



RESILIENCE SCIENCE AND TECHNOLOGY GRAND PATHWAYS FRAMEWORK

A Report by the
**SUBCOMMITTEE ON RESILIENCE SCIENCE AND
TECHNOLOGY**

COMMITTEE ON HOMELAND AND NATIONAL SECURITY

of the
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

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In May 2019, the National Science and Technology Council's (NSTC's) Committee on Homeland and National Security established an interagency subcommittee that focuses on strengthening and promoting science and technology to enable National resilience against threats and hazards that could have catastrophic consequences to National essential functions. The primary purpose of this group, the Subcommittee on Resilience Science and Technology (SRST), is to coordinate and improve Federal science and technology innovation and utilization through policy and practice.

About this Document

SRST examines the interdependencies among societal dimensions of resilience (including the key functions and cross-cutting enablers that support them), and identifying the critical gaps that impede resilience. This report outlines the Resilience Grand Pathways Framework, a tool for Federal, state, and local agencies and private sector partners to assess resilience-related programs to identify, align, and potentially prioritize science and technology (S&T) investments. The document describes an organizing construct that agencies can adapt and apply to their missions and programs. The document does not outline specific S&T gaps or provide recommendations or priorities, but it can help agencies and their partners develop them.

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Table of Contents

About this Document	i
Table of Contents	v
Abbreviations and Acronyms.....	vi
Executive Summary	vii
Introduction & Purpose.....	1
What is Resilience?	2
Conceptualization of the Framework.....	3
Definitions of Key Framework Elements	4
Societal Dimensions.....	5
Cross-Cutting Enablers	6
Relationship with Essential Government Functions.....	7
How to Use the Resilience Grand Pathways Framework.....	9
Audience & Value of Framework.....	10
Use Case 1: Identifying Gaps in Infrastructure as a Result of SARS CoV 2 (COVID-19)	12
Use Case 2: Texas Winter Storm and Power Crisis – Cascading Failures	13
Future Efforts.....	15
Appendix 1: Grand Pathways Framework and the Application to Essential Government Functions.....	16

Abbreviations and Acronyms

DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of the Interior
DOS	Department of State
DOT	Department of Transportation
EOP	Executive Office of the President
EPA	Environmental Protection Agency
IWG	Interagency Working Group
NASA	National Aeronautics and Space Administration
NITRD	Networking and Information Technology Research and Development
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
R&D	Research and Development
S&T	Science and Technology
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USPTO	United States Patent and Trademark Office

Executive Summary

In recent years, America’s communities have faced unprecedented shocks and stresses due to natural hazards, accidents, and human-caused disruptions, some occurring in tandem or as cascading disasters. Helping individuals, families, and communities recover from these immense challenges while building their resilience to historical, ongoing, and future stressors is a challenge that requires a whole-of-community effort, which includes harnessing science, technology, and innovation. The Bipartisan Infrastructure Law invests in addressing these challenges, including over \$50 billion to build the nation’s resilience to the impacts of climate and extreme weather hazards, and directs investment in billions more in infrastructure that will need to be resilient to both natural and human-caused hazards.

To contribute to addressing the challenge of building resilience, the United States National Science and Technology Council’s (NSTC) Subcommittee on Resilience Science and Technology (SRST) establishes a Resilience Science and Technology Grand Pathways Framework in this report. This Framework uses a focus on strengthening specific societal dimensions of resilience to better identify, align, and prioritize investments in science and technology to improve community resilience. The report defines and examines the interdependencies among five societal dimensions of resilience: safety and security, financial/economic resilience, healthy people, social cohesion, and trusted effective governance. These societal dimensions are compared to cross-cutting enablers, defined as the enabling resources and capabilities (for example, education, infrastructure, financial resources, and policy) that build towards the end states of a resilient community. The Framework weaves together the societal dimensions and cross-cutting enablers with key functions of a resilient community, which are defined as actions or services (e.g., continuity of government, emergency response operations) that use cross-cutting enablers to support one or more societal dimensions. Ultimately, the Framework integrates societal dimensions, cross-cutting enablers, and key functions to identify the critical gaps that impede resilience and that can be addressed by the advancement and application of resilience science and technology.

The Grand Pathways Framework is intended to help users identify, align, and prioritize science and technology solutions to improve resilience. The Framework identifies three modes of resilience: the *process* of resilience (anticipating, avoiding, adapting, withstanding, and building back better), the *property* of resilience, and the *desired outcomes* of societal resilience. In applying the Framework, SRST encourages adopters to carefully consider the distinctions between and relationships among the cross-cutting enablers, key functions, and societal dimensions of resilience.

Resilience is an ever-evolving challenge, as novel and unpredictable stressors continue to emerge, and historical and environmental factors influence the path to resilience. Resilience can be improved by investments in science and technology. The Grand Pathways Framework looks to support decisionmakers in achieving the goal of resilience by helping them design and implement multipurpose science and technology solutions that strengthen a community’s ability to withstand a wide variety of acute shocks and chronic stressors.

Introduction & Purpose

The Resilience Science and Technology Grand Pathways Framework aims to build resilient communities by identifying, aligning, and prioritizing science, technology, and innovation that equitably and justly strengthen multiple dimensions of American society.

In recent years, America’s communities have faced unprecedented shocks and stresses due to natural hazards, accidents, and deliberate acts, some occurring in tandem or as cascading disasters. According to the National Oceanic and Atmospheric Administration, in 2021, the United States experienced 20 weather or climate disaster events with losses that exceeded \$1 billion each; since 1980, 310 such events occurred.¹ Weather events, like the unusual cold snap in Texas in February 2021², lead to pronounced secondary effects, such as prolonged power losses. Deliberate disruptions, like the Colonial Pipeline ransomware attack that disrupted oil supply chains³, can have similar widespread impacts. Both of these events occurred while the Nation grappled with the COVID-19 pandemic, the opioid epidemic, and other health crises that have exacerbated pre-existing weaknesses in the built environment as well as social and institutional inequities.

Helping individuals, families, and communities recover from these immense challenges while building their resilience to historical, ongoing, and future stressors is a challenge that requires a whole-of-community effort, and that includes focusing and harnessing science, technology, and innovation. The Bipartisan Infrastructure Law highlights the need to address these challenges by investing over \$50 billion to build the Nation’s resilience to the impacts of climate and extreme weather hazards, and directs investment in billions more in infrastructure that will need to be resilient to both natural and man-made hazards.⁴ There are a number of other investments in the Bipartisan Infrastructure Law, as well as the Inflation Reduction Act⁵ that, if built with all-hazards resilience and cybersecurity in mind, will significantly enhance the Nation’s resilience to climate change and a wide array of other threats and hazards. Further, the Biden Administration’s commitments to increasing social equity⁶ and environmental justice⁷ will help remedy persistent inequities that have diminished the resilience of communities.

¹ National Oceanic and Atmospheric Administration. 2021. “Billion-Dollar Weather and Climate Disasters.” <https://www.ncdc.noaa.gov/billions/>

² National Oceanic and Atmospheric Administration. 2021. “Valentine's Week Winter Outbreak 2021: Snow, Ice, & Record Cold.” <https://www.weather.gov/hgx/2021ValentineStorm>

³ Department of Energy. 2021. “Colonial Pipeline Cyber Incident.” <https://www.energy.gov/ceser/colonial-pipeline-cyber-incident>

⁴ The Executive Office of the President. 2022. “President Biden's Bipartisan Infrastructure Law.” <https://www.whitehouse.gov/bipartisan-infrastructure-law/#resilientinfrastructure>

⁵ See, for example, The Executive Office of the President. 2022. “FACT SHEET: Inflation Reduction Act Advances Environmental Justice.” <https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/17/fact-sheet-inflation-reduction-act-advances-environmental-justice/>

⁶ The Executive Office of the President. 2021. “Executive Order on Advancing Racial Equity and Support for Underserved Communities Through the Federal Government.” <https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government/>

⁷ The Executive Office of the President. 2021. “Executive Order on Tackling the Climate Crisis at Home and Abroad.” <https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/>

The National Science and Technology Council (NSTC)'s Subcommittee on Resilience Science and Technology (SRST) investigated methodologies and strategies to assist agencies focusing their resources as they make use of the generational investments afforded by the Bipartisan Infrastructure Law⁸ and the Inflation Reduction Act.⁹ SRST was created in 2019 to address cross-cutting resilience science and technology issues related to all threats and hazards, at all stages of risk management, considering both physical and social science dimensions. SRST is investigating the interdependencies among **societal dimensions** of resilience (including the **key functions** and **cross-cutting enablers** that support them), and identifying the critical gaps that impede resilience. The goal of these investigations is to identify mechanisms, or "grand pathways," to align current and future resilience science and technology capabilities to address those gaps across multiple disruptions, resources and cross-cutting enablers, key functions, and societal dimensions to assist communities in advancing their own resilience. A sound, single framework will help prioritize investments and ensure that Federal dollars are spent to their best advantage.

A resilient community anticipates, avoids, adapts to, withstands, and builds back better in the wake of disruptions.

This report outlines the Resilience Science and Technology Grand Pathways Framework, which aims to identify science, technology, and innovation approaches that improve communities' abilities to anticipate, avoid, adapt to, withstand, and build back better from acute shocks and chronic stresses with the potential to cause disruption or destruction. End users of the Grand Pathways Framework include Federal agencies and their partners, such as planners, policy makers, community leaders, innovators, and others. This effort builds on the *Grand Challenges for Disaster Reduction* (2005) and follow-on hazard specific implementation plans (2008) published by the NSTC's Subcommittee on Disaster Reduction.¹⁰ The *Grand Challenges* provided a 10-year strategy for Federal agencies and external partners and stakeholders to deliver science- and technology-based investments to increase disaster resilience, with efforts aimed at increasing understanding, reducing vulnerability, informing decisions and otherwise promoting risk-wise behaviors.

What is Resilience?

The Grand Pathways Framework outlined in this document recognizes that building resilience requires communities to start with the societal outcomes desired as a Nation: safe, secure, and healthy populations; connected and cohesive communities; a robust economy; and trusted governance. The Grand Pathways Framework represents a process for decision makers who must look across threats and hazards, find common needs and interdependencies, and devise paths forward to develop the science and technology needed to achieve these outcomes. In developing outcomes, the Grand Pathways Framework encourages users to advance equitable solutions through a systematic approach to assessing science and technology solutions that further resilient communities.¹¹

⁸ The Bipartisan Infrastructure Law (P.L. 117-58) is also referred to as the Infrastructure Investment and Jobs Act (IIJA) of 2021, <https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf>

⁹ The Inflation Reduction Act is P.L. 117-169, <https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf>

¹⁰ National Science and Technology Council Subcommittee on Disaster Reduction. 2005. "Grand Challenges for Disaster Reduction." <https://www.sdr.gov/grandchallenges.html>

¹¹ See The Executive Office of the President. 2021. "Executive Order on Advancing Racial Equity and Support for Underserved Communities Through the Federal Government." <https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government/>

The term **resilience** means different things in different contexts and in different communities.¹² Even within a single community or context, individuals may have different perceptions about what resilience entails:

It is an outcome or desired end state. For example, community leaders work to create a prosperous and just community that is resilient against current and future severe weather and climate hazards.

It is a system property. For example, business leaders work to ensure data centers and financial networks are resilient against cyber-attacks, physical threats, and natural hazards.

It is a process. For example, decision makers work to anticipate threats and hazards; to choose actions that avoid these threats and hazards wherever possible; to take steps to adapt to and/or withstand unavoidable threats and hazards; and if damage strikes, to build back better.

Hereafter, the examples above are called “resilience modes.” Whether resilience is perceived as being an outcome, a system

The Grand Pathways Framework considers a community to be people connected through common physical, social, virtual, or hybrid characteristics. It can include individuals and families, businesses, non-profit groups, faith-based and community organizations, media outlets, and all levels of government.

Effective and meaningful resilience is synergistic, building simultaneously upwards from the individual level and downwards from the national, or even international, level.

property, or a process (or all three modes), building resilience is neither simply top-down or bottom-up.¹³ Effective and meaningful resilience is synergistic, building simultaneously upwards from the individual level and downwards from the national, or even international, level. A homeowner likely is not equipped with the knowledge or materials to harden their house against a hurricane, while a Federal strategy to harden homes against hurricanes is of little use unless homeowners and builders have the knowledge, resources, and ability to carry out the suggested actions. Resilience requires a synergy between high-level planners with the macro-level ability to predict and

prepare for disruptions and community-level organizations and regulatory and enforcement agencies, as well as individuals who make these plans actionable on a day-to-day basis.

Conceptualization of the Framework

The Grand Pathways Framework connects the three modes of resilience and uses a focus on strengthening specific societal dimensions of resilience to better identify, align, and prioritize investments in science and technology.

The Grand Pathways Framework (Figure 1) is an approach to consider resilience in the context of:

- **Societal Dimensions** – the essential characteristics or features of a resilient society
- **Key Functions** – those actions or services essential to delivery or realization of one or more societal dimensions

¹² Moser, S., Meerow, S., Arnott, J. et al. 2019. “The turbulent world of resilience: interpretations and themes for transdisciplinary dialogue.” *Climatic Change* 153, 21–40 (2019). <https://doi.org/10.1007/s10584-018-2358-0>

¹³ National Research Council. 2012. *Disaster Resilience: A National Imperative*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/13457>

- **Cross-Cutting Enablers** – the enabling resources and capabilities that underpin one or more key functions

The framework helps users identify, align, and prioritize science and technology solutions that use the **process of resilience** (anticipating, avoiding, adapting, withstanding, and building back better) to enhance the **property of resilience** of both cross-cutting enablers and key functions so that they effectively deliver the desired **outcomes of societal resilience**. In applying the Framework, SRST encourages adopters to carefully consider the distinctions between cross-cutting enablers, key functions, and societal dimensions of resilience. Cross-cutting enablers are resources (e.g., finances or infrastructure) that allow communities to perform specific key functions (e.g., facilitate emergency evacuation) that support enduring societies.

Resilient communities have...

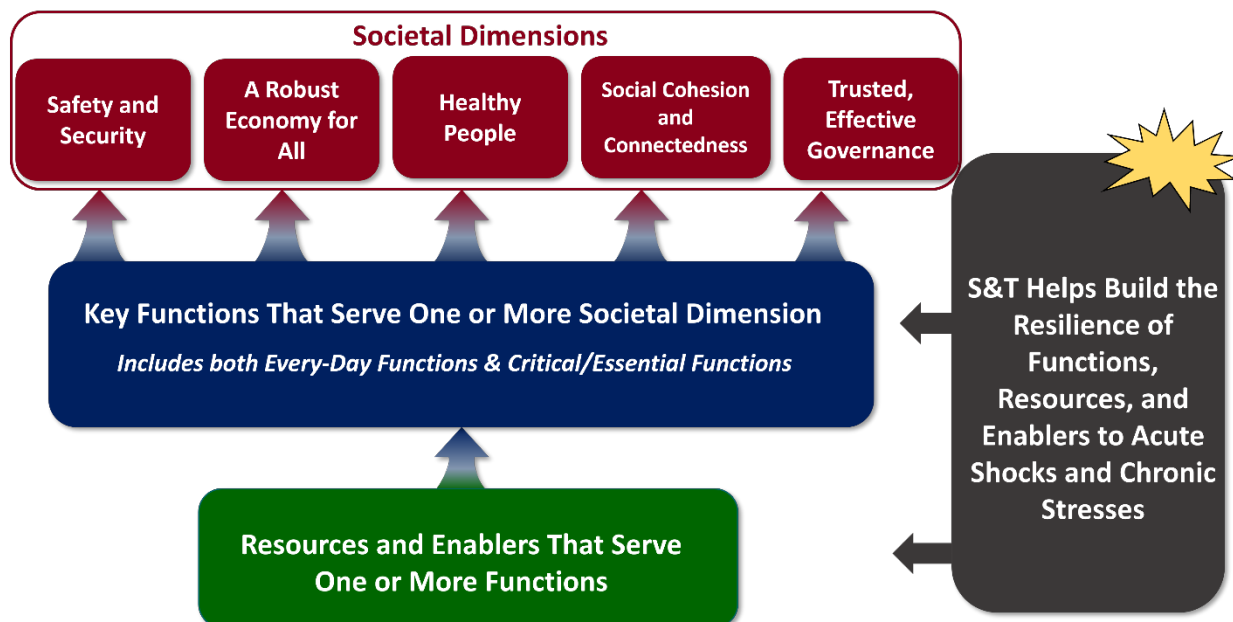


Figure 1. The Grand Pathways Framework displays how cross-cutting enablers (green) support key functions (blue). The continual fulfillment of these key functions serves to maintain important societal dimensions (red) emblematic of a healthy and functioning community. Strategic and intentional use of S&T (dark gray) can help build the resilience of these key functions and cross-cutting enablers to acute shocks and chronic stresses.

Definitions of Key Framework Elements

The Grand Pathways Framework is constructed to be conscious of (and responsive to) the context-dependent nature of **community** and the variety of actors that must work together to build resilient communities. The Grand Pathways Framework also identifies systemic factors that increase vulnerabilities in segments of a community and thereby reduce resilience overall, and seeks to highlight opportunities where science and technology can inform communities and support equity and resilience across societal dimensions.

Different communities have different responsibilities when it comes to building resilience. For example, Federal and Tribal governments may have more responsibility for policy and funding. State/Territory

and local governments typically have greater focus on emergency response exercises and implementation. Individuals and families may take their own steps to plan and prepare. Non-governmental organizations, academia, and private sector organizations often drive science and technology innovation. These roles, however, are fluid; local governments may create policy and both the Federal and Tribal governments, and private sector organizations certainly conduct exercises to evaluate their own resilience. These roles and responsibilities illustrate the requirements for specific actions at and across each level to build more resilient communities.

The intent of the Grand Pathways Framework is to identify and advance resilience science and technology capabilities that are broader than the single-service capabilities. **Resilience science and technology** is the study, research, engaged scholarship, analysis, experimentation, innovation, coproduction of knowledge, and other activities and applications that contribute to society's ability to anticipate, avoid, adapt to, withstand, and build back better from acute shocks and chronic stresses. This means that any ideal solution identified informs multiple societal dimensions and could be used in the context of multiple key functions and cross-cutting enablers.

Societal Dimensions

The Grand Pathways Framework identifies five principal **societal dimensions** of resilience, recognizing there are many more that could be used to characterize resilient communities and to serve as organizing constructs to identify science and technology gaps and opportunities. Over time, the Framework may be expanded based on further research and practice. The societal dimensions presented in this section and used in the case studies are intended to be a flexible, ever-evolving means to frame resilience science and technology discussions.

Safety and Security

- Ability to function and live life without fear of physical, social, emotional, or behavioral threat or hazard from other individuals, organizations, communities, governments, technologies, or the environment. Safety and security are broader than just safety and security from an intentional threat or hazard, and may include physical safety and security, freedom from discrimination, security from systemic disenfranchisement or subjugation, food security, and economic security.

Financial/Economic Resilience (i.e., a robust economy that works for all)

- Availability of and equitable access to financial resources, economic programming, economic development, and means of sustaining livelihood to increase the diversity of economic investments to stimulate growth, distribute the benefits, and address geographically-based shifts or decline

Physically and Mentally Healthy People

- Soundness of the population's bodies and minds. Physical and mental health is achieved through: activities such as medicine, public health, and social services; addressing the chronic conditions that diminish the resilience of a community; and identifying what people need to thrive physically and mentally
- Considering health as it applies at community levels beyond the individual

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Social Cohesion and Connectedness

- Strength of relationships and sense of common identity and solidarity among and responsibility for members of a community whether due to ethnicity, culture, organizational involvement, religion, location, or other source of connection
- Social cohesion encompasses social identity and connectedness, including:
 - Connections beyond individuals—between people and groups
 - Connection to a location, such as the ability and desire to remain or return
 - Value to and receipt of value from a community; something greater than self to focus outside the individual

Trusted, Effective Governance

- Participation and representation, inclusive of varied identities, races, ethnicities, national origins, incomes, abilities, cultures, and beliefs, in strategic planning, communications, and decision making to establish trust and account for unique perspectives and aspirations; governance can be provided by government and by organizations outside the government, including religious and community leadership, via institutions, structures, and processes
- Effective governance requires both:
 - Trust and engagement in governance processes
 - Use of institutions to manage change and address conflicting public priorities and interests

Cross-Cutting Enablers

In each societal dimension, there is a relationship between resilience and **adaptive capacity**—the ability of systems, institutions, organizations, and people to adapt to potential damage or disruption, take advantage of opportunities, or respond to consequences. Adaptive capacity is typically discussed in terms of adaptive development—the activities and actions required to establish and foster adaptation—and adaptive assessment—the activities and actions required to evaluate, learn from, and inform improvements to adaptive capacity. These concepts informed the identification of six **cross-cutting enablers** identified for the Grand Pathways Framework. These are the enabling resources and capabilities that build towards the end states of a resilient community. They are the physical, financial, and other resources that are essential to the function and improvement of communities, and the ability of these cross-cutting enablers to withstand acute shocks and chronic stresses are a focus of resilience investments, including resilience science and technology.

Education

- Process of receiving or giving systematic, practical, apprenticeship, or informal knowledge, instruction, and training, especially at a school, vocational institution, university, or in a virtual environment
- Education should encompass continual learning from early education to adult education, and across types of instruction including academic and vocational education as well as learning from research and innovation

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Employment

- Processes of earning a livelihood; ensuring opportunities for the conduct of work in a range of environments with established responsibilities, financial compensation, and job security; and enabling contributions to family, household, and community maintenance
- Employment includes:
 - Ability to have meaningful work
 - Ability to navigate personal and structural challenges/needs with employment
 - Component of the economic vitality of a community

Infrastructure

- Physical, cyber, natural, supply chain and transit, etc. Assets, systems, and networks, whether physical or virtual, that provide services used day-to-day to support the recurring needs of the community and contribute to security, economic security, public health or safety, or any combination thereof

Risk & Impact Analysis

- Systematic examination of the nature of a threat or hazard, vulnerabilities, probability of occurrence and likely intensity; devising and comparing courses of action; and measuring the potential consequence(s) for the purpose of informing priorities, devising or comparing courses of action, and informing risk-management decision making
- Discussions of risk and impacts should consider:
 - Interdependencies and dependencies of any system
 - Cascading failures
 - Use of scenarios, models, and other tools to support decision making in the face of complex risks and stressors

Financial Resources

- Allocation and application of monetary funds (e.g., budgets, grants, capital gains) and incentives (e.g., investment benefits, tax-reinvestment, discounts) for a particular purpose, activity, purchase, or investment
- Financial resources account for funds both from within and outside of an entity's control

Policy & Doctrine

- Policy – Directive body of rules intended to influence decisions and actions
- Doctrine – Authoritative statement of one or more guiding principles

Relationship with Essential Government Functions

Essential Government Functions align with and complement the societal dimensions and cross-cutting enablers established in the Grand Pathways Framework.

In the Grand Pathways Framework, **key functions** are actions or services that use cross-cutting enablers to support and deliver one or more societal dimensions. For example, community trust in its governance depends on execution of safe, secure elections, which in turn require secure cyberinfrastructure. Healthy populations require the ability of people to access necessary medical providers and services, which in turn requires the availability of educated and trained practitioners and the production and transport of essential medical supplies.

Some key functions have been identified as so vital to the national interest and national security that they have been formally designated and are used to assign and direct responsibility for Federal actions, some in steady-state settings while others are associated with significant incidents (Figure 2 and Appendix A):

- National Essential Functions (NEFs), Mission Essential Functions (MEFs), and Primary Mission Essential Functions (PMEFs) (Appendix 1): NEFs are the critical responsibilities of the Federal Government in sustaining the Nation. MEFs and PMEFs ensure that each Federal department and agency implements key functions required to ensure continued performance of the NEFs.
- National Critical Functions (NCFs): NCFs apply to the private sector and all levels of government and are vital key functions that, if disrupted, weaken national security.
- Emergency Support Functions (ESFs) and Recovery Support Functions (RSFs): ESFs are used to focus Federal response and coordination with non-Federal partners, and RSFs serve similar key functions during recovery.
- Community lifelines: Community lifelines establish a unity of effort between governments at all levels and non-governmental organizations (such as infrastructure owners and operators) to sustain the most fundamental services in the community that, when stabilized, enable all other aspects of society to function.

These function sets are principally used to drive contingency and continuity planning and in incident response, which tends to focus on preparedness, response, and recovery for specified shocks. While presented at the national level, communities benefit from an understanding of these functions. Other function sets like lifelines are familiar and relevant to local communities, particularly those frequently affected by natural disasters, and can be used beyond a specific incident to provide indicators of service delivery outside of an incident (e.g., power and water lifelines).

The Grand Pathways Framework is meant to allow users to identify key functions that are relevant to whatever dimensions of resilience they are concerned with, and use them to document the key building blocks (cross-cutting enablers) and any intermediate steps or resources that help them deliver value to the community (societal outcomes) in both steady-state (day-to-day) and in disruptive incidents. Breaking down outcomes using key functions and cross-cutting enablers allows users to discover common elements (e.g., one enabler that is vital to multiple key functions or outcomes) and key interdependencies. Such elements can emerge as priorities for study (i.e., new science), risk or vulnerability assessment, risk reduction (i.e., hazard mitigation or other resilience investments), or community engagement.

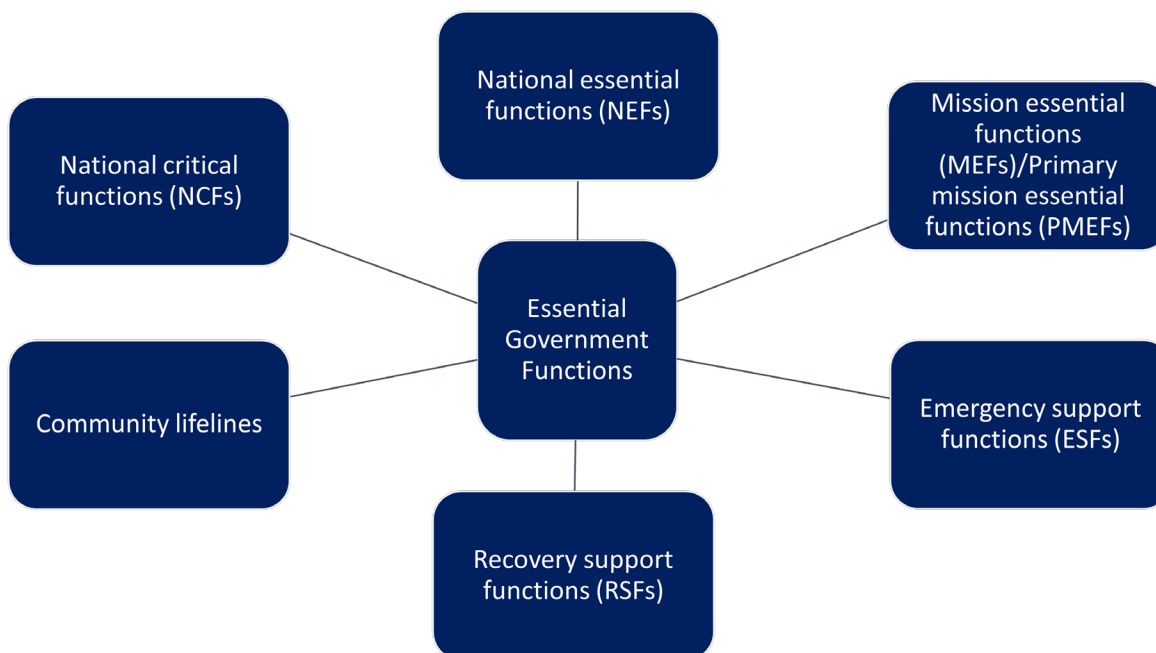


Figure 2. Essential Government Functions align with and complement the societal dimensions and cross-cutting enablers established in the Grand Pathways Framework.

How to Use the Resilience Grand Pathways Framework

The Grand Pathways Framework is designed to point the way to science and technology innovation supporting multiple **societal dimensions**, **key functions**, and **cross-cutting enablers**. For example, when considering the impacts of natural hazards and a changing climate on the safety and security of communities and the economy, the framework can help users map out the key functions and cross-cutting enablers that are necessary to support those societal dimensions. Users can then explore the vulnerabilities of those key functions and cross-cutting enablers to various threats and hazards, including natural hazards.

Such exploration helps users discover elements common across societal dimensions. For example, users could identify a surface transportation network that is critical to both the community’s economy in steady state and to safety in the event of a disaster (Figure 3). At the same time, they might identify a coastal park that creates ecotourism opportunities in steady state and that provides a buffer against storm surge during hurricanes. Framework users could then look for interdependencies across elements, such as a surface road and adjacent subsurface utility corridor that rely on the coastal park’s wetlands for protection against storm surge and scouring wave action.

With a fuller understanding of commonalities and interdependencies, framework users can then start to identify gaps where new science and technology investments would be most beneficial in building the property of resilience. In spanning multiple societal dimensions and/or cross-cutting enablers, the Grand Pathways Framework has the potential to make a large impact in strengthening a community’s resilience along multiple frontiers. Figure 3 overlays this example on the Grand Pathways Framework structure to show how a science and technology solution could investigate two cross-cutting enablers and one key function, in support of three societal dimensions. The next section explores other uses cases.

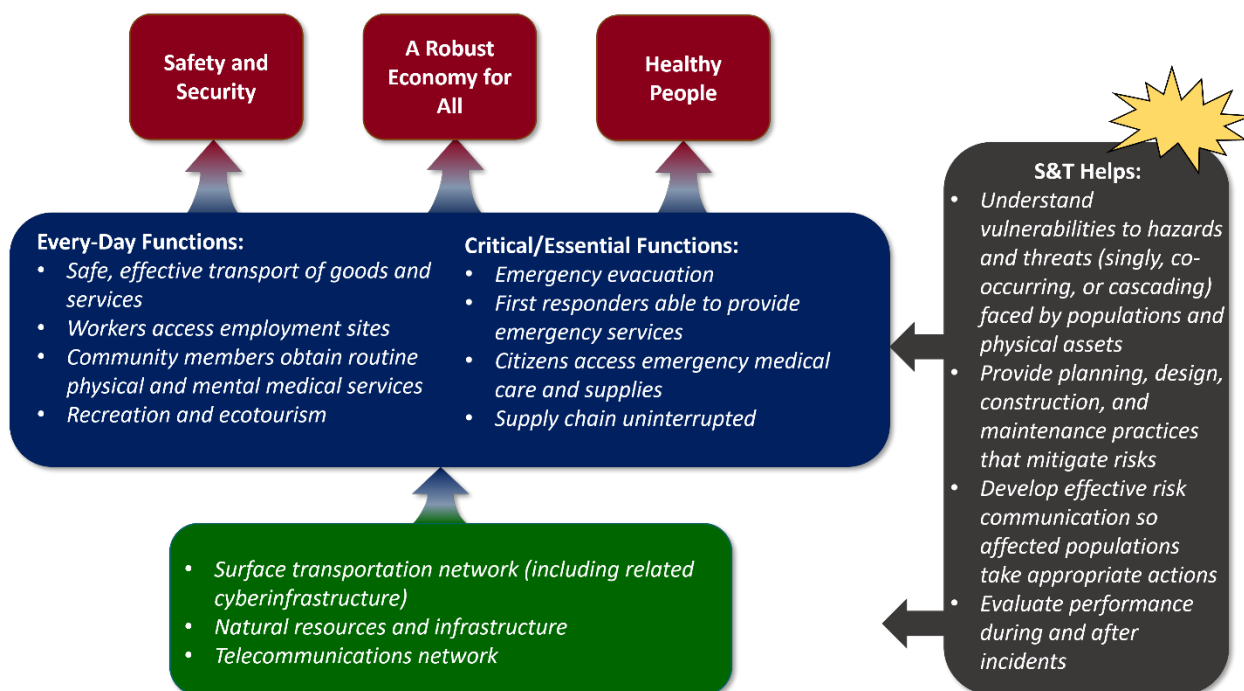


Figure 3. Sample Application of the Grand Pathways Framework

Audience & Value of Framework

The Grand Pathways Framework helps planners, policy makers, community leaders, innovators, and others identify opportunities for new resilience science and technology that build community resilience.

Resilience science and technology capabilities may be most effective when they are implemented at the intersection of societal dimensions and cross-cutting enablers. Science and technology capabilities that address multiple cross-cutting enablers and improve multiple societal dimensions help a community anticipate, avoid, adapt to, withstand, and build back better following disruption and destruction. Perhaps even more importantly, these science and technology capabilities enable both the societal dimensions and the cross-cutting enablers to function more effectively on an everyday basis (in the absence of disruption).

Science and technology can be an enabler itself, either as a direct means of advancing societal dimensions or as a contributor to other cross-cutting enablers.

Resilience is an ever-evolving challenge, as novel and unpredictable stressors continue to emerge, and historical and environmental factors influence the path to resilience. Resilience can be improved by investments in science and technology. The Grand Pathways Framework looks to support decisionmakers in achieving the goal of resilience by helping them design and implement multipurpose

science and technology solutions that strengthen a community’s ability to withstand a wide variety of acute shocks and chronic stressors.

Implementation of the Framework would:

- Encourage end users to think multidimensionally about solutions to science and technology gaps such that solutions could address more than one community need;
- Expand community and developer reference paradigms such that they might see additional applications for existing science and technology solutions or see how existing solutions might be modified to meet science and technology gaps; and
- Identify science and technology gaps that might be served by a single solution, even where the linkages may not be readily apparent.

The Grand Pathways Framework was constructed to be relevant and helpful to a variety of end-users, specifically those who interact with resilience science and technology. The implementation of the Grand Pathways Framework may vary by actor. For example:

- A public health official might use this framework to consider how particular interventions might be able to make a community more safe and secure and contribute to their social cohesion.
- A Federal employee may use this framework to consider which science and technology projects to fund based upon the breadth of their applications along several social dimensions and cross-cutting enablers and to determine if a single solution could address multiple science and technology gaps.
- A technology developer engaging with a city official may use this framework to demonstrate how architectural decisions or technical enhancements could improve a community's infrastructure while increasing financial resilience to hazards and safety and security from climate change.
- The superintendent of a school system might use this framework to invest limited capital dollars in a technical solution that would have the most impact to students' physical and mental well-being.
- An individual seeking to serve an underserved community might use this framework to propose science and technology solutions that contribute not only to education and employment, but also to a community's financial and economic resilience.

While the above examples represent some theoretical ways for different actors to implement the Grand Pathways Framework, the following use cases detail how the Framework could be applied in specific scenarios. The use cases highlight the need of many actors to collaborate to identify potential science and technology solutions.

Use Case 1: Identifying Gaps in Infrastructure as a Result of SARS CoV 2 (COVID-19)

Education is a major driver of **social cohesion**. During their time in school, children learn critical social skills and integrate within one or more communities—their classmates, their teammates, and others. **Education** is also a major source of **employment** (teachers, administrators, maintenance staff, etc.) and enables the **economy** as educational institutions allow parents to work during the day while their kids attend school.

When the **COVID-19 pandemic** struck in 2020 and schools shut down, the education sector was significantly impacted, which exposed major gaps and challenges.

- In terms of **safety and security**, in the absence of a traditional school day, many students lost their **food security**, as two of their three daily meals were provided at school.
- Students lost access to the counselors, teachers, and other staff who looked out for their **physical and mental health**; students who are victims of violence or abuse lost much of their opportunity to be identified and helped.¹⁴ The transition to virtual learning highlighted social inequalities, where students without reliable internet access, a quiet space to work, a caregiver to help with technology or assignments, or a personal computer were unable to participate meaningfully in a virtual educational format.
- There is also the **economic impact** of parents who need to stay home or find child care as their children learn remotely.¹⁵
- Ultimately, all of these concerns and more have led to a **governance** issue. Decision makers and policy makers must navigate the trade space between the **safety, security, and health** of teachers and school staff and the **economic, educational, and social ramifications** of school closures.
- New and increased demands on IT and **cyberinfrastructure and security emerged**, as the majority of students engaged in online learning.¹⁶
- This shift to remote learning also resulted in a **loss of training/workforce preparation**. This will have impacts on current or future employment of students, and impacts on employers who are operating to hire staff.

Therein lie the opportunities to identify resilience science and technology capabilities and innovations. For example, in **understanding the educational, mental, and behavioral effects** of prolonged remote learning, it is possible to develop innovative learning plans that are adaptive to social, economic, and cultural contexts while integrating the latest advancements in remote and in-person learning technologies and research. An additional example could be solutions that **improve HVAC systems and airflow** in school buildings so they can be reoccupied more safely. Another major gap that could be addressed by resilience science and technology is in **broadband access and other innovations that expand internet and computer access** to all students.

¹⁴ Hawrilenko M, Kroshus E, Tandon P, Christakis D. 2021. “The Association Between School Closures and Child Mental Health During COVID-19.” *JAMA Netw Open*. 2021;4(9):e2124092. doi:10.1001/jamanetworkopen.2021.24092 This article is available on the National Library of Medicine PubMed website at <https://pubmed.ncbi.nlm.nih.gov/34477850/>

¹⁵ Jackson, J.K., 2022. “Global Economic Effects of COVID-19: Overview,” updated February 14, 2022, Congressional Research Service Report, <https://crsreports.congress.gov/product/pdf/R/R46270>.

¹⁶ Government Accountability Office, 2022. “Critical Infrastructure Protection: Additional Federal Coordination Is Needed to Enhance K-12 Cybersecurity.” GAO Report GAO-23-105480 <https://www.gao.gov/assets/gao-23-105480.pdf>

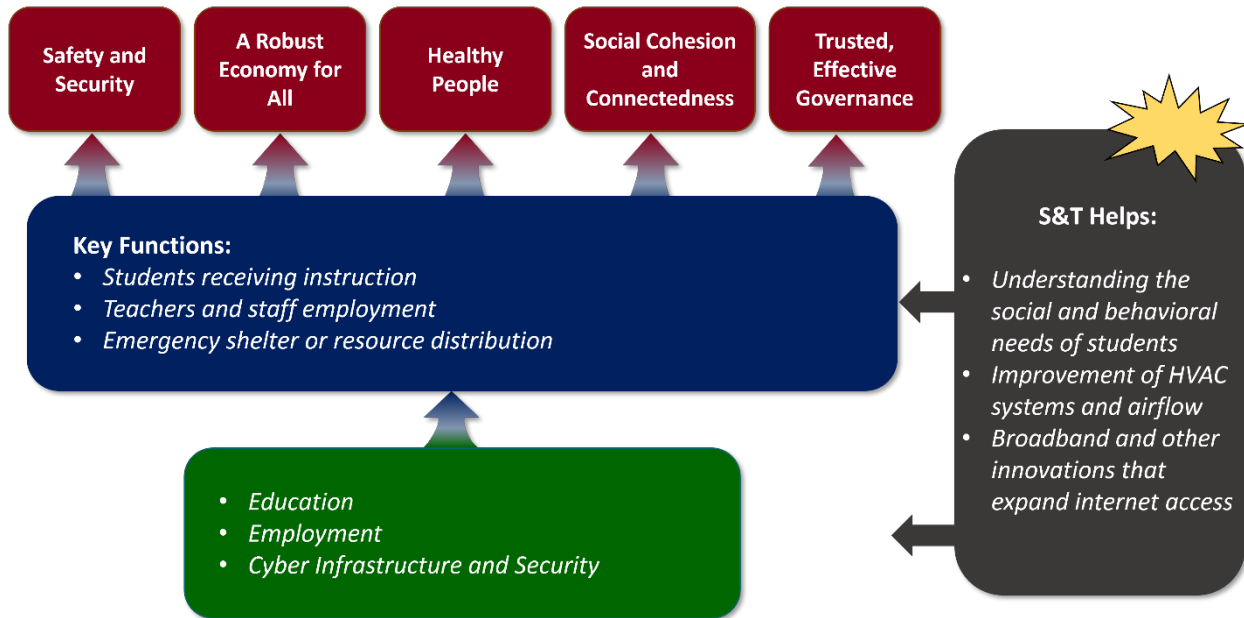


Figure 4. Identifying Gaps in Infrastructure as a Result of SARS CoV 2 (COVID-19)

Use Case 2: Texas Winter Storm and Power Crisis – Cascading Failures

In February 2021, the State of Texas suffered a **major power crisis** that came as the result of **severe winter storms** and resulted in shortages of housing, water, food, and heat.¹⁷ It is estimated that more than 4.5 million homes and businesses were left without consistent power, many for multiple days. Studies have shown that minority populations were more likely to experience blackout than White populations.¹⁸ The storm and subsequent power failures led to rolling blackouts and surging energy prices as the demand for energy far exceeded the available supply.

- In terms of **safety and security**, millions of people were left without power in the midst of a powerful winter storm. A major **cascading impact** from the rolling blackouts was houses and buildings becoming very cold, leading to pipes freezing and subsequently bursting.¹⁹
- These challenges had major adverse effects on **physical and mental health**, including hypothermia and carbon monoxide poisoning from the improper use of heaters, grills, and cars.
- Another consequence of the power loss was **supply chain breakdowns** specifically regarding grocery stores and their ability to restock and properly refrigerate products. Shelves were cleared, which led to panic and shortages.
- These cascading failures exposed **governance and communication** issues. There was a lack of public preparation, education, and warning in the days before the storm, and communication during the storm was hamstrung by the lack of power. This led to widespread confusion about

¹⁷ National Weather Service, 2021. “Valentine's Week Winter Outbreak 2021: Snow, Ice, & Record Cold,” <https://www.weather.gov/hgx/2021ValentineStorm>

¹⁸ Lee, CC., Maron, M. & Mostafavi, A. Community-scale big data reveals disparate impacts of the Texas winter storm of 2021 and its managed power outage. *Humanit Soc Sci Commun* 9, 335 (2022). <https://doi.org/10.1057/s41599-022-01353-8>

¹⁹ National Weather Service, 2021. “Valentine's Week Winter Outbreak 2021: Snow, Ice, & Record Cold,” <https://www.weather.gov/hgx/2021ValentineStorm>

the rolling power outages as well as major safety concerns such as the use of cars inside of garages for heat.

- The winter storm put a major strain on **infrastructure**, including the power grid, water systems, and gas pipelines. When power was cut, it disabled some compressors that push gas through pipelines, knocking out additional gas plants due to lack of supply. Pipe bursts led to extensive and expensive damage.
- **Risk and impact analyses** failed to identify and/or mitigate power grid vulnerabilities and the subsequent cascading failures. Also, local and statewide responses seemingly underestimated the lack of experience and awareness many Texans had regarding extreme cold weather and proper personal safety measures.
- Ultimately, all of these challenges exposed gaps in **policy/doctrine**, perhaps the most obvious of which pertains to the regulation of the power grid and winterization of infrastructure.²⁰

Opportunities exist to identify science and technology capabilities and innovations to avoid similar cascading events. For example, the **winterization of power infrastructure** could prevent widespread power outages due to extreme weather conditions. Similarly, there might be opportunities to build **redundancies and interoperable capabilities into the power infrastructure** to mitigate against cascading failures. Another major gap that could be addressed by resilience science and technology capabilities is in **communication methods** to access and educate communities to better prepare for and withstand extreme weather events and winter weather.

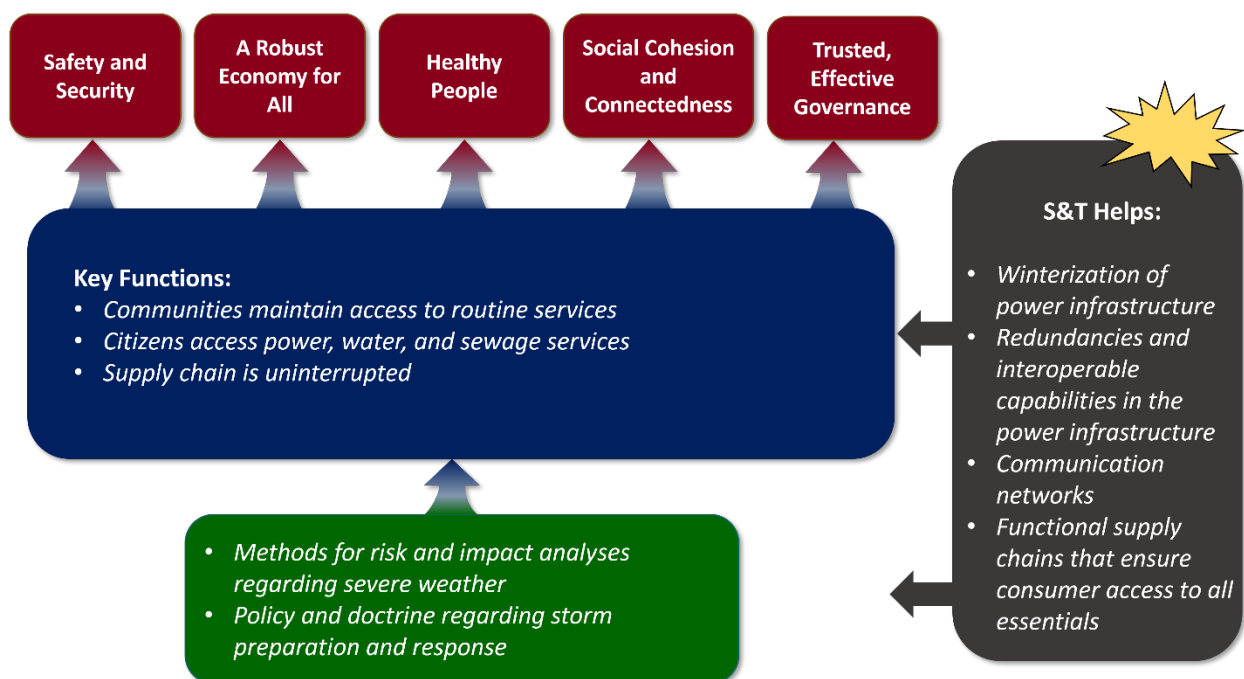


Figure 5. Texas Winter Storm and Power Crisis – Cascading Failures

²⁰ Federal Energy Regulatory Commission, 2021. “FERC, NERC, and Regional Entity Report: The February 2021 Cold Weather Outages in Texas and the South Central United States” <https://ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and>

Future Efforts

The Grand Pathways Framework provides an approach for identifying gaps, aligning capabilities and work streams, and prioritizing resilience science and technology capabilities to meet these needs and improve community resilience. This Framework can form the basis for stakeholder discussions across different communities in considering both the gaps in societal dimensions and cross-cutting enablers, and the role of science and technology in building resilience. By connecting the various aspects of resilience in a single combined framework, end users can seek solutions that address multiple concerns at once to more efficiently use limited resources. Moreover, SRST hopes that end users will be able to identify new opportunities to work more holistically to anticipate, avoid, adapt to, withstand, and build back better from acute shocks and chronic stresses with the potential to cause disruption or destruction.

To determine if the Grand Pathways Framework met SRST goals, it was piloted to a select group of interagency partners from April to June 2022. The pilot effort focused on obtaining feedback on the usefulness of core Framework principles and to identify areas for future improvements and efforts. Each piloting agency approached the implementation of the Grand Pathways Framework differently. For example, agencies found that the Grand Pathways Framework could be applied to individual program results and after-action reviews, as well as to larger, long-term research and development efforts. Pilot agencies noted the importance of establishing and promulgating a common resilience lexicon to ensure that collaborators at all community levels have the same understanding of critical terms. In addition, the outcome-based approach of the Grand Pathways Framework can focus technology developers on a range of potential solutions.

Following the publication of the Grand Pathways Framework, SRST will explore the development of supporting materials. While the Framework is meant to be flexible guidance, rather than a strict set of implementation rules, SRST notes that additional implementation guidance might be useful to facilitate community adoption. In addition, further uses cases could help explore the application of the Grand Pathways Framework to a large range of events to emphasize the distinction between commonly used concepts and terms (e.g., the difference between key functions and outcomes). Along with considering how best to develop supporting implementation guidance, SRST will continue to work with users to collect feedback on the usefulness of the Grand Pathways Framework, help catalog potential use cases to which the Grand Pathways Framework has been applied, and seek to understand the benefit of these Grand Pathways Framework. These stakeholder inputs will inform the development of and the next steps to achieve Resilience Science and Technology Grand Pathways and to develop a Resilience Science and Technology Research and Development plan.

If you are interested in piloting the Grand Pathways Framework or would like additional information on the Framework, please contact SRST at SRSTExecSec@ida.org.

Appendix 1: Grand Pathways Framework and the Application to Essential Government Functions

The Federal Government has prescribed a series of “Essential Government Functions” (EGFs), the complete set of functions of the Federal Government to lead and sustain the Nation. These functions include:

- National essential functions (NEF)²¹
- Mission essential functions (MEF)/Primary mission essential functions (PMEF)²²
- Emergency support functions (ESF)²³
- Recovery support functions (RSF)²⁴
- Community lifelines²⁵
- National critical functions (NCFs)²⁶

Verifying that the resilience science and technology capabilities identified within the Grand Pathways Framework align to the EGFs is an important part of ensuring that communities all the way from the individual up to the Federal Government can benefit from the proposed Framework. While the EGFs apply primarily to the Federal Government, the Grand Pathways Framework incorporates the intent and purpose of these functions on a broader scale. Instead of building another layer of complication on top of the Grand Pathways Framework, the EGFs can be understood to fold into the Framework.

Therefore, it is important to understand how the EGFs align with and complement the societal dimensions and cross-cutting enablers established in the Grand Pathways Framework. These will be addressed more fully in future documentation; however, examples are provided here to demonstrate these alignments. For example, just as the cross-cutting enablers underpin the societal dimensions (i.e., delivering the desired outcome of a resilience community), the NCFs, ESFs, and RSFs enable the NEFs, MEFs, PMEFS, and Lifelines (i.e., the continued delivery of essential functions and lifelines).

The NEFs align to the societal dimensions, describing the functions that need to be maintained/restored so that the United States and all of its communities can anticipate or otherwise prepare for and then withstand and evolve from disruption. Ultimately, the NEFs align to the societal dimensions as both are the ultimate goal for the United States and its communities to build resilience as shown in the table below. While there may be additional relationships beyond those shown in the

²¹ DHS/FEMA. Federal Continuity Directive 1: Federal Executive Branch National Continuity Program and Requirements (Washington, DC: FEMA, January 2017), p. 3, quoting Obama, PPD-40. Accessed March 20, 2023. <https://www.gpo.gov/docs/default-source/accessibility-privacy-coop-files/January2017FCD1-2.pdf>

²² DHS/FEMA, Federal Continuity Directive 2, Federal Executive Branch Mission Essential Functions and Candidate Primary Mission Essential Functions Identification and Submission Process (Washington, DC: DHS/FEMA, June 2017), Annex I-1, quoting PPD-40, p. 2. Accessed March 20, 2023. https://www.fema.gov/sites/default/files/2020-07/Federal_Continuity_Directive-2_June132017.pdf

²³ DHS. *National Response Framework*, Fourth Edition (Washington, DC: DHS, 2019), p. 33. https://www.fema.gov/sites/default/files/2020-04/NRF_FINALApproved_2011028.pdf

²⁴ DHS. *National Disaster Recovery Framework*, Second Edition (Washington, DC: DHS, June 2016), p. 36. Accessed March 20, 2023. https://www.fema.gov/sites/default/files/2020-06/national_disaster_recovery_framework_2nd.pdf

²⁵ DHS/FEMA. “Community Lifelines.” Accessed March 20, 2023. <https://www.fema.gov/emergency-managers/practitioners/lifelines>

²⁶ DHS/CISA. “National Critical Functions.” Accessed March 20, 2023. <https://www.cisa.gov/national-critical-functions>

table, these illustrated relationships show strong correlation between the societal dimensions and the NEFs.

Alignment of Societal Dimensions and National Essential Functions (NEF)

	Safety and Security	Financial/Economic Resilience	Physical and Mental Health	Social Cohesion	Effective Governance
National Essential Functions ²⁷					
NEF 1: Ensuring the continued functioning of our form of government under the United States Constitution, including the functioning of the three separate branches of government.					X
NEF 2: Providing leadership visible to the Nation and the world and maintaining the trust and confidence of the American people.					X
NEF 3: Defending the United States against all enemies, foreign and domestic, and preventing or interdicting attacks against the United States or its people, property, or interest.	X				
NEF 4: Maintaining and fostering effective relationships with foreign nations.				X	
NEF 5: Protecting against threats to the homeland and bringing to justice perpetrators of crimes or attacks against the United States or its people, property, or interests.	X				
NEF 6: Providing rapid and effective response to and recovery from the domestic consequences of an attack or other incident.	X				X
NEF 7: Protecting and stabilizing the Nation’s economy and ensuring public confidence in its financial systems.		X			
NEF 8: Providing for Federal Government services that address the national health, safety, and welfare needs of the United States			X		

²⁷ National Essential Functions (NEFs) from DHS/FEMA, *Federal Continuity Directive 2, Federal Executive Branch Mission Essential Functions and Candidate Primary Mission Essential Functions Identification and Submission Process* (Washington, DC: DHS/FEMA, June 13, 2017), accessed December 4, 2020, https://www.fema.gov/sites/default/files/2020-07/Federal_Continuity_Directive-2_June132017.pdf

As the MEFs and PMEFs ensure that each Federal department and agency implements functions required to ensure continued performance of the NEFs, most (if not all) are similarly relatable to the societal dimensions. Just as a resilience community is one that maintains and builds its societal dimensions, a resilient agency is one that maintains its MEFs and PMEFs.

Some MEFs and PMEFs could be seen as aligning with cross-cutting enablers, as they also are fundamentally cross-cutting enablers of the NEFs. Additionally, for some departments and agencies, the MEFs and PMEFs align to cross-cutting enablers due to the purpose of the agency. For example, the Department of Education and the Department of Labor have missions that build towards education and employment, which are both cross-cutting enablers.

The ESFs, RSFs, and NCFs are the cross-cutting enablers—the building blocks that allow the maintenance of the NEFs/societal dimensions, or outcomes of resilience. The ESFs, RSFs, and NCFs are the capabilities provided by the States/locals/private companies that ensure the MEFs, PMEFs, and NEFs can be accomplished.