Future-Proofed: Protecting Infrastructure in Uncertain Times

How strategic investment can build infrastructure resilience and maintain physical, social, and economic viability

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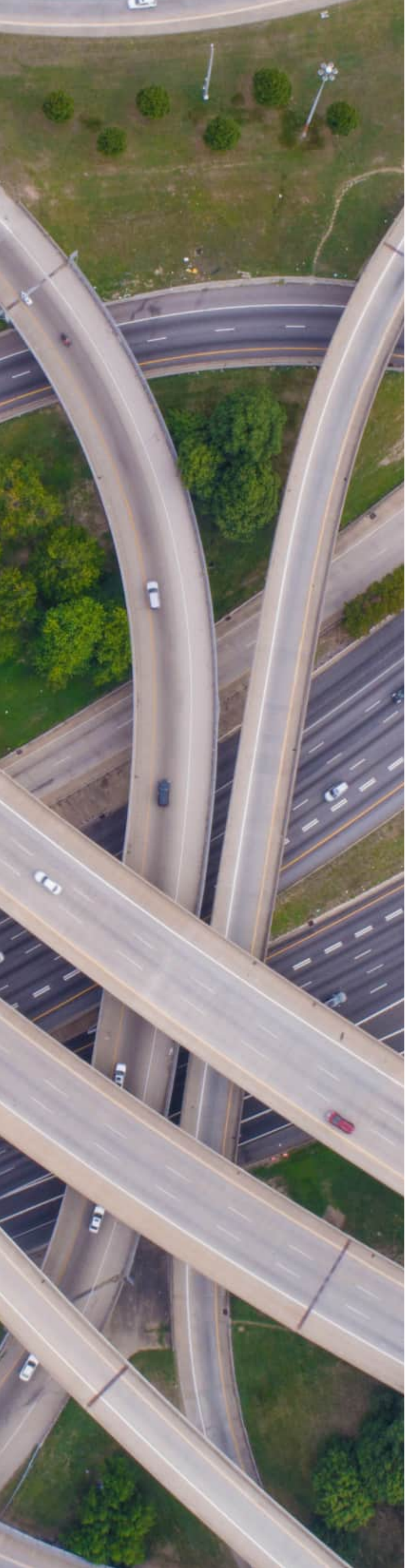
We live in a time of immense change and swirling threats. A worldwide pandemic coupled with surging climate-related disasters and an accelerating digital transformation has concentrated minds. Resilience is no longer a niche topic for business continuity specialists but at the top of leaders' action lists: and the time to act is now.

In this report, we explore the key infrastructure resilience challenges that organizations face, the need to rethink old models in favor of a more holistic, evolutionary approach, and how best to create a strategy that integrates resilience at every operational level.



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1.0 A New Perspective on Resilience Strategy

In the future, 100-year floods may happen every year, according to research from climate scientists at Princeton and the Massachusetts Institute of Technology.[1] As absurd as that sounds, it underscores both recent changes in weather activity and our inability to contextualize them in an experiential lexicon.

Why does this matter for business? Because just as planners often rely on historical trends to try to describe future events, organizations tend to rely on outdated ideas of what resilience should look like. These days, there's a lot happening, very rapidly, and the ways we used to talk about resilience are quickly becoming insufficient.

Think of the convergence of trends businesses and organizations must face now. Climate change, a worldwide pandemic, a major European war, digital transformation, the energy transition, a globalized economy, rapidly evolving markets, increasing and more sophisticated cyber attacks—some of these present opportunities, but each also increases the potential vulnerabilities any organization confronts. Added together, they drastically increase the possible threat vectors.

Infrastructure resilience now has to encompass a strategy that can account for the increasing variety of potential shocks. Weathering these disruptions successfully will lead to more equitable access to goods and services, continuous operability, greater durability of service and supply chains, and a higher degree of adaptability in response to unpredictable changes. More robust resilience strategy can also aid rapid emergency response capabilities.

Resilience is often conceptualized as the ability to build back after disasters. But the traditional model where damaged infrastructure is rebuilt on the same pattern that failed before no longer holds. It's vital to build for the future, not the past, and treat damage as an opportunity not simply to repair but to rethink and to rework—essentially, in the too familiar phrase, to build back better.

Leaders increasingly recognize this. In 2012, Super Storm Sandy triggered a storm surge which caused around $6 billion of damage to New York City (NYC) and New Jersey rail infrastructure.[2] Since then, agencies have worked not only on repairs but on a sustained program of resilience, from sealing tunnels through to elevating equipment and adding flood control covers to stations. After Hurricane Maria

1. Reza Marsooli et al, "Climate change exacerbates hurricane flood hazards along US Atlantic and Gulf Coasts in spatially varying patterns," *Nature Communications* 10 (2019).
2. Ramiro Alberto Ríos et al, "Resilience in urban transport: what have we learned from Super Storm Sandy and the New York City Subway?" World Bank, https://blogs.worldbank.org/transport/resilience-urban-transport-what-have-we-learned-super-storm-sandy-and-new-york-city-subway.

devastated Puerto Rico in 2017, causing the worst blackout in US history,[3] the territory has had to redesign its antiquated grid, adding flexibility and redundancy.

Yet resilience spans more than recovery from disasters and building back better also requires ensuring that infrastructure is just and equitable. Equal access to infrastructure, be that fast internet or clean drinking water, is vital for social progress and national resiliency. Further, infrastructure projects can create huge economic opportunities which, when precisely targeted, can help mitigate historic injustices. Notoriously, however, Black, low-income Americans are disproportionately likely to die from particulate emissions from fossil fuel power plants, which are typically sited in lower income neighborhoods.[4] Environmental justice is no longer a fringe concern but a central issue for both public and private sectors—and one that's increasingly litigated in court.

While climate destabilization is perhaps the most obvious issue planners must confront, other longer-term trends emphasize the need to work now to anticipate the future. On current patterns, the world faces a $15 trillion infrastructure spending gap by 2040,[5] which will increase the likelihood of failure in legacy systems. The convergence of physical and virtual systems as seen most obviously in smart cities presents both opportunities and risks, while accelerating technological change will mean obsolescence hits harder and faster.

Rather than simply reacting to failures, organizations need to take a precautionary view, anticipating and planning for evolutionary change. That means migrating to new models of physical infrastructure and developing new strategies for maximizing it. These models should factor in multiple serious disruptions and incorporate effective response planning through improved materials, value chain flexibility, asset agility, intelligent automation, and cyber security self-healing, among other strategies.

Cyber Resilience: an Ever-Evolving Challenge

The Colonial Pipeline ransomware attack in 2021 disrupted nearly half the fuel supply for the US East Coast, causing panic buying and price volatility, and highlighting infrastructure's vulnerability to cyber threats. Increasing digitalization means infrastructure from banks and hospitals to air traffic control and water treatment plants is at risk from a diverse array of hostile actors, as well as from obsolescence, systems failures, and human error. Perhaps especially for organizations that do not consider themselves digitally focused, cybersecurity is a critical piece of the resilience picture and the landscape is evolving fast.

1.1 Case Study: Joplin, Missouri Rebuilds and Renews after Deadly Tornado

Entity: The City of Joplin, Missouri, a former mining town and busy commercial center of the four-state area with a population of around 55,000.

Background: In 2011, America's most deadly tornado since official records began ripped through Joplin, killing 161 people, injuring more than 1,000, and causing losses approaching $3 billion. Flash flooding and winds that were estimated to reach over 200 mph affected 553 business structures and more than 7,000 residential buildings, heavily damaging or destroying more than

3. Doug Criss, "Puerto Rico's power outage is now the second-largest blackout on record," CNN, https://edition.cnn.com/2018/04/16/us/puerto-rico-blackout-second-largest-globally-trnd/index.html.
4. P.S. Marinder et al., "Fine Particulate Air Pollution from Electricity Generation in the US: Health Impacts by Race, Income, and Geography," *Environmental Science & Technology*, 53, 23 (2019): 14010-14019.
5. Anita George, Rashad-Rudolf Kaldany, and Joseph Losavio, "The world is facing a $15 trillion infrastructure gap by 2040. Here's how to bridge it," World Economic Forum, https://www.weforum.org/agenda/2019/04/infrastructure-gap-heres-how-to-solve-it/.

3,000 homes.[6] The disaster left many residents grappling with post-traumatic stress disorder, the city's downtown devastated, and around 40% of yards contaminated with lead, a toxic legacy of Joplin's mining past.[7]

Challenges: Following the catastrophic events, Joplin remained at risk of tornadoes and focused on a goal to build back better. It received Community Development Block Grant—Disaster Resilience funding totaling $158 million[8] from the Department of Housing and Urban Development. Yet with multiple stakeholders; dramatic levels of damage, deprivation, and trauma; and specific fund distribution requirements to meet, the task ahead seemed daunting.

The disaster showcased weaknesses in the city's resilience, from communication systems to utilities, housing stock to healthcare systems. As often occurs during natural disasters, feedback loops between linked systems caused cascading failures. Building back better meant building back differently, so the City of Joplin worked with the Guidehouse team to address key questions including:

- How to repopulate and reinvigorate devastated downtown areas.
- How to rebuild damaged infrastructure to help mitigate future natural disasters.
- How to improve communications resilience for future disasters.

Solutions:

Reversing Population Flows with More Sustainable Housing

To obtain funding for rebuilding Joplin, it was vital to understand what had been lost. But even assessing the scale of the damage for valuation purposes proved an enormous task, with no digital records in existence and many paper records destroyed by the tornado. Quantifying details such as the square footage of sidewalk shattered or the number of streetlights uprooted became a matter of generating reverse archaeology with partners ranging from utilities to small contractors. Stakeholders worked together to reconstruct a record of what had been lost.

However, urban resilience extends beyond architecture to communities. In the aftermath of the disaster, many residents abandoned Joplin's devastated downtown. Extensive community engagement helped build a shared goal of long-term social and economic recovery coupled with revitalization of infrastructure and public facilities. To revivify Joplin's heart, the city launched the Joplin Homebuyer Assistance Program, which provided down payment assistance to low-income families to encourage them to move into areas where housing stock had been damaged. The team worked with the banking industry and builders to create access to financing and to develop affordable housing stock, thereby expanding homeownership to communities that had not previously benefited from it.

New homes naturally featured resilient design. They were also, importantly, more sustainable—a strategy that further increases resilience by reducing energy use, environmental harms, and associated climate change impacts. The team coordinated with the Historic Joplin Preservation Commission to protect heritage neighborhoods and historic areas; an extensive urban forestry scheme followed a seasonal plan, as did construction, to avoid impacting

6. "Joplin Missouri Tornado 2011." National Institute of Standards and Technology website. https://www.nist.gov/disaster-failure-studies/joplin-tornado-ncst-investigation.
7. Bienkowski, Brian. "Extreme Weather Stirs Up Forgotten Lead from Old Smelters," *Scientific American*, May 21, 2014.
8. Woodin, Debby. "CDBG Projects Could Cost $97 Million." *Joplin Globe*. June 11, 2015.

endangered species. Homes were sited away from floodplains, while lead testing, coupled with cleanup, prevented rebuilding in hazardous areas. Policies encouraged the use of energy-efficient materials and construction methods, with energy-efficient appliances as standard.

In addition, Joplin rebuilt existing infrastructure, created three streetscape projects that enabled more pedestrian-friendly environments, and recreated some of its downtown shopping areas. A redesign of the city's sewerage and stormwater systems—which had been overwhelmed by tornado debris—increased capacity while routing water away from floodplains. Concrete piping built to withstand not only 100-year floods but also 200-year floods replaced antiquated lead sewer systems.

From Disaster Communications to Smart Cities

In the aftermath of the tornado, communications failed, with phone lines jammed and even emergency services reduced to old-fashioned two-way radios. Joplin identified internet access as a key tool not only to provide the unambiguous warning of impending disaster that was obviously lacking in 2011, but also to help with communications in the aftermath of tornadoes, flooding, or other disasters.

But by amplifying social and public services, building community, and enhancing agility, digital inclusion helps build resilience on a deeper level than disaster response alone. Understanding that the city is exposed to the megatrends of increasing urbanization and the fourth industrial revolution, Joplin and Guidehouse are looking past mere internet connectivity to a smart city model. Joplin plans to extend beyond its traditional industries of mining and manufacturing to attract remote workers, entrepreneurs, and the technology industry.

Priorities for the first five years include expanding internet access, making city operations more efficient, creating an innovation district, building the city's brand, and designing smart education and training programs to help citizens navigate the digital era.

In addition to powering economic and social resilience, smart cities also have their role to play in disaster resilience. Smart water gauges that can anticipate and warn against flooding are on Joplin's radar as the city gears up to navigate the myriad challenges of the 21st century: climate change, economic crises, demographic shifts, pandemics, and more.

> "The way everyone came together was exceptional. We were all working to build back better, to build back a stronger, more resilient community."
>
> Dami Kehinde,
> Associate Director, Guidehouse

How Joplin Overcame Disaster to Rebuild and Renew

From the immediate stage of disaster recovery through to the longer-term process of preparing the city to withstand looming mid-century challenges, Joplin displayed many of the characteristics that help entities build resilient systems:

Teamwork: In the aftermath of the disaster, it was striking how strongly residents pulled together to work on reconstruction. Stakeholders, likewise, put aside short-term differences of objectives and worked together on a common goal, engaging deeply with the community.

Innovation: Rather than rebuild the city on its old footprint, Joplin seized the opportunity to build more sustainably and futureproof the community, creating a bold vision of renewal that transcends resilience alone.

Resourcefulness: Joplin's journey back from the 2011 disaster has been a long and winding one. Throughout, the city has drawn on both internal resources and external expertise to chart its own course.

1.2 A System of Systems Problem

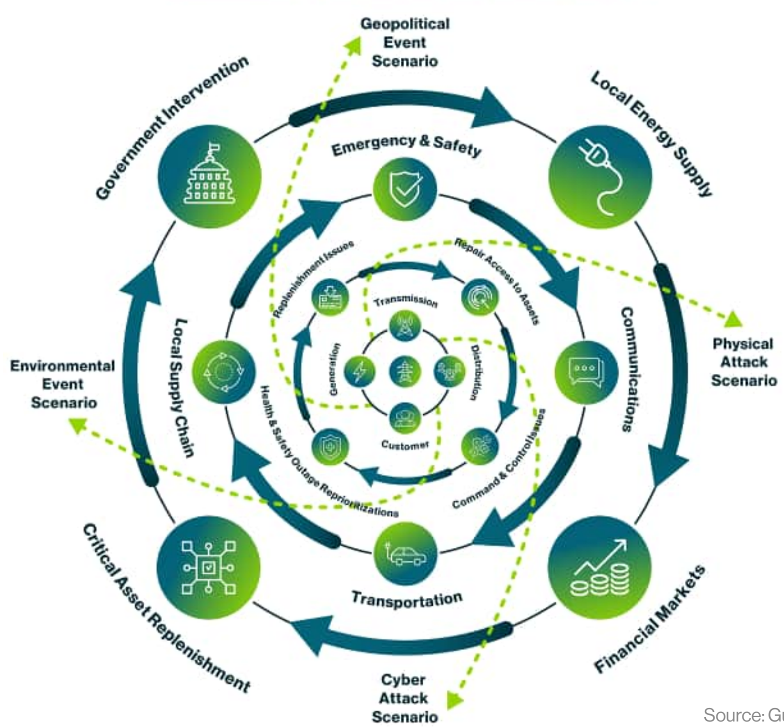
Infrastructure resilience is a critical issue. Cascading failures are characteristic of highly integrated infrastructure, which has historically been structured as interdependent networks. In 2003, for example, a high-voltage power line in Northern Ohio shut down after brushing some overgrown trees, an alarm system failed to alert operators, then three more lines sagged into foliage, causing system after system to collapse under the pressure of excess load. In the end, 50 million people in southeastern Canada and eight northeastern states were without power, some for as long as two days.[9]

Yet the interconnected nature of the different types of infrastructure makes resilience a system of systems problem, with linked systems causing failures which often exacerbate one another: consider the complex interplay of communications and power during a grid failure, for example. Whether caused by natural disasters, systems error, bad actors, gray rhinos, or black swans, infrastructure failures can escalate in the physical, societal, and cyber arenas simultaneously.

During the 2021 floods in Zhengzhou, China, heavy rainfall overwhelmed smart flood detection systems, took out power, water, and the internet, and killed at least 300 people, including 14 who drowned in flooded subways.[10] Hospitals, struggling for power, evacuated patients; electric vehicles ceased to function; in a society where most payments are conducted using mobile apps, the loss of internet left citizens not just unable to communicate but unable to buy food.

Events such as physical attack, cyber-attack, environmental disasters, and geopolitical events are risks that can directly impact the normal operation of the grid. Unchecked, these events can cause grid outages which if prolonged can expand to impact communications, transportation, supply chain, emergency and safety services. These are critical services society depends on for normal operation. When these services are impacted society starts to experience issues with all energy supplies, with critical asset replenishment, with financial markets and possibly require government intervention. The key is to mitigate the risks as close to the point of origin, within the grid domain, to prevent the outward migration of impact.

Cascading Impacts of Grid Failure



Source: Guidehouse

9. JR Minkel, "The Northeastern Blackout—Five Years Later," *Scientific American*, August 13, 2008.
10. Keith Bradsher and Steven Lee Myers, "How Record Rain and Officials' Mistakes Led to Drownings on a Subway," *The New York Times*, September 25, 2021.

Compounding threats can exacerbate these risks. Evacuating and accommodating citizens during disasters becomes much more challenging when a pandemic demands public health measures such as social distancing, temperature screening, and isolation zones for sick evacuees. In many parts of the world, wildfires and heat waves go hand in hand, with demand for air conditioning (AC) adding load to a grid strained by shutdowns and fire damage, and heat illnesses intensifying the pressure on hospitals and emergency services.

While it's tempting to see the different pieces of the infrastructure puzzle in isolation, resilience cannot be addressed piecemeal. These complex, interlocking systems are not siloed and the solutions can't be either. Close cooperation between public and private sectors is essential.

1.3 Navigating the Resilience Continuum

Resilience means more than rebounding quickly from unanticipated disruptions to critical systems. It requires organizations to re-evaluate long-term strategies across interdependent systems and anticipate a variety of challenges.

But resilience is not only something bought by high-dollar investment in futuristic technological deployments. It can—and should—be augmented by low-tech investments already available. And those investments generate real return: in advanced economies, $1 million of infrastructure spending can generate more than six jobs, while in developing economies that same budget can create up to 30 jobs.[11]

Finally, resilience is not an end state. It exists on a continuum and must be regularly calibrated. How can organizations know when they've reached the right balance and how to continuously maintain it?

To start—or accelerate—your resilience journey, reach out to Guidehouse.

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Defining Resilience

In the context of this discussion, here is a working definition of resilience: the ability of an organization or society to prevent, withstand, adapt to, and quickly recover from system damage, shocks, and operational disruption. Resilience is defined in relation to high-impact, low-likelihood events.

1.4 Towards a New Model of Resilience

To be resilient, organizations need to re-evaluate long-term strategies—including flexible financing and approaches to deployment—to better prepare for and anticipate a variety of challenges, both expected and unexpected. The most resilient and future-proofed infrastructure is possible through a combination of low-tech solutions (improved design, materials, processes, organization, for instance) and aggressive adoption of technologies that make infrastructure more autonomous, self-healing, and intelligent. And, of course, strategies have to take into account the likelihood of multiple high-impact events—the near-time concurrence of, say, geopolitical strife that disrupts supply chains with the disastrous consequences of a 100-year flood.

Improved resilience also takes into account impacts and seeks to achieve solutions that mitigate inequitable outcomes. Lower income communities are more vulnerable to shocks of all kinds, from heatwaves to water pollution, and factoring in equity is critical when building resilience. For example, when NYC closed the subway

11. Mariano Moszoro, "How spending on infrastructure creates more jobs," World Economic Forum, https://www.weforum.org/agenda/2021/08/government-spending-infrastrucure-jobs/.

overnight for cleaning during the pandemic, frontline employees who could not work remotely and did not own their own vehicles were most impacted. Just and equitable resilience programs help close gaps that could otherwise fracture societies.

Sustainability and resilience are intimately connected, with both the EU and China spending heavily on green infrastructure: after all, it would be disastrous if attempts at climate adaptation counteracted climate mitigation efforts. To combat climate change, plans for resilient infrastructure need to favor renewable energy over fossil fuels, mass transit over private vehicles, alternative fuels over internal combustion engines, and nature-based solutions over carbon-intensive construction.

There are economic as well as societal benefits to this approach. Green infrastructure creates more jobs than unsustainable infrastructure: solar energy projects create 1.5 times as many jobs as fossil fuel projects per $1 million spent, while ecosystem restoration creates 3.7 times as much employment as oil and gas production.[12] And business as usual is simply not an option: expansion of urban infrastructure alone is projected to generate 470 metric gigatons of carbon emissions by 2050 if sustainable solutions are not adopted.[13]

1.5: Case Study: International Climate Initiative Supports Upscaling Sustainable Cooling Solutions

Entity: International Climate Initiative (IKI), a funding instrument of the German federal government that supports climate action and biodiversity in developing and emerging countries, with an annual budget of around €600 million.[14]

Background: The built environment is key to developing climate resilience. Warming temperatures coupled with population growth, urbanization, and higher standards of living mean that demand for cooling is set to soar. An estimated 3.6 billion cooling devices are already in use worldwide, with roughly 10 being added every second. Without further policy intervention, direct and indirect emissions from cooling and refrigeration may rise 90% above 2017 levels by 2050 in a vicious feedback loop.[15]

Challenge: Using more sustainable cooling solutions could prevent up to 0.9°F (0.5°C) in additional global warming by 2100.[16] The Nationally Determined Contributions (NDCs) set at the 2015 Conference of the Parties in Paris commit nations to meeting specific greenhouse gas (GHG) emissions targets. The 2016 Kigali Amendment to the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer requires signatories to phase down the use of hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) as coolants.

12. Joel Jaeger et al, *The Green Jobs Advantage: How Climate-friendly Investments Are Better Job Creators*, World Resources Institute, 2021.
13. Graham Floater et al, *Cities and the New Climate Economy: the Transformative Role of Global Urban Growth*, New Climate Economy, 2014.
14. International Climate Initiative, "The IKI in 2020," International Climate Initiative, https://www.international-climate-initiative.com/en/iki-annual-report-2020/the-iki-in-2020.
15. United Nations Environment Programme and International Energy Agency, *Cooling Emissions and Policy Synthesis Report: Benefits of cooling efficiency and the Kigali Amendment*, 2020.
16. Y. Xu et al., "The role of HFCs in mitigating 21st century climate change," *Atmospheric Chemistry and Physics* 13 (2013): 6083.

Egypt, Jordan, Lebanon, and Turkey all face rapidly growing demand for cooling, as well as structural energy challenges. IKI wanted to support these four partner countries to build heat resilience while mitigating climate change. Its goals were political, technical, and financial. The agency sought to:

- Support the implementation of Paris Agreement and Kigali Amendment objectives.
- Enable natural refrigerants and energy-efficient solutions to mitigate rising cooling demand.
- Develop financial models to boost sustainable cooling.

Solutions:

Building Partnerships with Governments

IKI turned to Guidehouse to create and lead a consortium that could deliver a sustainable cooling program spanning six years, four countries, and both private and public sectors. Guidehouse's project team pairs international cross-sector expertise with local insight. Spread across Germany, the UK, and the Netherlands, the Guidehouse team encompasses people from four continents, including Turkish, Jordanian, and Egyptian nationals, and spans disciplines from finance and policy to technology and communications. The consortium combines technical authorities, including Dresden's Institute of Air Handling and Refrigeration; global thought leaders, including the UN Development Programme and Frankfurt School of Finance and Management; and local partners, such as the Lebanese Centre for Energy Conservation and the National Energy Research Center, part of Jordan's Royal Scientific Society.

The program, titled Cool Up—Upscaling Sustainable Cooling, launched in 2021 and will run until 2027. Guidehouse and the consortium have already achieved buy-in from partner governments and are working on policy and high-level action plans. Policy and regulation are key not only to transforming the cooling industry but to reducing demand for cooling, since options such as improved shading, ventilation, and building shell quality, as well as demand control, all increase heat resilience. A 2022 regional conference will help governments, NGOs, and the private sector share best practices across borders.

Nurturing the Sustainable Cooling Sector

Many air conditioning (AC) and refrigeration systems utilize HFCs and HCFCs, chlorofluorocarbon (CFC) substitutes adopted when the ozone-depleting impacts of CFCs became clear, but subsequently revealed to be potent GHGs. In addition to reducing demand for cooling, IKI sought to drive the adoption of natural, sustainable refrigerants that are safe, affordable, and environmentally benign, with no negative impacts on the ozone layer or the climate. These include hydrocarbons and CO2.

There are significant barriers to adoption of these proven sustainable refrigerants. Hydrocarbons are highly flammable, causing safety concerns, although precautions such as limited gas exchange volumes, leakage alarms, and well-trained service personnel can render them entirely safe. CO2 is both affordable and abundant. This is a positive for end users but presents a challenge for the refrigerant industry. Businesses in this competitive sector are highly motivated to develop and market more lucrative alternatives. While such novel refrigerants have lower global warming potential than HFCs and HCFCs, their full environmental impact remains unknown.

The Cool Up Programme covers residential and commercial air conditioning as well as commercial refrigeration, specifically supermarkets. Demonstration projects will help build trust in sustainable cooling technologies, inspire new technology innovation backed by solid evidence, and help local manufacturers transition to sustainable product lines. Stakeholder dialogues will facilitate work on implementation, including the replacement and safe disposal of inefficient cooling appliances and refrigerants, and the promotion of improved cooling appliance operation, training, and awareness.

Opening New Avenues for Finance

The transition to sustainable cooling requires financing for new equipment as well as active evolution of the manufacturing sectors involved. It therefore requires rethinking financial incentives. Conversion to cooling systems based on natural refrigerants requires upfront investment, and so does not intrinsically provide direct financial savings. The Guidehouse team is working with both governments and the financial sector to develop new climate financing solutions that can boost the cooling transition and improve access to finance for sustainable cooling technologies.

Finding a path to more sustainable cooling requires a holistic approach. With partnerships in place across government, the private sector, and the financial sector, and a clear roadmap for the program, IKI is well placed to support Lebanon, Jordan, Turkey, and Egypt in transforming their cooling sectors and meeting their climate and environmental commitments.

How IKI Is Developing a Sustainable Cooling Industry

IKI's broad remit spans international climate initiatives in developing and emerging countries around the world, including a sustainable cooling portfolio. The agency's Cool Up program exemplifies some common strengths found in entities that successfully build infrastructure resilience:

Innovation: IKI is not only open to new ways of doing things, but goes out of its way to source them. The inspiration behind the Cool Up program was an ideas competition, with grant funding for successful organizations.

Connectedness: As part of the German government's Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, IKI boasts strong links to both governments and NGOs.

Teamwork: IKI supports partner countries across the globe, with many different political and business cultures. This experience of international collaboration helps it brace the efforts of four very different nations.

> "We're working in the international space, but we're also connecting the outcomes to implementation in different countries. It's really about understanding the international needs, understanding the country need, and linking that to implementation and enabling scale-up."

Katja Eisbrenner,
Director, Guidehouse

2.0 Building Resilience in an Uncertain World

Climate change is rewriting our playbook for how—and how often—we should anticipate natural disasters. Digital transformation has accelerated the speed of business while also opening new avenues of attack for state actors, individual opportunists, and organized crime gangs. Rapidly advancing technology means organizations must plan for obsolescence over a far shorter time span as communication infrastructure that used to last a lifetime is mothballed every few years.

In a global economy, geopolitical shocks and shifts make interactions with trade partners and foreign states a game that moves as you play it. Evolving consumer standards around corporate responsibility—issues such as sustainability and fair-trade practices along the supply chain—continually reshape sourcing and value chains. A pandemic has restructured how we work—and nobody knows what the next pandemic will bring. Markets continue to evolve more quickly than ever in history. Twenty-five years ago, Amazon was just an online bookstore; 15 years ago, Uber didn't exist.

Changes are occurring rapidly and on many fronts. But physical infrastructure tends to evolve very slowly. In the past, physical infrastructure upgrades might take place on the scale of decades—or, in the case of some facilities like dams or transportation structures, centuries. Smart infrastructure, while tending to increase resilience, accelerates the pace of change and exposes systems to a galaxy of cyber risks. Multiplying threat vectors can damage infrastructure stability and exacerbate the problems that would likely follow a serious disruption.

Different parts of the globe face different challenges when it comes to infrastructure resilience. North America generally has inherited legacy systems that propelled economic growth over the last century but are now falling into disrepair and facing obsolescence. In the US, cultural resistance to long-term investments to counteract future risks, exemplified by the nation's low savings rate, and widespread skepticism about government spending make the climate for investment challenging.

Europe is also working with legacy systems but has taken a more precautionary approach to anticipating change, implementing policies and directing investments to adapt the system in real time. While an expensive approach, in sectors from transportation to green energy its infrastructure is ahead of the resilience curve.

Despite spending over 8% of GDP on infrastructure, China still faces a 2.5% shortfall in spending as infrastructure fails to keep pace with economic growth, rapid urbanization, and an aging population.[17] Elsewhere in Asia-Pacific, advanced economies such as Japan have demonstrated greater willingness to invest in state-of-the-art infrastructure systems, including smart cities which may assist with the demographic challenges its "super-aged" society presents.

But the corporate dice are stacked against infrastructure resilience. Similarly to sustainability initiatives, investing in resilience runs contrary to the short-term incentives that drive most companies. CEOs are generally rewarded based on quarterly performance, not on how the business delivers in 15 years' time, when both board and executives will likely be long gone.

17. Anita George, Rashad-Rudolf Kaldany, and Joseph Losavio, "The world is facing a $15 trillion infrastructure gap by 2040. Here's how to bridge it," World Economic Forum, https://www.weforum.org/agenda/2019/04/infrastructure-gap-heres-how-to-solve-it/.

2.1 Case Study: New York State Energy Research and Development Authority Evaluates How Best to Protect Vulnerable Residents from Extreme Heat

Entity: A public benefit corporation, New York State Energy Research and Development Authority (NYSERDA), has been advancing energy solutions and working to protect the environment since 1975.

Background: Climate change is set to increase average annual temperatures in New York City (NYC) by 1.5˚F–3.2˚F by the 2020s, 3.1˚F–6.6˚F by the 2050s, and 3.8˚F–10.3˚F by the 2080s.[18] At the same time, climate change will increase the frequency, intensity, and duration of extreme weather events, including heat waves. Heat waves will disproportionately affect neighborhoods with poor housing conditions and less green space and communities where residents are more susceptible to heat-related illness.

Challenges: Around 9% of NYC residences—home to an estimated 750,000 people—have no air conditioning (AC).[19] The 2021 heat wave in the Pacific Northwest saw at least 600 excess deaths,[20] highlighting how extreme heat events can have tragic consequences. A popular mitigation solution, AC systems are also a major driver of peak electrical demand. NYSERDA wanted to understand how best to address the cooling usage and needs of vulnerable communities, while also continuing progress towards city and state climate and clean energy goals. Specifically, the agency wanted to know:

- How much cooling would be needed for NYC in the future?
- What technology and policy options might increase cooling access for vulnerable populations?
- How best could NYC balance the cost and energy impacts of increased cooling access?

Solutions:

Designing a Robust Model for New York City's Future Cooling Needs

NYC's building stock currently comprises around a million buildings and 3.2 million residential housing units, with space cooling representing about 17% of total electricity consumption for residential and commercial buildings.[21] To understand the city's future cooling needs, NYSERDA partnered with Guidehouse.

Cities are constantly evolving and over the next three decades NYC's demand for cooling and associated electricity consumption will change. Some factors, such as warming temperatures and population growth, will increase electricity demand; others, such as energy efficiency building codes, will mitigate this. Guidehouse created a rigorous, spreadsheet-based model that analyzed how NYC residential space cooling demand, energy consumption, peak electricity demand, and building stock characteristics would change between 2020 and 2050.

Modeling showed that electricity demand for residential cooling would remain relatively flat as already committed energy efficiency policies offset greater demand.

18. New York State Department of Environmental Conservation. *Observed and Projected Climate Change in New York State: An Overview*. 2021.
19. NYSERDA. *Climate Change: Equitable Access to Cooling in New York City*. 2021.
20. Popovich, Nadja and Winston Choi-Schagrin. "Hidden Toll of the Northwest Heat Wave: Hundreds of Extra Deaths." *New York Times*. August 11, 2021.
21. NYSERDA. *Climate Change: Equitable Access to Cooling in New York City*. 2021.

The energy impact of extending high-efficiency AC to vulnerable residents' homes would likely be mild, but residents below the poverty line might struggle with bills.

Identifying Barriers to Access to Cooling

Before exploring how to support vulnerable populations facing extreme heat, the team investigated barriers to equitable cooling access in NYC. A literature review identified more than 20 different barriers, from ownership structures for multifamily buildings to lack of awareness about the danger of high temperatures and gaps in current financial assistance programs.

A second literature review found more than 60 available technology and policy solutions, which the team narrowed to around 20 possible options. Structured dialogues with stakeholders highlighted that the priority should be to increase cooling in residents' homes rather than communal spaces—an insight emphasized when pandemic stay-at-home orders closed shared cooling centers.

It emerged that delivering financial access to AC through incentives and/or rebates and expanding access to support for building shell improvements were vital policy levers. Yet the team also determined that cooling centers should be made more inviting and accessible, since, whether because of personal preference or financial constraints, some residents will not use AC systems at home.

Modeling the Costs and Benefits of Cooling Access

NYC has already taken significant steps to expand access to equitable cooling solutions, with ambitious laws to improve urban greening, cool roof adoption, and building energy efficiency, as well as programs that provide low- or no-cost AC systems. The city's 2020 Cooling Assistance Program provided around 70,000 AC units and utility bill relief to households in need during the pandemic.[22] NYSERDA wanted to understand the cost of extending at-home cooling access to the roughly 300,000 homes currently without AC, as well as more comprehensive solutions including weatherization, cool pavements, and enhanced urban greening.

Guidehouse modeled three scenarios to evaluate the impact on cooling equity, electricity consumption, implementation cost, and other factors. All provided AC and weatherization to 300,000 homes by 2030 and improved cooling centers. The most comprehensive strategy included greater saturation of high-efficiency AC and building envelope improvements, plus increased investments in cool pavements, tree planting, and community solar.

The project team learned that the most comprehensive strategy would completely eliminate the increased energy consumption from the additional AC units, but would incur significant capital and incremental costs. Across the range of scenarios, extending cooling access to homes without AC today would carry costs of approximately $170 million to $260 million per year through 2050.

While these implementation costs are significant, the health, economic, and societal value of extending cooling to all NYC residents is very real. Utilizing research into low-income weatherization programs in Massachusetts, the team found the annual per-home value of low-income weatherization programs amounts to almost double the estimated $700 annual cost of a potential equitable cooling program.

22. NYSERDA. *Climate Change: Equitable Access to Cooling in New York City*. 2021.

> "NYSERDA wanted to look at the cooling equity problem and available solutions comprehensively, to try to dispel some of the myths that hold up work being done around this topic. What we tried to do was evaluate the energy, cooling, and cost impacts of potential solutions that could rapidly address this issue."
>
> Jim Young,
> Associate Director, Guidehouse

NYSERDA published the final report in fall 2021. It will support future discussion by government, utility, community, and other leaders on how best to address cooling equity in NYC, an issue that becomes more pressing with every passing year.

2.2 Planning for Disruption

Today agencies and companies must build infrastructure that accounts for "gray rhino" events, such as the coronavirus pandemic. Unlike black swan events, which are highly improbable, perhaps almost unimaginable, these are highly probable events—global and national health officials have warned for years that a pandemic was likely at some point. Yet, despite their huge impact and evident likelihood, authorities may either fail to make plans or neglect to follow those plans when the crisis hits.

The effects of the pandemic have been both enormous and pervasive, and we will be reckoning with them for years to come. Not only did the coronavirus catch health agencies with perilously low access to the tools for basic responses—such as masks and ventilators—it caught businesses with high fixed real estate costs or extensive real estate investments flat-footed when employees pivoted to working from home.

The Four Types of Gray Rhino

Michele Wucker, who coined the term "gray rhino" in her 2016 book, describes four types of rhino: charging, recurring, meta, and unidentified. A charging rhino is something that needs to be dealt with right away: a novel pandemic, for example. A recurring rhino is something entities have seen in the past and have a roadmap for, perhaps heatwaves or seasonal viruses. Meta-rhinos describe structural factors that affect an organization's ability to handle other rhinos, such as poor decision-making processes and incentives. Unidentified rhinos are disruptors, such as artificial intelligence (AI), whose significance is obvious but whose impact is not yet clear. Resilient entities gear for the full herd.

Individually these events present low risk—how many global pandemics have we seen in our lifetimes?—but in aggregate they require a reassessment of risk analysis and plans for future-proofing infrastructure operations.

Some common threats to infrastructure include the following:

- Weather and climate events
- Natural disasters
- Terrorism
- Cyber breaches, attacks, or mishaps
- Age, and the problems associated with aging infrastructure
- Pandemics, wars, and other disruptions to business continuity and/or supply chains
- Political gestures such as trade wars and sanctions
- Decentralization, which can both help build resilience and create new vulnerabilities
- Obsolescence, stranded assets, and stranded resources

In the past, any of these events was possible, even probable. Today, we are more likely to see a combination of events that can impact infrastructure, like massive wildfires occurring during a global pandemic, or the double whammy of political instability disrupting supply chains and then a hurricane hitting a key port.

Recent examples of interlinked disruptions, such as the spate of ransomware attacks on hospitals already struggling with the COVID-19 pandemic, illustrate how quickly they can occur, how enduring their impacts can be, and how, occurring in tandem, their individual impacts are amplified.

Planning for uncertainty is essential. Engineers designed Japan's Fukushima Daiichi nuclear power plant with sufficient resilience that it withstood the seismic impacts of the magnitude 9.0 earthquake that struck in 2011. Yet, relying on historic run-up heights, they had only planned for a 10-foot tsunami: the wave that inundated Daiichi's turbine halls, causing one of the world's worst nuclear disasters, was almost 50 feet high.[23] In Russia's far north and east, airports, roads, pipelines, power poles, and government buildings were all constructed on the basis that the permafrost would never melt. Those decisions mean Russia could face a $97 billion infrastructure bill by 2050.[24]

Rather than attempting to predict the future, the key is to prepare for it. And that means looking beyond historical patterns to possible extreme events and combinations of events. Resilient systems need to have the ability to adapt rapidly to unforeseen circumstances, using a networked approach that's regularly reviewed and evolving.

2.3 Pillars of Resilience: the Components of Effective Strategy

Infrastructure resilience is an ongoing journey, not a static end state. Leaders need to evaluate their risk tolerance in planning, monitoring, and adapting their resilience strategies. In many areas absolute resilience is either impossible—how can one insulate 100% against every cyber issue the future may throw up?—or impractical—does it matter if an earthquake dislodges some roof tiles? A risk-based lens and evolutionary measurement lets stakeholders track key indicators and evaluate whether steps taken are appropriate use of resources in light of risk, and whether they have increased or decreased resilience.

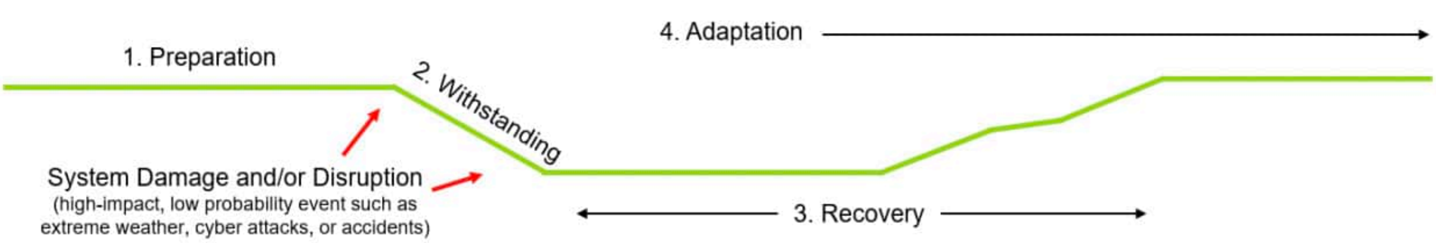
It's best to conceptualize building resilience in stages. It's possible to identify the low-hanging, low-tech solution to a vulnerability—say a utility's power pole—and solve for that. Maybe you build and place more poles. Then you can measure that level against the initial plateau, and move onto the next plateau: perhaps that's building poles out of bamboo, so they create less of a carbon footprint, or connecting them to internet of things (IoT) sensors that can report movement and tilt. Maybe the next plateau is work on a self-healing grid that can route power around fallen poles and downed lines without the need for human intervention.

Another approach is to steadily increase the target resilience quotient. In Japanese manufacturing, a sector highly exposed to natural disasters, that's been the approach for years. Once companies reach the level of resilience previously set as their objective, managers recalibrate and move the goal posts.

The curve in this infographic shows how Guidehouse considers the phases of resilience strategy:

- Preparation: the ability to prepare for and prevent initial system disruption.
- Withstanding: the ability to withstand, mitigate, and manage system disruption.
- Recovery: the ability to quickly recover normal operations and repair system damage.
- Adaptation and continuity: the ability to implement actionable insights and resilience principles into existing structures and processes.

The Energy System Resilience Curve



23. World Nuclear Association, "Fukushima Daiichi Accident," World Nuclear Association, https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-daiichi-accident.aspx.
24. Maxim Shemetov, "Russia's remote permafrost thaws, threatening homes and infrastructure," Reuters, https://www.reuters.com/world/europe/russias-remote-permafrost-thaws-threatening-homes-infrastructure-2021-10-18/.

2.4 Case Study: Duke Energy Florida Gears Up for the Coming Storms

Entity: Duke Energy Florida, a subsidiary of leading utility holding company Duke Energy that provides electricity to 1.9 million in-state customers.[25]

Background: Some of the most destructive hurricanes in recorded history have hit Florida, sometimes with dire consequences for utilities. In 2017, for example, Hurricane Irma knocked out power to 6.7 million customers, or almost two-thirds of the state.[26] In 2019, the Florida Legislature passed Senate Bill 796, requiring every utility to create a 10-year storm protection plan that hardens and increases the resilience of electric transmission and distribution facilities to extreme weather events through managing vegetation, installing sturdier overhead wires and poles, and undergrounding distribution power lines.

Challenge: With assets such as poles and power lines exposed to high winds and falling trees, and transformers and substations vulnerable to storm surges and flooding, Duke Energy Florida had already implemented several programs to reduce outages and restoration costs. But the new legislation meant the company needed to develop a longer-term plan that reflected a systematic approach to enhancing resilience and reliability, while also ensuring overall program investments were reasonable and benefited customers.

To comply with Senate Bill 796, the company needed to develop a formal storm protection plan filing that demonstrated a systematic hardening approach and would withstand close regulatory scrutiny, including:

- Rigorous analytics to identify and assess which assets were most subject to risk and estimate likelihoods of failure.
- Application of industry-accepted cost-benefit analysis methodologies.
- Prioritization of programs and projects in a manner that balanced implementation efficiency with real-world resource limitations.

Solutions:

Identifying Assets at Risk and Prioritizing Projects

Duke Energy Florida had identified a wide range of possible programs and projects to harden its transmission and distribution systems against extreme weather events and was seeking a robust methodology to understand the cost-benefit trade-offs of each potential intervention. Interventions ranged from traditional practices, such as removing trees that might threaten power lines, to installation of new technologies and solutions, such as self-optimizing grid technologies that reroute power around damaged lines. However, the company knew that even with a potential investment of many billions of dollars over the 10-year plan horizon, not all of these projects could—or should—be attempted.

Duke Energy Florida turned to Guidehouse to help evaluate its options and craft a rigorous 10-year storm protection plan. The goal of the plan was to build resilience, deliver value to customers, and comply with

25. "Duke Energy Florida expands solar energy in Sunshine State with completion of Duette facility." Duke Energy. November 9, 2021. https://news.duke-energy.com/releases/duke-energy-florida-expands-solar-energy-in-sunshine-state-with-completion-of-duette-facility.

26. Justine Griffin and Caitlin Johnston. "Half of Irma's power outages restored, but lights still out for 3.3 million Florida homes, businesses." *Tampa Bay Times*. September 14, 2017.

regulatory requirements while reducing both customer service interruptions and storm restoration costs.

Guidehouse's first task was to identify and quantify extreme weather risk across all transmission and distribution system assets. The team modeled three hurricane scenarios, one based on empirical average observed weather hazard frequency in the territory, a second increasing the annual chances of storm strike by 10%, and a third increasing them by 25%.

To build the risk model, Guidehouse imported data from Duke Energy Florida's mapping systems. The team charted asset types, age, and condition; their latitude and longitude; and the way in which assets interconnected. Weather models simulated assets' exposure to hurricanes' three key weather effects—flooding, storm surge, and high winds—enabling an assessment of the degree and cost of damage that would occur under various scenarios. Granular mapping meant that simulated weather impacts varied according to an asset's location.

With asset exposure risks understood, the team then quantified the exposure risk and the value of mitigating investments. Guidehouse utilized industry-recognized methodologies to conduct a cost-benefit analysis of each of the proposed distribution and transmission hardening programs. Investment program benefits included reduced customer outages, decreased restoration and facility replacement costs, and lower operations and maintenance expense for hardened assets. Costs included capital expenditures, operation, and maintenance of new programs and investments.

Finally, Guidehouse worked closely with Duke Energy Florida to develop a prioritized 10-year road map and detailed three-year investment plan that recognized funding, timing, and resource constraints. Duke Energy Florida was then able to develop a practical program implementation plan that reflected its understanding of community needs, technology risk, and customer experience to deliver maximum value and reduce customer disruptions in a cost-effective way.

Navigating the Regulatory Maze

A multibillion-dollar 10-year investment plan, with some projects extending out for decades beyond that timeframe, necessarily attracts extensive regulatory scrutiny to ensure it is in the best interests of customers. As required by legislation, Guidehouse and Duke Energy developed a filing that included a detailed description of methodologies, assumptions, and the implementation plan.

Drawing on in-house multidisciplinary expertise, Guidehouse united and merged over 750 GB of data across six major systems, extensive proprietary modeling, and billions of dollars of resilience investments into a clear but comprehensive storm protection plan, which Duke Energy Florida filed for regulatory approval in 2020.

Guidehouse professionals then supported the utility through the regulatory filing of the plan, which involved hundreds of data and evidentiary requests from a diverse range of stakeholders and interest groups. The commission approved Duke Energy Florida's storm protection plan, enabling the company to move forward with proposed investments that will harden its systems against extreme weather, reduce power outages, and benefit customers.

> "There has to be a very sound methodology any time you're substantiating a multibillion-dollar plan. It will be scrutinized very closely to make sure it's a good investment for the customers. We had a laundry list: We had to make sure there were a thousand things checked off."

Chip Wood,
Partner, Guidehouse

2.5 The Resilience Strategy Curve in Practice

When we talk about infrastructure, people tend to imagine what we would classify as "hard" infrastructure—roads, dams, power plants, network servers. But "soft" infrastructure, such as emergency services, government, financial services, and healthcare, is equally critical, and equally in need of new strategies.

Applying the phases of the resilience strategy curve (above) to hard infrastructure is fairly straightforward. Take a utility company, for instance. The utility can use physical materials to build a power plant that is hardened in preparation against disruption. When, eventually, an event occurs that is too powerful even for the carefully constructed plant, the utility enters the "withstanding" phase. Here, executives must strategize to manage the disruption in the system. This might include designing microgrids—smaller, independent grids that can disconnect from the main grid—so a disruption doesn't have to occur system-wide.

Recovery strategies are often process-related. How well trained is the workforce to respond? How quickly can they deploy? How close at hand is the equipment and material needed to rebuild? The adaptation and continuity phase involves incorporating lessons learned and planning to avoid failures in the next event.

The same phases of the resilience strategy curve apply to soft infrastructure. In 2021, New Orleans Children's Hospital was hit hard by Hurricane Ida, which cut power to at least 1.2 million customers,[27] including the hospital. Long before the storm even formed, the hospital had a plan in place, with backup power, including additional redundancy, a hurricane handbook so employees understood key policies and how to protect their own homes and families, and contingency plans for relocating emergency or critically ill patients to facilities that could meet their needs. During the storm, the hospital went into lockdown with a pre-briefed team working a three-day shift to cover essential care.

The recovery phase saw the hospital maintaining essential care on auxiliary power with relief teams. Not only did it patch up physical issues, mainly roof damage and minor flooding—it supported team members with everything from showers and laundry facilities to ice for refrigeration at home, before reopening non-essential services. During the adaptation and continuity phase, the hospital reviewed its management of the response and adapted its resilience and recovery planning.

The Building Blocks of Organizational Resilience

Resilience is a process that needs to be enshrined within an organization's DNA. Yet entities that are successful at building infrastructure resilience need seven basic building blocks: flexibility, commitment, innovation, preparedness, resourcefulness, teamwork, and connectedness. The evolutionary nature of resilience demands flexibility. The timeframes involved require significant institutional commitment. Innovation enables the rapid, proactive adaptation demanded by a fast-changing landscape, while preparedness and resourcefulness are vital attributes when facing an uncertain future. The complex web of connections that comprise the infrastructure landscape means working well internally and with partners and building strong relationships across the spectrum is critical.

27. Owen Comstock, "Hurricane Ida caused at least 1.2 million electricity customers to lose power," U.S. Energy Information Administration, https://www.eia.gov/todayinenergy/detail.php?id=49556.

3.0 The Guidehouse Approach to Building Resilience

Guidehouse believes that linking resilience decisions and decision lifecycles is critical to long-term success. Asset flexibility plays a key role. This may entail more redundancy, distributed computing, and distributed architecture, as well as machine learning and AI.

As well as increasing resilience, distributed networks can also be more sustainable. Rather than build expensive centralized water treatment plants, which are themselves vulnerable to flooding, to handle stormwater runoff, cities can utilize nature-based solutions such as wetlands, rain gardens, and green roofs, which create both jobs and liveable spaces. Adding flexibility in the form of renewable microgrids can enhance grid resilience to challenges such as wildfires and reduce emissions too.

Emerging technologies such as intelligent automation, IoT-enabled devices, and predictive maintenance can build resilience into systems of all kinds. Remote sensing and IoT technology can identify water leaks and check water quality, helping ensure safe access to drinking water. Smart vehicles, smart traffic lights, and smart calling systems with GPS can dramatically accelerate emergency service response times. Earthquake early warning systems can alert hospital operating theaters, shut down fuel hydrant systems at airports, and halt elevators at the nearest floor while broadcasting a warning, allowing riders time to escape and seek cover.

Those are high-tech fixes. But it's important to see resilience strategy holistically—which means in operational as well as physical and technological systems. Where is the necessary redundancy in processes? Who steps up when one piece fails? Low-tech fixes are every bit as critical to the preparation and recovery phases of resilience strategy as technology. Human processes—communication, decision-making, deployment—matter tremendously when disruption strikes.

Because financing infrastructure is so expensive, resilience strategies should be considered and evaluated across multiple interrelated critical systems. Flexibility in financing tools and strategies can inform planning for future infrastructure investment. A new road can pay for itself through tolls, but also creates its own economic benefit as fuel stations, convenience stores, and restaurants pop up along its length. Other infrastructure—5G communications, for instance, or solar power in certain areas—can also help transfer value and offset investment costs.

Financing the Infrastructure Transition

To meet development goals and comply with the aims of the Paris Agreement, the world would need to spend $6.9 trillion on infrastructure each year to 2030.[28] Financing a transformation of this scale requires innovation. Familiar tools include green bonds, carbon offsets, local subsidies, and international institutional programs. Yet in addition to these, a holistic approach is vital, perhaps funding longer-term plans with a negative ROI using the returns from measures with a quick payback. Strategies such as energy service agreements or "efficiency as a service" utilize third-party ownership structures to keep liabilities off the balance sheet. For most companies, Scope 3 emissions represent 65%–90% of their carbon footprint.[29] Besides carbon emissions reduction finance, unlocking the value of a lower cost and more resilient supply chain can support essential investment in supply chain infrastructure while increasing enterprise resilience and thereby enterprise value.

28. OECD, UN Environment Program, and World Bank Group, *Financing Climate Futures: Rethinking Infrastructure Policy Highlights*, OECD Publishing, 2018.

29. Eric Rosenbaum, "Climate experts are worried about the toughest carbon emissions for companies to capture," *CNBC*, August 18, 2021.

And, when operating in an arena as interlinked and all-embracing as infrastructure, it's important that public and private sectors work hand in hand. Direct government spending is one key tool, as is research and thought leadership, but policy and regulatory requirements can help the private sector justify its investments to shareholders and customers alike. The EU makes access to many infrastructure development funds contingent on both climate resilience and sustainability.

Public-private partnerships can operate in varied ways. In western US states, federal agencies such as the Department of the Interior and the US Forest Service are working alongside state and local government and utilities to build wildfire mitigation and resilience programs. In the UK, multiple government departments and agencies work alongside an independent regulator, communications providers, data center owners, and the internet sector to build communications resilience.

3.1 Case Study: TriMet Transit Services Plots a Course to Decarbonizing Its Bus Fleet

Entity: TriMet, a public agency providing bus and rail services in the Portland, Oregon, area that generates around $320 million in annual sales.[30]

Background: Decarbonization and resilience are closely linked. As well as helping to mitigate transportation's contribution to climate change and extreme weather events, decarbonized fleets are less vulnerable to price volatility during the fossil fuel transition. While mass transit use reduces Portland's overall carbon footprint, TriMet was committed to addressing its own operational footprint with a resilient, futureproof solution.

Challenge: TriMet had the ambitious target of transitioning its entire bus fleet to all alternative fuels and was planning trials of electric buses. But the agency wanted to explore the opportunities and costs of transitioning from diesel to different alternative fuels so it could make an informed decision on which to pursue.

TriMet partnered with Guidehouse to develop an objective overview that would help the agency:

- Understand the current and projected GHG emissions of its existing fleet.
- Evaluate the various alternative fuel options available to it.
- Establish whether to proceed with its planned electric bus trials.

Solutions:

Counting the Cost of Going Green

Guidehouse estimated that TriMet's bus fleet would generate more than 2.8 million metric tons of GHGs from 2019 to 2055 if no changes were made to its fleet, fuel, and vehicle mix. Costs, including capital, fuel, and pollution harms, approached an estimated $4 billion, while leaving the agency open to the risks of regulatory changes and fuel price volatility.

Clearly, new technologies would be needed. But which ones? A report explored a suite of possible strategies: hydrogen, electricity, biofuels, and natural gases. Each option carried costs and risks beyond the price of fuel and vehicles alone. While biofuels could utilize existing refueling infrastructure, other alternative fuels required new infrastructure, which might in turn necessitate expanding a bus yard's footprint. Factors as diverse as maintenance costs, energy efficiency, and the resale value of alternative vehicles were

30. Dun & Bradstreet. "Tri-County Metropolitan Transportation District of Oregon." https://www.dnb.com/business-directory/company-profiles.tri-county_metropolitan_transportation_district_of_oregon.bfc41c19818fc376cc010dd02773c239.html.

all part of the calculation mix, although grid resilience strategies, such as microgrids, were out of scope.

To understand these lifetime costs and GHG emissions, Guidehouse had to pull together a diverse range of data and streamline it into a single analysis. Some data points were in the public domain, others required surveys. The team looked at costs, including vehicle purchase, infrastructure development, energy, and operation, as well as additional factors, such as the ambient environment and technology maturity.

TriMet learned that a battery electric bus transition fleet would be the most cost-effective option for maximally reducing the agency's GHG emissions. The organization found that new vehicles would not begin to pay themselves back within a 16-year period until around 2025. By this time, vehicle costs would also have decreased, while a wider range of both buses and charging technology would be on the market. In addition to these cost savings, delaying transition to 2025 would allow TriMet to calibrate real-world metrics from its electric bus trials.

As of 2022, despite reduced rider numbers and revenue due to the pandemic, the agency was testing four different types of electric buses, gathering vital information to define its future fleet, and powering them all on 100% renewable electricity.

Reducing the Footprint of the Existing Fleet

Building a resilient, decarbonized fleet entails more than transitioning to electric vehicles. TriMet also needed to address its legacy bus fleet, which is expected to operate until 2035. Given that the fleet is equipped with internal combustion engines, the natural route to reduce GHG emissions is biofuels: biodiesel, a nontoxic biodegradable fuel that is blended with diesel, generally at levels of 5%–20%, or renewable diesel, a biomass-based fuel which is chemically the same as petroleum diesel so can be used without blending.

The TriMet fleet already ran on a blend of 5% biodiesel. Renewable diesel likely performs better than biodiesel and is currently less carbon intensive to produce. But the low scale of current production capacity relative to demand makes it more expensive than either diesel or biodiesel, although California's Low Carbon Fuel Standard credits should lower costs in the long run.

Guidehouse modeled costs and emissions reductions over the period 2019–2035 for diesel blends containing 5%, 20%, and 99% renewable diesel. With a 99% mix, TriMet could avoid up to 495,000 metric tons of CO_2e emissions at a cost of more than $46 million. Trading the current 5% biodiesel blend for a 5% renewable diesel blend would produce a small decrease in emissions and minor cost reductions, increasing efficiency somewhat while still shrinking maintenance costs. A 20% blend would significantly reduce emissions yet also increase costs.

Equipped with this information, TriMet plotted a path and, in December 2021, transitioned all TriMet buses covering routes through the Portland metro area to a mix of 99% renewable diesel, lowering its bus fleet GHG emissions by about 61%.[31] Coupled with the shift to renewable electricity, the agency is helping to accelerate the transition away from fossil fuels and mitigate climate change while building both a more resilient fleet powered by futureproof fuels and a cleaner, more resilient city.

How TriMet Made Its Bus Fleet Cleaner and Greener

The transition to alternative fuels is a major one for any organization, but particularly one whose core business is transportation. Throughout its decarbonization journey, TriMet has demonstrated many of the qualities that help entities build resilient systems and futureproof their business model:

Commitment: TriMet stakeholders are passionate about pursuing decarbonization, both to mitigate the agency's climate impacts and to build a healthier, more resilient community through cleaner air. That motivation is helping to power the agency through its ambitious decarbonization journey.

Flexibility: TriMet brought a wide range of perspectives and backgrounds, from business managers to engineering and technical professionals, to the project. The team approached the research without preconceptions and with a healthy degree of skepticism.

Resourcefulness: Founded in 1969 and one of America's most heavily utilized transit services, TriMet has a deep institutional knowledge of transportation. This helped it ask and refine the right questions, then act on the answers at speed.

31. Altstadt, Roberta. "The future of cleaner air is now as TriMet buses run on cleaner-burning renewable diesel." *TriMet News*. https://news.trimet.org/2021/12/the-future-of-cleaner-air-is-now-as-trimet-buses-run-on-cleaner-burning-renewable-diesel/.

"Within the transportation industry, there's been a pretty steep learning curve as it pertains to thinking about alternative fuels, and the fleet needed to come up to speed relatively quickly. They needed to have some independent entity come in and help them understand how they would process and decide on what technology to move forward with."

Scott Shepard,
Associate Director, Guidehouse

3.2 The Stages of Building Resilience

Guidehouse's approach to building resilience operates in four stages, with two guiding principles.

3.2.2 Evaluation

The process begins with a thorough evaluation of baseline conditions of current infrastructure and systems. The assessment must include an examination of vulnerability to disruption from multiple vectors, both predictable and unpredictable.

Naturally, exploring the financial picture is key. Opting for electrified infrastructure over diesel, for example, might reduce exposure to fluctuating commodity prices by providing the option of solar or wind microgrids. Where equipment sits in the replacement cycle will directly impact both capital and operational expenditures.

After establishing how the client currently understands resilience and the role it can play in broader business planning, it's possible to explore the pieces they may be missing. A scenario-based approach allows entities to begin to recognize the multitude of possible hazards and how those might affect their operations.

Yet resilience runs deeper than scenario planning alone: it needs to be embedded within an organization. An entity's organizational structure, team incentives, and decision making are all predicated on a certain approach to risk. Achieving resilience often entails adapting strategy: after all, if resilience is not part of the metrics for decision making, there's no incentive to make a sound decision.

3.2.3 Risk Assessment

Risk assessments should filter vulnerability through the lens of likelihood. Vulnerability is a function of exposure, sensitivity, and adaptive capacity. This stage addresses a deceptively simple question: Where are the most likely vulnerabilities for critical infrastructure and what do they place at risk? The possibilities are myriad: from volatile commodity and capital markets through to war, hurricanes, earthquakes, pandemics, ransomware attacks, and human error, to name but a few.

Quantifying the vulnerabilities at issue is, obviously, essential. Next comes translating that quantification into dollar terms. Whether for private companies or public entities, dollars speak volumes. An electricity utility, for example, will have metrics around the minutes that the power is shut off per customer, but translating those to dollars is fundamental. For government agencies, the metrics may be even more complex, with calculations delicately balancing equity, sustainability, public health, economic benefits, and more.

3.2.4 Mitigation

The next stage entails developing a list of risk mitigation steps. This will include identifying activities to execute and should be inclusive of social equity and sustainability considerations. Guidehouse advises clients to develop decision metrics for project selection and prioritization, as well as expected impact, so decision making can be defined in light of physical, social, and financial resilience.

Alternative and innovative routes to financing infrastructure investment can increase the range of mitigation options and even serve as mitigation in themselves. Options such as leasing or off-balance sheet arrangements can reduce the impact of commodity and capital market volatility, while savings from short-payback investments can be used to finance longer-term projects.

3.2.5. Success Metrics

A careful cost-benefit analysis should determine which investments will deliver the greatest benefit to the system relative to the cost, while integrating the—often substantial—impacts of how a project is structured financially. Resilience is a process, and, while it's always possible for an organization to gain resilience, it might not make sense to act on every recommendation. Interrogating the business case for each investment is essential and robust modeling is vital.

3.2.6 Embracing Low-Tech Strategies

High-tech, high-spend investments to protect interrelated systems often appeal to clients. But simple is often best and Guidehouse finds that low-tech, low-cost efforts will often serve to protect the foundations of existing and future infrastructure.

For example, low-tech solutions such as flood barriers and building code reforms to require more porous materials in roads and parking lots are often a more appropriate first step to managing flood waters than high-tech solutions. After all, adding new systems means adding monitoring requirements and it's often best to solve the problem with the things that are causing the problem.

3.2.7 A Multidisciplinary Approach

Resilience cannot be approached in siloes. It takes a diverse skill set to adopt a multidisciplinary approach that looks at solutions in different ways. A team might need to span the gamut from strategists and risk managers through to communications consultants, urban planners, and financial professionals.

Resilience discussions must bring everybody to the table who might provide an answer. Instead of focusing solely on engineers and IT experts, it is critical to talk to the people who are in the building every day, understanding how things work and where the complexities pile up.

3.3 Case Study: US Government Department Builds Cyber Risk Office

Entity: A major federal government department with a worldwide presence.

Background: The cybersecurity landscape is mired in tactical threats such as phishing attacks, ransomware attempts, and incursions by foreign state actors, to name just a few. These tactical challenges can distract mission owners from aligning with organizational priorities and communicating strategic risk information to stakeholders. Further challenges, such as systems upgrades to address hardware obsolescence, power outages, and user error, can also impact an organization's total risk and even its ability to meet its obligations. Effective cybersecurity risk management is vital for building resilience.

Challenges: The department operated with decentralized technology and risk management governance.

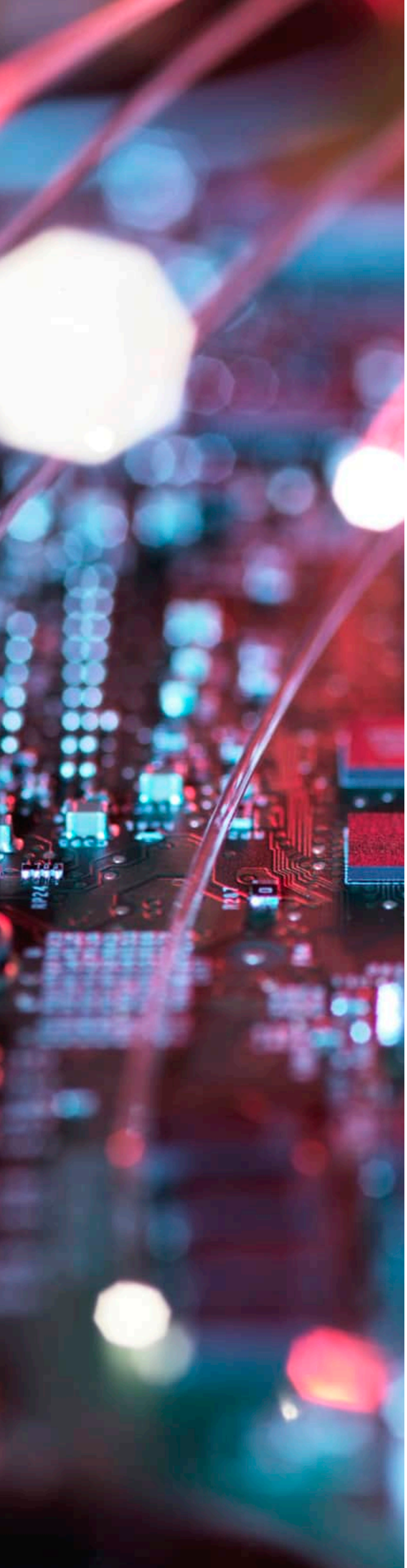
Internal and third-party reviews had shown it lacked strategic risk awareness and mitigation policies, and was facing some cyber hygiene issues. The organization was concerned that:

- Both senior leaders and mission stakeholders were not receiving risk and impact data.
- Cyber-related policies needed updating.
- Cybersecurity defenses could be improved.

Solutions:

Opening Communications Channels

The department partnered with Guidehouse to identify and address its cybersecurity risk management issues. Guidehouse formed a multidisciplinary team, spanning enterprise risk management, data analytics, change management, communications, and cybersecurity.



An initial gap analysis determined where the agency needed to bolster existing cybersecurity risk management processes, policies, procedures, and governance. Meetings with cybersecurity and risk program stakeholders quickly isolated specific areas for improvement.

As is often the case in large organizations, many business and mission leaders were not aware of the potential repercussions of cyber or technology risks on their specific areas of responsibility. Risks were often expressed in technical terms that didn't generally convey the real-world impact on operations and objectives.

Effective communications would be key. So executives, including the chief information officer, chief information security officer, and enterprise cyber risk officer committed to proactively improving communications throughout the department.

Guidehouse developed a new communications schema following National Institute of Standards and Technology organizational risk guidance. This enabled technical teams to share cyber and technology risk information with key stakeholders using language and framing that made its potential impacts clear.

The team also developed a custom awareness campaign outlining the importance of managing cyber risk to the enterprise. This resonated with mission and business leaders, helping improve the department's cyber hygiene issues and create buy-in across the organization.

Monitoring the Cybersecurity Landscape

In addition to lacking information on impacts, the department's senior leadership were often not current on the cybersecurity risks the organization faced. To improve cybersecurity defenses and keep stakeholders informed, Guidehouse leveraged metrics reporting and guidance from the Federal Information Processing Standards and the National Institute of Standards and Technology to promote a dynamic monitoring ecosystem.

Specific key performance indicators and key risk indicators, tailored to the department's needs, helped improve compliance and made cybersecurity more effective. A cybersecurity performance scorecard documented trends across the organization's disparate components. This valuable reference tool aggregated inputs from the authorization process, enterprise network monitoring, patch and vulnerability scanning, active directory reporting, and plan of action and milestones tracking to build an evolving, real-time picture of the cyber threat landscape.

Thanks to this scorecard, executives now have access to up-to-the-minute cybersecurity information to inform their investment and resource allocation decisions.

Embedding Cybersecurity Risk Management within the Organization

The department had found its cyber-related policies needed updating. A new cybersecurity risk management strategy document outlined how and why the organization should address cyber risk, while document updates refreshed key policies.

Furthermore, in collaboration with Guidehouse, the department took action to embed cybersecurity risk management within its organizational structure. In an unprecedented move, the department created an innovative enterprise cybersecurity risk management office charged with leading the identification, management, and monitoring of cybersecurity risk to its mission and business processes.

This durable entity, fully staffed and funded, is the first office of its kind within the federal government and will play a central role in the department's cybersecurity resilience for years to come. Coupled with accurate, real-time data and institutional risk awareness, it will help keep the department safe from threats as diverse as systems obsolescence and ransomware attacks.

"Everyone's under attack: power companies, government agencies, financial services organizations, banks are under attack every day. So it's no longer a case of 'Will I get attacked?' Pretty much anybody who's online is vulnerable."

John Eckenrode,
Director, Guidehouse

How the Department Built Cybersecurity Resilience

From initially commissioning external reviews to creating a fully staffed office, the department demonstrated many of the critical attributes that help entities of all kinds on their journey to resilience:

Commitment. Buy-in from executives was key to delivering the project successfully, as it yielded the organizational weight required to achieve change at the operational level. Leaders perceived that cybersecurity was a risk for the organization as a whole rather than conceptualizing it as a problem for the chief information security officer alone.

Flexibility. The department was ready to think of cybersecurity outside of the current compliance box and approach it from a risk perspective. Stakeholders saw the challenges posed within the accepted compliance paradigm and the risks they potentially posed to their mission, and were prepared to break new ground, including creating the first cybersecurity risk management office within the federal government.

Teamwork. Leaders, managers, and initiative owners at every level and in all geographies, including many from outside the information technology arena, participated in the cybersecurity project. This organization-wide openness to assist with an organization-wide challenge helped build awareness, traction, and, ultimately, resilience.

4.0 A Road Map for a Resilient Future

Infrastructure is vital to both economic continuity and social equity. Yet a complex web of interconnections means failures can easily cascade, while multiplying threat vectors are forcing organizations to think about resilience strategy in a new way. With every disruption, however, lessons and adaptations can build more resilient future states. Open communication among parties across interrelated infrastructure, and closer links between public and private sectors, will aid in keeping entire systems resilient as society faces down the myriad of challenges the 21st century presents.

But resilience doesn't happen by chance. It's a process and inputs can be measured for efficacy. It's important to build resilience strategy into every infrastructure acquisition—but also into the systems, processes, and incentives that shape an organization's day-to-day operations. The resilience journey is a path with many false summits, but by investing in resilience planning now, embedding risk and resilience thinking into the organization, and working with partners with the expertise to model and measure inputs, it's possible to take those first few steps towards a robust, resilient future.

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About Guidehouse

Guidehouse is a leading global provider of consulting services to the public sector and commercial markets, with broad capabilities in management, technology, and risk consulting. By combining our public and private sector expertise, we help clients address their most complex challenges and navigate significant regulatory pressures focusing on transformational change, business resiliency, and technology-driven innovation. Across a range of advisory, consulting, outsourcing, and digital services, we create scalable, innovative solutions that help our clients outwit complexity and position them for future growth and success. The company has more than 13,000 professionals in over 50 locations globally. Guidehouse is a Veritas Capital portfolio company, led by seasoned professionals with proven and diverse expertise in traditional and emerging technologies, markets, and agenda-setting issues driving national and global economies. For more information, please visit www.guidehouse.com.

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