, such as a high-level marketing firm, to develop an effective and massive PR campaign that reaches a wide swath of the public by developing memorable slogans. Welcome celebrities to reach out to the public and create climate-change awareness. Hire geoscientists to speak at service clubs like Rotary, Lions, Kiwanis, etc. Develop short documentary films to be shown on PBS and other public-service outlets that focus on the reality of climate change and climate adaptation strategies. Embed best practices in communication in the geoscience education and professional systems.
 - making a real and tangible connection between climate change and our livelihoods by highlighting the effects of climate change on the economy, public health, food access, and diversity;
 - creating awareness in people of the importance of making climate-friendly decisions for themselves, communities, and humankind;
 - educating the public on modern nuclear energy capability and safety;
 - using a trusted local source (i.e., local news affiliates) to run short spots educating about climate;
 - communicating to the public that significant reductions in greenhouse gas emissions are possible and giving them an understandable cost-benefit analysis; and
 - connecting local communities and policy makers with geoscientists who can help advance local resilience and sustainability.
2. Develop graphics, including 3-D visualizations and videos, much more effectively. Add digestible educational material to websites for easy dissemination, and advertise that they are publicly available. Present data, maps, and images defined during research that can be used to build a Google Earth Paleo-Terra that the public can use to fly through the landscapes of North America 20,000 years ago to the present day.
3. Jump on all opportunities for public outreach by:
 - communicating proactively to the public and educate the public about resource needs and the criticality of geoscientists as integral to providing for the needs of water, building materials, cement, steel, geothermal energy, lithium, and hi-tech materials (Rare Earth Elements);
 - enlisting existing county extension systems to become more abundantly resourced to stage well-attended public events (the effectiveness of chili cook-offs should not be underestimated) aimed at local environmental concerns and including presentations by scientists of national/international stature when possible;
 - placing geoscientists on corporate boards and/or in public office;
 - developing an app for water conservation strategies to inspire people to tap into their civic duty;
 - providing a platform for local people to discuss their concerns, how they see their future, and how they can participate in achieving that future in light of climate change;
4. Change the nature of public knowledge of science by:
 - beginning STEM education in grade school;
 - raising the level of knowledge and breadth of understanding of the earth science and climate change of science teachers;
 - incorporating climate change curriculum into schools;
 - elevating geosciences to a discipline as important as biology, chemistry, and physics in K–12 education;
 - increasing efforts to reinstate geosciences at the state level;
 - building a community of citizen scientists who directly monitor and collect data on the patterns and impact of climate change;
 - providing funding to have climate sessions at national meetings open to the public;
 - supporting financially online resources for teachers (i.e., SERC/Cutting Edge);
 - providing resources to workers as to how to transition to work in a new low-carbon economy; and
 - building capabilities to contribute to adaptation and mitigation science targeted directly at the Indigenous, Black, Latinx, and other communities.

Q4: How can we effectively embed a culture of innovation, entrepreneurialism, and translational research in the geosciences? What resources, training, pedagogical change, etc., are needed to drive forward that change?

The responses to this question were generally aimed at better communication and education of the public and students on climate change and engineering solutions and making scholarly products more readily available and accessible. They also addressed the nature of incentives afforded to researchers and actions that the NSF can take in the short-term to creating and fostering research in climate change solutions as well as translational research. The principal, actionable recommendations for the short term include the following:

- Enhance the NSF I-Corps program and make it more extensive and flexible for researchers, scientists, and students. Lower barriers to participation by researchers. Make the program more attractive to businesses. This seems like a critical area in which to instill an entrepreneurial spirit and opportunity. Provide a clearinghouse for those in industry looking to partner and those in academics with ideas.
- Make financial incentives better for both economic and engineering geologists. The earth sciences have flourished with an influx of students to train and work in the oil and energy fields because of the salary structure with oil companies. Immediately create, through policy, such as tax credits, carbon tax, or carbon capture and sequestration funding, a thriving industry that pulls in the best and brightest students.
- Make our scientific results more accessible to the general public. Through information and outreach, engage the public as citizen scientists to teach them about science and involve them in data collection. Fund programs that place data collection using apps such as iPlant, National Map Corps, Climate Crowd, and StraboSpot. Make apps that both collect data and teach the citizen user. Team more with computer science to build the national cyberinfrastructure that engages the public. Bring science to the public.
- Have GSA and the American Geophysical Union plan and hold a joint meeting on climate change engineering, geological engineering, and economic geology and economics as the focus in 2022. Bring in other societies as possible and make the conference open and significant to a completely virtual component.
- Create pedagogical changes in education that highlight Earth, and involve students in projects investigating climate change and engineering solutions to problems. This will require long-term effort and some restructuring of curricula.

Methodology

GSA used various mechanisms to crowdsource ideas, focus areas, and research and development roadmaps where the most impacts can be made in the shortest amount of time (two to three years) for creating a thriving planet in a warming world. A website was created to submit text and video answers to questions designed to elicit requested information on the following general questions.

1. What do you view as the most transformative climate change challenge(s) that can be addressed with actionable solutions in a two- to three-year timeframe? Examples include ideas to address climate change and human health, population dislocation, and impacts to underserved communities.
2. How would you reach that goal? What stakeholders, technology, and/or partnerships are needed to effect change?
3. How do we effectively communicate the critical role of geoscience to the public and decision makers in providing solutions, tools, utilities, and technologies to help address identified challenges in climate change?
4. How can we effectively embed a culture of innovation, entrepreneurialism, and translational research in the geosciences? What resources, training, pedagogical change, etc., are needed to drive forward that change?

GSA used multiple social media platforms to broadly solicit feedback from its membership and community during the two-week comment period. These include emailing all GSA members, highlighting opportunities in GSA's monthly newsletter, "GSA Connection," multiple posts on social media (GSA Twitter [47,794 followers]; GSA Instagram [6,163 followers]; and GSA Facebook [278,123 followers]), and discussions on GSA's Connected Community network that reaches its entire membership.

GSA also conducted **targeted outreach** to ensure the project received responses from **students, early career professionals, groups underrepresented in the geosciences**, and multiple disciplines and stakeholders. Targeted outreach included:

1. Climate Solutions Brainstorming Sessions. GSA held three online brainstorming sessions to ensure participation by students, early career professionals, and underrepresented groups. Targeted invitations were sent to GSA student members, early career professional members, and On To the Future alumni to participate in climate-solution brainstorming sessions and submit feedback. These sessions were hosted and moderated by GSA leadership, student advisory committee members, and GSA staff. The session allowed these targeted groups time and space to discuss these questions and have their answers considered.
2. We invited participation through "GeoScene," GSA's monthly communication to students and early career professionals.
3. We sent each of GSA's 22 scientific Divisions, which span interests from structural geology and tectonics to soil and soil processes, easily shareable content to encourage submission from their members.
4. GSA sent information packets to encourage submissions from its associated societies and did outreach to other geoscience organizations. More than 75 societies across a range of disciplines, countries, and stakeholders were contacted. Input from these societies ranged from the Association of American State Geologists, which provided an opportunity to solicit ideas from those working at the local level, to the Global Network for Geoscience and Society.
5. GSA leadership identified leaders in climate science and personally contacted them to provide information and encourage participation.

Overall, more than 100 responses were received through the portal, GSA connected community, and social media, in addition to the responses collected during the climate brainstorming sessions.