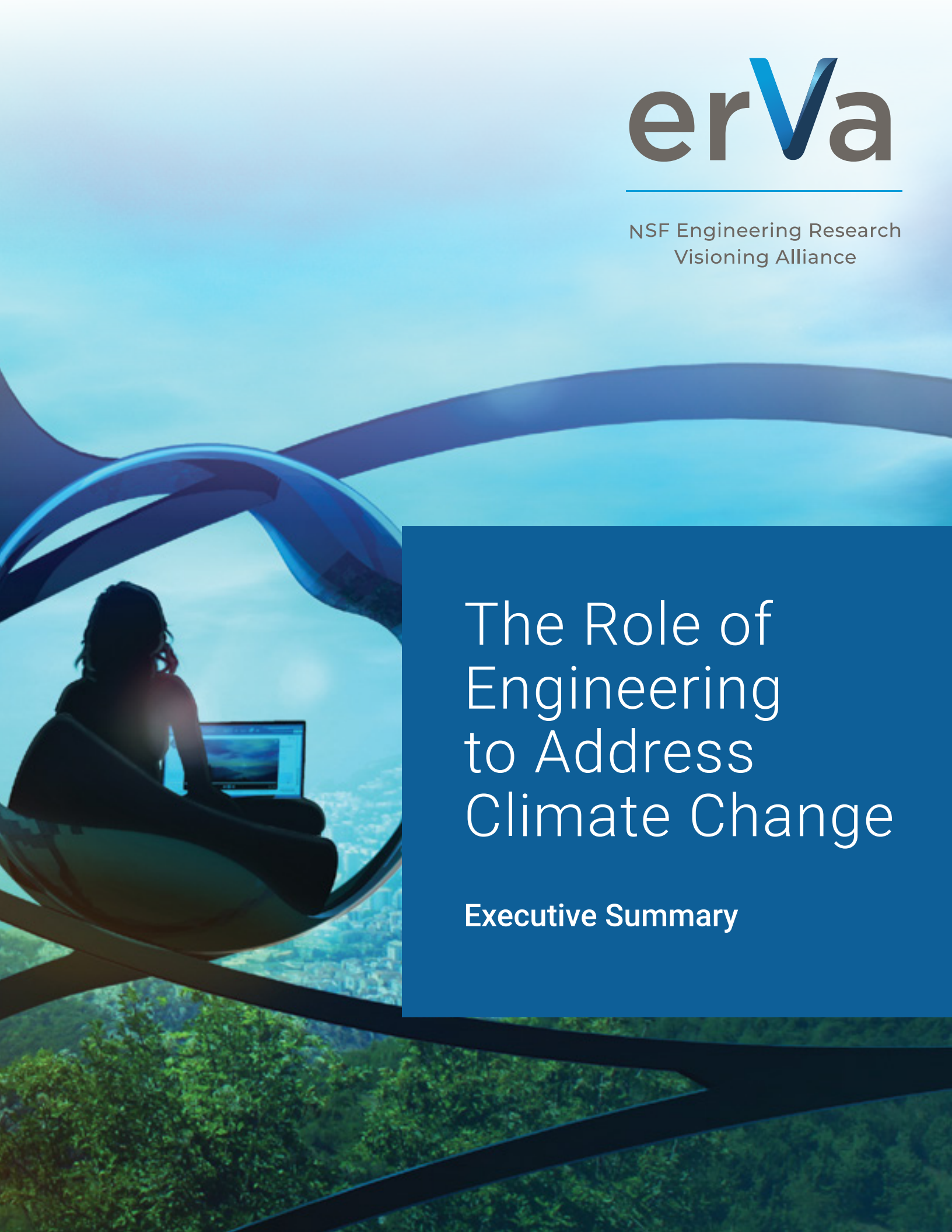

NSF Engineering Research Visioning Alliance

The Role of Engineering to Address Climate Change

Executive Summary

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Catalyzing Engineering Innovation

More than 30 years have passed since the Intergovernmental Panel on Climate Change (IPCC) was created by the World Meteorological Organization and the United Nations Environment Programme to provide governments at all levels with scientific information they can use to address climate change. Although respected scientific bodies have produced dozens of reports in the ensuing years, few point to engineering-specific research directions and the critical role the engineering community can play in addressing climate change.

Effectively mitigating the impact of climate change requires deliberate tools wielded by the engineering research community. Facilitated by significant and sustained investment, these tools can bring transformative change to the way society confronts the causes of and impacts of climate change. This is the key recommendation of a recent visioning event coordinated by the Engineering Research Visioning Alliance (ERVA) to identify the role of engineering in addressing climate change. From this event, three cross-cutting thrusts emerged:

- **Focus on critical materials in all engineered systems**, especially in extraction, separation, recycling and upcycling, and energy conversion, as well as CO_2 mitigation.
- **Invest in sensor, sensing, and communication capabilities** to facilitate data compilation and analysis.
- **Enable and strategically exploit artificial intelligence (AI) modeling** for forecasting and trend analyses.

To accelerate solutions, it is imperative to focus on *ways that engineering can lead foundational research efforts to address climate change*, with full understanding that technical solutions cannot be separated from consideration of societal impact. The event's Thematic Task Force, comprised of academic, corporate, and nonprofit experts, selected 10 discrete areas to consider. The convened scientists and engineers evaluated bold ideas, probed unexamined questions, and leveraged their combined expertise. The results were distilled into two overarching topics for this report: *synergistic engineering research priorities to address climate change, and developing a comprehensive and inclusive vision for addressing climate change*.

Synergistic Engineering Research Opportunities to Address Climate Change

Climate change is an enormously complex topic, spanning many engineered systems that impact not only carbon dioxide emissions from fuels, but also the health of people, water systems, ecosystems, and infrastructure. The fundamental research topics prioritized to address climate change include:

ENERGY STORAGE, TRANSMISSION, AND CRITICAL MATERIALS

- Nanoengineered materials for critical mineral separation, extraction, and recycling;
- Chemicals or materials for non-traditional energy storage such as reversible electron shuttles in flow batteries, and hydrogen gas;
- Materials for extracting additional energy from heat cycles by harvesting low-grade heat in new ways, such as thermal flow batteries and thermoelectrics; and
- Developing new ion exchange membranes to replace fluorinated membranes used in critical electrification systems, such as fuel cells and water electrolyzers and other separation systems, with non-PFAS (per- and polyfluoroalkyl substances)-based membranes with sufficient durability to withstand harsh conditions.

GREENHOUSE GAS (GHG) CAPTURE AND ELIMINATION

- Processes for capture and to eliminate methane and nitrous oxide in agriculture operations and the environment by focusing on high emission sites such as dams and water impoundments, mines, landfills, and farms;
- Researching bio- and genetic-engineering of plants or inclusive microbial communities for selective non-CO_2-based GHG capture (e.g., for methane and nitrous oxide); and
- Exploring the feasibility of intensive biotic ocean carbon capture to deep-sea sediments with a key area of preventing loss of nutrients, and electrochemical methods with a focus on devising materials suitable for challenging seawater conditions.

RESILIENT, ENERGY-EFFICIENT, AND HEALTHFUL INFRASTRUCTURE

- Developing low-cost coatings for buildings, roads, and infrastructure that reduce heat island effects, increase self-cooling, and thermal energy transmission back into the exosphere;
- Infrastructure engineering that demonstrates positive impacts on health arising from de-fossilizing/decarbonizing the energy infrastructure and reducing transportation, industrial, and power-plant emissions; and
- Extensive life cycle analyses, frameworks, or environmental product declarations of embodied carbon in our infrastructure, ranging from the existing built environment to commonly used materials.

WATER, ECOSYSTEMS, AND GEOENGINEERING ASSESSMENT

- Sensing, measuring, and AI models for water flow analysis across large landscapes and proposing, through modeling and forecasting, future solutions to mitigate large swings in water availability due to increasingly disruptive events associated with climate change;
- Advancing solutions to threats of substantial losses of treated water in aging distribution systems through improved data collection and analytics, combined with novel in-line and self-powered sensing feeding forward into AI models; and
- Conceptualizing and testing at appropriate scales potential geoengineering solutions, with consideration of impacts on the environment and emphasis on economic and social costs of such technologies.

A Comprehensive and Inclusive Vision for Addressing Climate Change

The areas selected by the Thematic Task Force provide opportunities to address climate change by catalyzing the engineering research community. Encouraging the engineering research community to pursue research directions for climate solutions provides an opportunity for federal agencies and the entire engineering research community to invest their resources and talent to address this problem with broader impacts on society. Engineering has unique opportunities to advance consideration of underrepresented populations through research with the potential to transform the energy and urban infrastructure in response to preventing or mitigating changes due to climate change. In this vein, participants emphasized topics of importance related to energy and climate education for all. Topics of particular importance to pursue include:

- **Convergent solutions that remove social barriers** and provide universal, affordable access to renewable energy sources and energy-saving devices;
- **Addressing the utility-scale solar and community acceptance conundrum** by enhancing multi-use land applications for solar and wind and identifying effective methods for community engagement;
- **Creating efficiencies and increasing impact** by investing the time and resources to create and leverage multinational programs of sufficient scale and that equally weigh both technical and social benefits;
- **Communicating energy use and carbon emissions without complex jargon** and confusing arrays of units for building heating and cooling, transportation systems, food systems, and consumer goods;
- **Advancing energy use tied to reduced carbon emissions in all aspects of daily life**, ranging from fossil fuels to consumer materials and goods used in daily activities; and
- **Incentivizing transitions** to energy conservation, efficiency, and renewable energy solutions.

Credit: Jeff Fitlow/Rice University

"Engineers are driven by devising elegant solutions to complex problems. Engineering research will make solutions to climate change possible – with innovations that bring our natural world, our built world and our societies into balance."

AMY HEINTZ

Member of ERVA's Executive Committee, co-chair of the Thematic Task Force and technical fellow at Battelle.

Taking Action

There is powerful momentum to pursue meaningful steps to reduce CO_2 and other greenhouse gas emissions, build more resilient infrastructure and increase the use of solar and renewable energy, resolve energy storage challenges, improve water and ecosystem management, improve health through engineering infrastructure changes to address climate change, and explore the potential of geoengineering for CO_2 capture, storage, and conversion if it becomes needed. Behind each of these thrusts is the power of engineering research to catalyze critical advances, create community awareness, and enable convergent and inclusive solutions.

The full report is not a comprehensive review of all solutions, but instead a look at critical needs in engineering that provide unique opportunities relative to climate change. There are important ways to address climate change that do not require cutting-edge engineering research, but the ERVA report describes specific research directions through which engineering can take the lead and have impact. The aim is to inspire researchers and funders (public, private, and nonprofit) to support and pursue these priorities. ERVA challenges readers to disseminate this report and prioritize areas with potential for the greatest return on investment. Collaboration across the engineering community is needed now to seize opportunities to mitigate climate change and secure our future.

Credit: CasarsaGuru (used with permission)

The Engineering Research Visioning Alliance (ERVA) was established to catalyze the engineering research community's pursuit of innovative, high societal impact research through identification and communication of compelling research visions responsive to pressing national and global challenges. On Dec. 7-8, 2021, ERVA held a visioning workshop on "The Role of Engineering in Addressing Climate Change." The diverse array of experts representing over 100 organizations from academic, industry, and government sectors converged to identify engineering research priorities across a breadth of climate change challenges. This document summarizes their key findings.

NSF Engineering Research
Visioning Alliance

Our mission is to identify and develop bold and transformative new engineering research directions and to catalyze the engineering community's pursuit of innovative, high-impact research that benefits society.

ERVA IS FUNDED BY THE NATIONAL SCIENCE FOUNDATION THROUGH AWARD NUMBER 2048419

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This material is based upon work supported by the National Science Foundation under Grant # 2048419. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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