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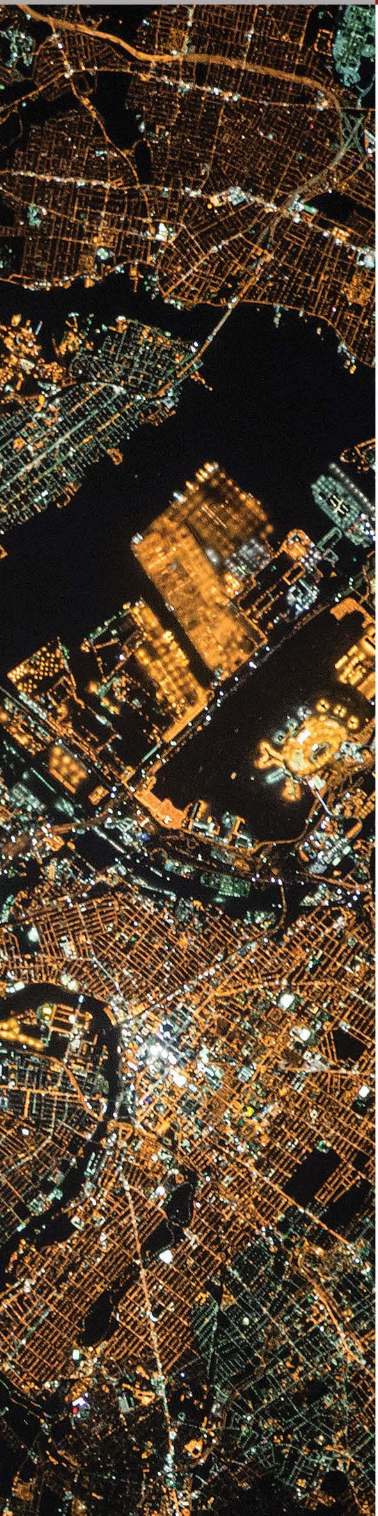

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JCIP

Richard M. Krieg, PhD, Editor-in-Chief

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Editor-in-Chief's Letter

Richard M. Krieg, PhD

It is increasingly evident that the development of microreactors, small modular reactors (SMRs), and other advanced reactor designs will be needed to produce the least cost plan to decarbonize the nation's energy sources by 2050.[1,2] Much of this JCIP issue supports the view that the deployment of these small reactors should be moved to the forefront of national policy.

A reduction in nuclear plant size is essential to decrease capital costs and to increase plant safety. Small reactors in the US fleet would be factory-assembled with advanced quality control. They would incorporate passive safety systems as well as safer 10-year refueling cycles, faster component production, and greater economies of scale. Moreover, microreactors could power individual industrial plants, military bases, remote communities, and be rapidly deployed to natural disaster areas. These smaller units could also contribute to renewable heating. And with many nations jockeying for primacy in what is anticipated to be a market exceeding a trillion dollars, it is essential that the US maintain technological leadership and manufacturing capacity in the advanced nuclear sector.

More rapid deployment of this promising technology will require adequate federal R&D support, an increased domestic nuclear fuel supply (both LEU and HALEU)[3], with solid progress in streamlining regulatory barriers. In particular, the total time required for development and regulatory reviews must be reduced in a smart fashion.

Previous issues of the *Journal* have addressed how SMRs could enhance electric grid and critical infrastructure resilience. They included the development of resilient nuclear power plants, resilient critical infrastructure islands and the ability of SMRs to function as grid black start units.[4] We recently published a cornerstone article by Decker and Rauhut on incentivizing good governance beyond regulatory minimums in the civil nuclear sector.[5]

1 SMR generation 50-300 megawatts electric (Mwe); microreactors <50 MWe; conventional reactors 1,000 MWe

2 M. Stein, J. Messinger, S. Wang, S, J. Lloyd, J. McBride, R. Franovich, *Advancing Nuclear Energy: Evaluating Deployment, Investment, and Impact in America's Clean Energy Future*. Breakthrough Institute. July 2022.

3 LEU = Low Enriched Uranium; HALEU = High-Assay Low-Enriched Uranium

4 S. Greene, "How Nuclear Power Can Transform Electric Grid and Critical Infrastructure Resilience", *Journal of Critical Infrastructure Policy*, Fall/Winter 2020.

5 D. Decker and K Rauhut, "Incentivizing Good Governance Beyond Regulatory Minimums: The Civil Nuclear Sector", *Journal of Critical Infrastructure Policy*, Fall/Winter 2021.

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The current edition begins with my **Editor-in-Chief's Interview with Maria Korsnick**, President & CEO of the Nuclear Energy Institute (NEI). A highly respected leader on Capitol Hill, in State capitals, and internationally, Ms. Korsnick and her organization provide a unified industry voice on key nuclear policy issues. Her operational background as a chief nuclear officer (CNO) and other high-level nuclear facility and regional corporate leadership roles provide an ideal perspective to integrate the scientific, organizational, professional and policy dimensions of the nuclear power transformation. Our interview drills down on Ms. Korsnick's perspective on the rolls that nuclear energy should play in addressing climate change, the need for SMR and microreactor deployment, and other issues of importance to the nation.

"Nuclear Policy in the States: A National Review", by **Daniel Shea**, represents a major advance in understanding state policy contributions to nuclear industry momentum in recent years. From his post at the National Conference of State Legislatures (NCSL), Mr. Shea has produced a number of authoritative reports on state energy policy. In the present article, he describes a doubling since 2016 in nuclear energy-related policies considered by state legislatures—to more than 160 bills in the past legislative session. The in-depth analysis drills down on the precursors to state-level nuclear energy action, the history of nuclear energy policy, and the dynamics of state-level policy development and implementation in the nuclear area. It is essential reading even as recent federal legislation can be expected to have an outsized effect in the nuclear policy.

Richard Mroz, in "How Advanced Nuclear Generation Technologies Support Electric Grid Resilience", addresses how advanced nuclear generation technologies can directly enhance electric grid resilience as well as support the resilience of renewable generation sources tied to the grid. In addition to many national leadership roles, as former President of the New Jersey Board of Public Utilities and former Chair of the Critical Infrastructure Committee of the National Association of Regulatory Utility Commissioners (NARUC), Mr. Mroz has a ground-level understanding of the integration of advanced nuclear with current energy production systems.

In "The Energy Transition: Advanced Nuclear Needed but Address Climate Change Vulnerabilities Now", **Andrew Bochman** provides a strategic perspective on grid security, the national energy transition underway, and critical infrastructure climate resilience. Based on the electric grid's crucial roles in permitting national economic health as well as being central to population health, Mr. Bochman's editorial argues that utility planners need to adequately respond to climate vulnerabilities. The decision rules and criteria used to set energy policy at the state and national levels must reflect the reality of climate change as the US moves forward.

Jean-Paul Allain and Sandra Allain in "The Post-Industrial and Appalachia (PIMA) Nuclear Alliance," provide a vision of the future of microreactor deployment. The Alliance is aimed at having transformational impact on the region, in mitigating the climate crisis and fostering economic development by introducing micronuclear reactors across difficult-to-decarbonize industrial sectors enabling a sustainable, just, and resilient clean energy transition in the PIMA region at scale. Penn State with its 24 commonwealth campuses throughout Pennsylvania serves as an important demonstration hub for advanced nuclear technology supporting research, development, deployment, and community economic development. The University's plans are predicated on a sophisticated understanding of the multitude of factors required for successful implementation.

Central to the initiative is a Penn State and Westinghouse collaboration on research and development efforts focused on exploring and applying nuclear engineering and science innovations to societal needs. A memorandum of understanding detailing the partnership — the first one between Westinghouse and a university in the United States. The partnership entails exploring the siting of Westinghouse's eVinci micro-reactor, a next-generation, small modular reactor designed to address sustainable power needs from immediate use in large communities to decentralized remote applications.

Hillary Fishler, Nahuel Guaita, Dawn Davis, and Joshua Fishler, in "Challenges to Implementing Microreactor Technologies in Rural and Tribal Communities", explore community receptivity to microreactor deployment. Specifically, this technology has the potential to provide inexpensive and reliable electricity for isolated and disadvantaged populations. However, deployment in rural and tribal communities may face more barriers than in urban areas due to a lack of capacity at the institutional and organizational levels. Potential barriers include difficulty in gaining community buy-in for microreactor deployment and pressure to address community issues deemed to be more important.

The authors of provide recommendations to overcome these barriers. One such strategy is robust community engagement and outreach, which aims to address roadblocks in a mutually beneficial manner. Additionally, the authors recommend considering current networks of informal governance, citizen groups, and the inherent values, social norms, and cultural beliefs of each community. The article is relevant to the Biden administration's Justice40 Initiative, which aims to allocate 40% of infrastructure funding towards disadvantaged communities experiencing environmental injustice. Research and development priorities under the Department of Energy also prioritize addressing service gaps and energy poverty.

Juhann Waller's "Stormwater Capital Improvement Planning: A Framework for Project Identification and Prioritization for Pluvial Flood Mitigation",[6] presents a new multi-criteria decision and analysis (MCDA) conceptual frame-

6 Pluvial floods refer to surface water floods as opposed to river (Fluvial) floods. This type of flooding typically occurs when surface water accumulates from intense rainfall that saturates, for example, an urban drainage system.

work for stormwater capital improvement planning, hazard mitigation and resiliency planning. It is also applicable to broader policy development and planning activities. Specifically, it is a novel approach to integrate resilience and environmental justice principles into planning and urban drainage infrastructure policy decisions. Called UDRIS (Urban Drainage Resilience Index System), the framework should enhance the ability of policy makers and policy implementers to reach compromise between competing interests and to increase transparency and pragmatism in evaluating the needs of different communities for flood infrastructure investment.

Mary Lasky, in "Outcomes of the 2022 InfraGard National Disaster Resilience Council Summit", describes strategic directions that the NDRC took in 2022, some of which will continue into 2023. In addition to serving as NDRC chair, she coordinates all InfraGard Cross Sector Councils and serves on the InfraGard National Board. InfraGard National has over 80,000 active members across the US, representing the organizations, government entities and businesses comprising the Nation's sixteen critical sectors. In her *Practice Advances* piece Ms. Lasky describes work that NDRC undertook in 2022, including a three-dimensional assessment of the severe critical infrastructure challenges faced by Ukraine, monitoring and analyzing foreign adversary threats to US critical infrastructure, a Grid-in-the-Box project, as well as improving both critical infrastructure and citizen resilience. Consistent with their missions, JCIP has a partnership with InfraGard National to coordinate on behalf of critical infrastructure resilience.

In "The Electromagnetic Threat to the US: Resilience Strategy Recommendations", **Samuel Averitt, Erik Dahl, and Daniel Eisenberg** generally assess US readiness to withstand the effects of a large-scale electromagnetic pulse or geomagnetic disturbance. In addition to providing basic background on these challenging threats, they use a thought experiment methodology and a resilience engineering approach to determine vulnerabilities and potential courses of action. These include applying four concepts of resilience—Sense, Anticipate, Adapt, and Learn (SAAL Model)—and four concepts associated with resilience: Rebound, Robustness, Extensibility, and Adaptability. The authors' readout of vulnerabilities and potential impacts confirm the need for a sharper focus and greater haste in implementing appropriate EMP/GMD resiliency measures.

Small Nuclear Reactors Essential to the US Energy & Climate Change Future

Editor-in-Chief's Interview with Nuclear Energy Institute President Maria Korsnick

Maria Korsnick is president and chief executive officer at the Nuclear Energy Institute (NEI). The Institute's mission is to promote the use and growth of nuclear energy through efficient operations and effective policy. It accomplishes this by providing a unified industry voice before Congress, the executive branch, state and local legislatures, and federal regulators, as well as international organizations and venues, on key policy issues. Drawing on her engineering background, hands-on experience in reactor operations, and deep knowledge of energy policy and regulatory issues, Korsnick aims to increase understanding of nuclear energy's economic and environmental benefits among policymakers and the public. Before joining NEI, she was senior vice president of northeast operations for Exelon Corp., responsible for overseeing operation of the Calvert Cliffs 1 and 2, R.E. Ginna, and Nine Mile Point 1 and 2 nuclear power plants. Exelon operates the largest fleet of nuclear plants in the US with 21 reactors at 12 facilities spanning Illinois, Maryland, New York and Pennsylvania. Prior to Exelon, Korsnick served as chief nuclear officer (CNO) and acting chief executive officer at Constellation Energy Nuclear Group. She began her career at Constellation in 1986 and held positions of increasing responsibility including engineer, operator, manager, site vice president, corporate vice president, and CNO. She holds a bachelor's degree in nuclear engineering from the University of Maryland and has held a senior reactor operator license.

Krieg How has your engineering background and experience in nuclear reactor operations influenced your work as NEI President & CEO?

Korsnick It all really comes down to my passion for nuclear energy, technology, and what it means for our clean energy future. Before joining NEI, I

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spent more than 30 years hands on at nuclear plants, from engineer, operator, manager, site vice president to corporate vice president and CNO. Each step of the way has really led me here to this critical moment for climate and energy.

At a certain point in my career, I realized that nuclear is not widely understood or valued for the reliable, resilient, carbon-free power it provides, which thankfully led me to the Nuclear Energy Institute (NEI). It has always been NEI's mission to help get that message to policy makers, regulators, and the public. My passion and deep knowledge of energy policy and regulatory issues made it an easy choice to help lead NEI's efforts to increase understanding of nuclear energy's economic and environmental benefits among policymakers and the public.

Krieg The logic for a robust and dynamic nuclear sector is becoming abundantly clear. As DOE Secretary Jennifer Granholm and others have argued, expanding the domestic nuclear sector will be essential to meet national energy system decarbonization goals. Could you elaborate on that?

Korsnick We already know that nuclear energy is the most reliable, scalable, carbon-free option we have. So, if we really take a look at what it takes to achieve the true, deep decarbonization that the world desperately needs, it is clear that nuclear must be the backbone of the power sector, alongside growing shares of wind and solar.

Nuclear energy is the source that can make it all work—not just electricity production, but job creation, economic revitalization, and decarbonization. Nuclear plants produce the most carbon-free electricity in the country, which is why urban and rural communities count on them for clean, reliable power around the clock.

Krieg We are at a seminal moment—some would say an inflection point—in the development of advanced reactor technologies, including small modular reactors (SMRs) and microreactors. Key SMR benefits are linked to their small footprint and the fact that prefabricated reactor components can be manufactured and shipped to deployment sites. What are the full range of SMR benefits?

Korsnick When we talk about the next generation of reactors we are not talking about your grandfather's nuclear plants. Developers are creating simpler designs, incorporating factory construction, and working to lower overall construction and operating costs to be more competitive with other forms of energy generation.

These new designs will come in a wide range of sizes, from a few megawatts to more than 1,000 (like traditional reactors). This will allow owners to tailor their electricity generation to their energy demands. This is particularly important for smaller companies, rural electric cooperatives, or municipal agencies and for isolated and distributed applications.

But the possibilities go well beyond electricity generation. The nuclear reactors of tomorrow—some less than a decade away—will offer a variety of benefits such as water desalination, process heat and alternative fuels generation, and access to power beyond the grid. They will help remote areas have reliable and clean electricity options and provide immediate power after a disaster. Some designs will even allow us to recover and recycle elements in used nuclear fuel that can still produce energy.

Krieg How does the existing nuclear fleet and advanced large design reactors fit into the nuclear industry in the future?

Korsnick The clean energy system of the future is anchored by the strength and resilience of our current reactors, which produce nearly a fifth of U.S. electricity and half of our carbon-free generation, but we will need even more nuclear energy to meet increasing demand. In this clean-energy future I talk about, hundreds of reactors, from large, existing models to newer, advanced reactors, dot the landscape.

The momentum we're seeing at the federal and state level is a testament to the value of our existing fleet and our progress on next-generation technology. On the federal level the passage of the bipartisan infrastructure act and the Inflation Reduction Act sends a clear signal that nuclear is essential in the transition to a carbon-free economy and provides confidence to invest in not only nuclear's present but its future as well, opening a bright path toward the next generation of reactors.

In states like California and Illinois, we have seen policymakers pass legislation, keeping critical nuclear plants open when faced with closure, while in states like West Virginia, Montana and Wisconsin policy makers have lifted legacy bans on new nuclear projects. When looking at advanced reactors, we are seeing states like Indiana pass laws paving the way for SMR deployment and similarly with support from the state of Tennessee, TVA announced a $200 million program to explore advanced light-water designs.

What's exciting is I don't think we are going to see a one-size-fits-all future with nuclear. Especially when you look beyond the United States. People will have options—various makes and models that make nuclear a versatile solution to decarbonize the economy.

Krieg In September, the Department of Energy released a report indicating that fully 80% of US coal power plant sites could be converted to small reactor sites, with numerous benefits to local mining communities, substantial cost savings, and positive environmental implications. Do you agree?

Korsnick As next-generation nuclear reactors come to the market, customers recognize that these technologies can meet their electricity and economic needs at the same time. The new reactors, which are simpler, smaller, and more flexible, can use much of the existing infrastructure surrounding a coal plant. This will allow host communities to maintain existing jobs while also creating high-paying new ones.

A recent report looked specifically at communities transitioning from coal to nuclear. The report estimated that each small modular reactor sited to replace a retiring coal plant would provide hundreds of on-site jobs. At coal sites, we estimate that up to 75 percent of the current workforce could transition to work at a nuclear plant. These jobs would exist throughout the entire life of the plant, 60 plus years, and pay substantially higher wages.

Hundreds of coal plants are scheduled to close in the next several years but that shouldn't leave local economies behind. When we invest in next-generation reactors, they can utilize existing coal infrastructure, which avoids the need for new transmission to connect these plants to the grid.

Advanced nuclear reactors will be local economic engines. They'll provide quality, secure jobs. They'll bring tax revenue to support schools, libraries and first responders. And they do it all without emitting air pollutants that harm people's health.

Building these reactors can make the transition to clean energy a just economic transition. Investments in nuclear energy are investments in working people.

Krieg Over 70 commercial SMR designs are in various stages of development here and overseas. Two SMRs began operation at Russia's floating Akademik Lomonosov facility during 2020. China is building the world's first land based commercial SMR in Hainan. Given the tempo of foreign-led SMR activity, is the pace of domestic SMR development, nuclear R&D, and actual facility construction on the right trajectory?

Korsnick We are confident we will see new technologies built this decade. This is our time to prove ourselves. It's on the industry to demonstrate that we can build these technologies on time and economically. That's why these demonstration projects are critical--to take learnings that will create a system that is efficient. We need to get into the rhythm of new builds. As we build confidence, I anticipate we will see even more customer commitments for all the reasons that make nuclear a valuable part of our climate solution.

Krieg How can the pace of U.S. SMR development and deployment be quickened? Beyond national security and climate change concerns, it's been estimated that global demand for nuclear power could eventually produce a multi-trillion-dollar export market for the U.S. nuclear industry. In broad strokes, what is the critical path to meet this opportunity?

Korsnick The industry must demonstrate we can get these deployed on time—and that's what we will see this decade. Companies are waiting to see these demonstration projects take off—and from there I anticipate, based on what we are hearing from our members, we will see a wave of new builds.

At this point, our challenge isn't a lack of demand, it's being able to build fast enough to meet the demand before us. First, the Nuclear Regulatory Commission is going to face a rapidly growing volume of applications for new reactors and siting & construction permits. If we're going to build them, we need a more efficient process. Regulators must have the capacity to efficiently review and approve licenses and permits so these reactors can come online.

We are not talking about demand for 10 or even 20 reactors. NEI recently polled Chief Nuclear Officers at our member utilities. Together, they are expecting to add 90 gigawatts of nuclear power to the grid in the U.S. with the bulk of that coming online by 2050.

That translates to about 300 new small modular reactors in the next 25 years. That type of production would double U.S. nuclear output today.

We are working with our members to help prepare the NRC to meet this moment. We are exploring solutions to improve the licensing process to be more efficient and develop a framework that recognizes the unique characteristics of these new designs. This is all critical to ensuring these reactors can be online in time to meet our climate goals.

Financing plays a key role in bringing these technologies to reality, and we are going to need investments in our technology to reach the reliable, carbon-free grid of the future. We need investors to see what global leaders see in the next generation of reactors. These designs are more cost-efficient than ever. They're smaller and simpler. Some designs can even be factory-made and shipped to their destination.

One of the most important things we can do as an industry is engage and educate the ESG and larger financial community about both existing nuclear power and new reactor technologies. That is something we are taking on at NEI. We are making a case that nuclear is a critical part of a just and clean energy transition. Over the next five to six years, investors will see for themselves that the newer designs are not your grandfather's nuclear plants. The newer designs being developed are being built with economic and consumer needs of the future in mind.

Krieg Assuming that the US can marshal itself to deploy the current nuclear fleet and advanced reactor designs of all types to 40 percent of overall electricity production by mid-century, what would that year 2050 energy sector look like?

Korsnick The numbers are clear—renewables alone can't meet our climate goals. The United Nation's Climate Panel has been clear that nuclear energy is a necessary part of our energy transition. We must look at the whole picture, and that starts with looking at what the customer needs.

What they need is a complement of sources that will get us both carbon-free energy, but abundant amounts of reliable and affordable energy that can flow 24/7, and that means a partnership between wind, solar and nuclear.

Study after study has shown the surest way to affordably achieve carbon reductions is by including nuclear energy. Doing so will allow us to decarbonize while avoiding the need to over-build renewables and to massively expand our long-distance transmission system. A study commissioned by Energy Northwest found that under a complete decarbonization scenario, the Pacific Northwest could save more than $8 billion PER YEAR by keeping nuclear plants online and adding multiple SMRs instead of trying to decarbonize the grid using just renewables and storage.

If we rely on wind and solar to do the heavy lifting, the system costs would be truly prohibitive according to research from Stanford University, the Clean Air Task Force, Environmental Defense Fund, and other groups. Nuclear energy forms the backbone of a stable electric grid that includes large shares of other carbon-free sources like wind, hydropower and solar, alongside the latest in battery storage technology. The upshot is clear: Nuclear is the critical component that actually makes complete decarbonization affordable while keeping our grid reliable.

Krieg How would you characterize both federal and state policy support for nuclear industry revitalization and leadership? From a public policy perspective, is sufficient attention being paid to the need for efficient processing of advanced reactor licensing, government funding streams, and other policy-level changes capable of advancing the timetable for advanced reactor deployment.

Korsnick The level of bipartisan support for nuclear is remarkable. No matter where you sit on the political spectrum, nuclear has something for everyone. Support for nuclear starts at the White House. In 2021, the Biden Administration declared the next few years a "can't miss opportunity" for nuclear. U.S. Energy Secretary Jennifer Granholm has also called nuclear an "absolutely critical part of our decarbonization equation."

At the other end of Pennsylvania Avenue, a bipartisan majority in Congress recognizes that the path to an affordable, carbon-free future runs through nuclear energy and that means maintaining our current fleet as well as deployment of new technologies. And they're backing it up with unprecedented levels of funding. We have seen support in the Inflation Reduction Act proposal for nuclear tax credits, which will preserve the current plants, while also incentivizing new nuclear builds.

States have harnessed this support as well in their transition away from coal. Ten years ago, we would have been lucky to see even a dozen pro-nuclear bills moving through state legislatures. In recent years we've seen ten times more action in the states and more than 100 bills supporting nuclear. It's becoming "not so much, not in my back yard—but please in my back yard."

Nuclear Policy in the States: A National Review

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Introduction

The nuclear energy industry has regained momentum over the past several years, with state policy serving as a major springboard for that change in fortune. Following a decade characterized by disaster and disappointment for the nuclear industry, policy decisions in the early 2020s have propelled nuclear power forward as a viable resource to support decarbonization efforts while maintaining power system reliability.

Despite only constituting 8% of electric generating capacity in the United States, nuclear power produces nearly 20% of total electricity because nuclear reactors are nearly always operating—outperforming all other resources in this statistic [1] [2]. Perhaps more significantly, given recent trends in public opinion and energy policy, nuclear power accounts for around half of all carbon-free electricity in the U.S.[3] [4] [5]. As lawmakers from across the political spectrum reckon with how the energy transition could affect their communities and constituents, many have increasingly found common ground in the role nuclear energy can play in the process.

While recent federal legislation will have an outsized effect on nuclear power developments over the coming years, state policies have paved the way for many of the clean energy technologies that will transform the U.S. electric grid over the coming decades. State legislatures, in particular, oversee the regulatory environment in which electric utilities operate; these policies affect how utilities plan for the future and the investments they make. While states have widely focused on renewable energy and energy efficiency, a growing number are considering the role nuclear power might play moving forward.

The National Conference of State Legislatures (NCSL) tracks state energy policies across a variety of topic areas[6]. Since 2016, NCSL has seen a near-doubling

1 "Electricity generation, capacity, and sales in the United States," U.S. Energy Information Administration, Washington DC, July 2022.

2 "What is Generation Capacity," U.S. Department of Energy, Office of Nuclear Energy, Washington DC, May 2020.

3 A. Tyson, C. Funk, B. Kennedy, "Americans Largely Favor U.S. Taking Steps to Become Carbon Neutral by 2050," Washington DC, March 2022.

4 A. Ray, D. Shea, C. McMichael, A. Igleheart, "2021 Legislative Energy Trends," National Council of State Legislatures, Washington DC, April 2022.

5 J. McDermott, "Majority of US states pursue nuclear power for emissions cuts," Associated Press, Washington DC, January 2022.

6 "Energy State Bill Tracking Database," National Council of State Legislatures, Washington DC, November 2022.

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in nuclear energy-related policies considered by state legislatures—up from 74 total bills considered in 2016 to more than 160 bills during the current legislative session. State legislatures have also enacted a greater number of bills over that same timeframe. While five states enacted nine bills in 2016, at least 12 states have enacted 14 bills in 2022.

These policies vary in their approach and scope. In the mid-2010s, the focus among state policymakers mainly involved existing reactor preservation. Many operating nuclear power plants were struggling to compete with natural gas and renewable generation, leading to the premature closure of several nuclear power plants. In response, at least six states enacted policies to prevent the premature closure of existing reactors. While those efforts have remained poignant, in more recent years, a growing number of states enacted policies aimed at developing new nuclear capacity to support of clean energy goals or reliability. This represents a shift from defensive posturing toward a more proactive posture.

These policies have been enacted by both red and blue states—a reflection of the increasingly bipartisan position nuclear power occupies in U.S. political discourse. The passage of recent federal legislation—in particular, the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA)—only appears to have added momentum to initiatives that began at the state level. In the coming years, NCSL anticipates that state legislatures will continue to enact policies in support of nuclear power to leverage funding and financing opportunities in the IIJA and IRA. This article provides a review of these recent state and federal initiatives, along with a brief historical review of nuclear developments in the U.S. over the past two decades.

How We Got Here

The nuclear power industry has experienced a whirlwind over the last 20 years. Following the passage of the 2005 Energy Policy Act, many anticipated a "nuclear renaissance" in the United States. It had been nearly a decade since the last nuclear reactor was brought into service—Watts Bar Unit 1, which began construction in 1973 and wasn't completed until 1996. Since then, new reactor development largely dried up due to high upfront costs and a history of construction delays. But the Energy Policy Act promised to change those dynamics with loan guarantees, cost-overrun support and a production tax credit (PTC) for the first 6,000 megawatts (MW) of new nuclear capacity to come online.

To leverage the federal incentive, Florida, Georgia and South Carolina enacted state policies to further incentivize utilities to pursue new nuclear. Understanding that the upfront costs were still a major hurdle for utilities, state legislators in these states enacted construction work in progress (CWIP) laws for new nuclear projects. CWIP is a financing mechanism that enables utilities to finance capital projects by periodically recovering costs from customers throughout the duration of construction. Normally, utilities can't recover those costs until the project has been brought into service. However, since large nuclear projects can take upwards of a decade to build, CWIP laws aim to make those initial hurdles easier to clear by allowing utilities to recover costs throughout project development, thereby reducing the risk to utility companies and their shareholders, and reducing the overall amount that is needed to finance a project. While state utility regulatory commissions (PUCs) approve costs and oversee progress, consumer advocates have argued these laws shift too much risk to customers.

Between the federal incentives and state CWIP laws, a flurry of activity between 2007 and 2010 suggested that a nuclear renaissance would materialize. In fact, the Nuclear Regulatory Commission (NRC) received applications for construction and operating licenses to build nearly 30 new reactors—a staggering figure since the combined capacity of those units would represent more than a third of the existing fleet.[7]

Disaster and Economic Troubles

However, that momentum came to a sudden halt in March 2011 after the disaster at the Fukushima Daiichi nuclear power plant in Japan. Triggered by an earthquake and tsunami, the event catalyzed opposition to nuclear power over safety concerns. Ultimately, only four of the new reactors broke ground—two at Plant Vogtle in Georgia, and two at V.C. Summer Nuclear Generating Station in South Carolina.

Not only had public sentiment turned against nuclear power, but so had the economics of power generation. In 2005, the average price of electricity in the PJM Interconnection, the largest wholesale electricity market in the U.S., was $63.46 per megawatt-hour (MWh).[8] By 2009, the average price had dropped to $39.04 per MWh. This was no aberration. It was the first hint at the Shale Revolution's impact on the U.S. power market. Hydraulic fracturing unlocked vast natural gas resources, causing the price of natural gas to plummet and—until this past year—largely stabilize.

Over the ensuing decade, natural gas has taken on a larger share of electricity generation, recently accounting for nearly 40% of total electric generation in the U.S.[9] Not only did natural gas almost halve the emissions from coal-fired power, but it complemented another increasingly cheap source of power: renewable ener-

7 "Combined License Applications for New Reactors," U.S. Nuclear Regulatory Commission, Bethesda, Maryland, September 2022.

8 "2020 State of the Market Report for PJM," Monitoring Analytics, Eagleville PA, March 2021.

9 "What is U.S. electricity generation by energy source?," U.S. Energy Information Administration, Washington DC, November 2022.

gy[10]. Together, natural gas and renewables set wholesale power prices in organized wholesale electricity markets throughout much of the 2010s. Until this year, those power prices trended lower and lower—generally between $30 and $40 per MWh in the PJM region, but dropping as low as $21.77 per MWh in 2021.

Generally, that's a good thing. Lower wholesale power prices translate into lower power bills for customers. But for nuclear power plants in wholesale markets, those prices led to thinner and thinner operating margins, ultimately causing many nuclear plants in wholesale markets to operate in the red. Since 2013, 13 nuclear reactors with more than 10,000 MW in combined capacity closed prematurely due to these market conditions[11]. That capacity has been replaced largely by new natural gas-fired generation.[12]

States Decide to Act

As nuclear plants began to close, policymakers began considering whether to respond. Nuclear power accounts for only around 8% of total electric generating capacity in the U.S., but generates nearly 20% of total electricity.[13] That is because most nuclear plants operate around-the-clock, with a capacity factor of nearly 93% in 2021[14]. That means that, on average, nuclear plants in the U.S. generated at maximum capacity around 93% of the time last year—nearly twice the capacity factor of resources like coal and natural gas, and triple that of wind and solar. In all, nuclear generates around half of the carbon-free electrons that flow on the U.S. power grid. At a time when electric grid decarbonization became a growing priority, some policymakers felt the need to prevent these large, reliable sources of carbon-free power from closing.

In an effort to preserve carbon-free energy and high-paying jobs, six states have enacted policies since 2016 to provide financial support to struggling nuclear power plants. Four of those states—Connecticut, Illinois, New Jersey and New York—have active policies that provide nuclear power plants with additional revenue. These policies were designed to provide support only to nuclear plants that demonstrate they would likely shut down without state assistance—largely justified based on the avoided carbon dioxide emissions that those power plants represent. Three of those policies were designed in the form of zero emissions credits

10 G. McGrath, "Electric power sector CO2 emissions drop as generation mix shifts from coal to natural gas," U.S. Energy Information Administration, Washington DC, July 2021.

11 M. Holt, P. Brown, "U.S. Nuclear Plant Shutdowns, State Interventions, and Policy Concerns," Congressional Research Service, Washington, D.C., June 2021.

12 J. Anderson, K. Hallahan, "Gas-fired power increased with nuclear plant closure; path to climate goals unclear," S&P Global Commodity Insights, New York NY, November 2021.

13 "Electricity generation, capacity, and sales in the United States," U.S. Energy Information Administration, Washington DC, July 2022.

14 "What is Generation Capacity," U.S. Department of Energy, Office of Nuclear Energy, Washington DC, May 2020.

(ZECs), which provide qualifying reactors with a supplemental payment for every MWh of carbon-free electricity sold. A new federal program created by the IIJA, the Civil Nuclear Credit Program, was predicated on these state ZECs programs.

Most recently, the Illinois General Assembly doubled down on supporting the state's nuclear fleet with the passage of the Climate and Equitable Jobs Act in 2021. The new law expanded the state's programs to support five nuclear power plants in the state—up from two nuclear plants that were supported under initial legislation passed in 2016. Last year, the Ohio legislature repealed a similar program designed to support the state's two existing nuclear plants just two years after the law was enacted. The legislature's decision to repeal the program followed federal corruption charges related to individuals involved in the original bill's passage.

The U.S. Congress recently enacted legislation establishing a similar program at the federal level. The new policy is substantially similar to these state ZECs policies. The U.S. Department of Energy is in the process of implementing this new program, which will be discussed in more detail below.

Struggles Persist for New Projects

While some states in the North were acting to preserve their existing reactor fleets, states in the South found themselves managing the new-build projects. The Tennessee Valley Authority became the first U.S. utility to bring a new reactor online in the 21st century. In an interesting twist, it was Watts Bar Unit 2—the sister unit to the last reactor brought online in the 20th century. While construction on Watts Bar Unit 2 began in 1973 alongside Unit 1, the reactor was 60% complete when TVA mothballed the project in 1985[15]. In 2007, TVA decided to complete Unit 2, which became operational in 2016. The project experienced nominal cost-overruns and construction delays—though nowhere near those happening at two projects in Georgia and South Carolina.

Projects in Georgia and South Carolina were building Westinghouse Electric Company's AP1000 reactor—a pressurized water reactor with a designed capacity of 1,110 MW, which represents a significant upgrade from the previous generation of large, light-water reactors. Georgia Power was developing two AP1000s at its Plant Vogtle, while two more AP1000s were being developed at the V.C. Summer plant in South Carolina by Santee Cooper, a state-owned utility, and SCANA Corp., an investor-owned utility.

In March 2017, Westinghouse entered Chapter 11 bankruptcy, throwing both projects into crisis—especially in South Carolina. By August 2017, the V.C. Summer reactors had been abandoned after the developers had already charged customers $2 billion for the project. Neither utility survived unscathed; Domin-

15 S. Hoff, M. Gospodarczyk, "First new U.S. nuclear reactor in almost two decades set to begin operating," U.S. Energy Information Administration, Washington DC, June 2016.

ion Energy purchased SCANA Corp., while the South Carolina state legislature required closer state oversight of Santee Cooper. The legislature also repealed its CWIP for nuclear policy, while Florida did the same and Georgia amended its statute to expire following the completion of the Vogtle project.

Ultimately, only the two reactors at Plant Vogtle survived. The plant's first AP1000 is now scheduled to come online in the first quarter of 2023, while the second is expected to follow by the end of 2023. The projects total cost is expected to exceed $30 billion—more than double the original price tag[16].

These events served as a deterrent to large reactor construction. Slowing growth in electricity demand, recent cost-overruns, along with the long timelines to development large reactors—on average, between 10 and 15 years from initial construction to when the reactor is brought online—have led many to question whether there's a role for new nuclear in the clean energy transition[17]. This is perhaps the reason the emphasis in recent years has shifted away from large reactors to prioritize small modular reactors (SMRs), which promise a departure from the previous generation's problems. Whether the industry can deliver on the promise of SMRs will be tested over the coming decade.

State Action to Support New Nuclear

In spite of the beleaguered projects in the South, the nuclear power industry finds itself with wind in its sails once again. While recent federal legislation has added considerably to this progress, state policies led the way. However, the focus has shifted considerably since 2005. The problems associated with large reactor development have not gone unnoticed, and the clear emphasis has been on technologies that tend to be smaller and modular in their design.

If a traditional reactor has a generating capacity around 1,000 MW, small modular reactors tend to be under 300 MW capacity, while microreactors have been designed to generate less than 10 MW. On a basic level, these reactors are scaled to the times. Utilities are no longer experiencing the rapid growth in electricity demand that required huge capacity additions throughout the 20th century; in some regions, demand has flattened or decreased.[18] However, the real advantage according to nuclear advocates is in the modular design and what that means for construction efficiency[19].

16 J. Amy, "Georgia nuclear plant's cost now forecast to top $30 billion," Associated Press, Washington DC, May 2022.

17 S. Hoff, M. Gospodarczyk, "First new U.S. nuclear reactor in almost two decades set to begin operating," U.S. Energy Information Administration, Washington DC, June 2016.

18 F. Kahrl, "Why have U.S. electricity sales flattened?," Energy Policy, December 2021.

19 J. Liou, "What are Small Modular Reactors (SMRs)?," International Atomic Energy Agency, New York NY, November 2021.

Building a traditional reactor is an enormous endeavor. At Vogtle, the new-build project required around 9,000 workers at its peak.[20] The reactor components are also built to specification on-site. These factors contributed to cost-overruns and delays. By contrast, SMRs are designed to benefit from factory fabrication and assembly for systems and components, which are then transported and assembled on-site. While still theoretical, centralized, standardized design and fabrication could significantly reduce the problems associated with traditional reactor projects and diminish the upfront barrier due to capital costs.

The reduced size of these reactors holds additional benefits, making these projects easier to site and tie into the existing transmission grid. Their size and capacity is similar to many coal-fired generating units, making siting SMRs at retired or retiring coal power plants of particular interest as the electric sector continues to decarbonize. Not only do these facilities have existing transmission infrastructure and water access that would benefit SMRs, but these projects could support communities and workers affected by the clean energy transition through lost jobs and tax revenue when coal plants shut down.

The U.S. Department of Energy released a recent report on this topic to investigate the potential challenges and benefits of converting retired coal plant sites into SMR sites and concluded that 80% of the nearly 400 retired and operating coal plants identified for the study could be good candidates to host SMRs[21]. In total, these sites could host a combined capacity of 265 gigawatts (GW) in generating capacity—a staggering figure in relation to existing nuclear generating capacity in the U.S., which is around 95 GW. Additionally, the report claims the use of existing transmission and other infrastructure could reduce the cost of capital for "coal-to-nuclear" projects by 15% to 35% compared with greenfield projects.

Increasingly, states are also turning to nuclear power to address reliability concerns as the resource mix shifts toward more variable resources, such as wind and solar[22]. As more variable generation comes online, the grid will require additional "dispatchable" generation to fill in the gaps in generating capacity—resources that can reliably provide power whenever the grid operator calls upon them. Nuclear is one such resource, and one of the few that does so at capacity without generating carbon emissions. In fact, recent research notes that nuclear power plant regulatory standards require these facilities to be designed to safely withstand weather events far beyond those considered for other critical infrastruc-

20 "5 Things You Should Know About Plant Vogtle," U.S. Department of Energy, Office of Nuclear Energy, Washington DC, April 2019.

21 J. Hansen, W. Jenson, A. Wrobel, N. Stauff, K. Biegel, T. Kim, R. Belles, F. Omitaomu, "Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants," U.S. Department of Energy, Office of Nuclear Energy, Washington DC, September 2022.

22 "Nuclear Power is the Most Reliable Energy Source and It's Not Even Close," U.S. Department of Energy, Office of Nuclear Energy, Washington DC, March 2021.

ture facilities[23]. As a result, researchers found that nuclear plant operations in the U.S. were rarely affected by extreme weather between 2011 and 2020—causing an average 0.1% loss of capacity factor[24]. While this argument is often a driving force in Republican-controlled states, several Democratic-controlled states have also taken action to support nuclear power for reliability.

California, with the passage of a bill aimed at extending the operating life of the state's last remaining nuclear power plant, is the latest example. Under a 2018 agreement between Pacific Gas & Electric (PG&E), state regulators and environmental groups, PG&E's Diablo Canyon nuclear power plant—a 2,250 MW plant that generates 9% of the state's total electricity—is scheduled to close its two reactors in 2024 and 2025[25]. However, the state's grid has struggled in recent years to cope with several heat waves, leading to rolling blackouts across the state and recent calls to consider extending the life of the plant to support reliability and avoid increasing the use of natural gas-fired generation.

In response to these concerns—and to recently available federal incentives—California lawmakers enacted Senate Bill 846 in September. The law allows Diablo Canyon to operate through 2030, contingent on several requirements. First, PG&E must apply to receive financial support through a new program administered by DOE: the Civil Nuclear Credit Program. Second, PG&E must relicense the two reactors—a costly process addressed by lawmakers through a $1.4 billion forgivable loan from the state. If those two requirements are met, the plant is likely to continue operations through the end of the decade. In late November, DOE announced that Diablo Canyon had been conditionally selected to receive up to $1.1 billion in credits from the Civil Nuclear Credit Program[26]. While the final terms are still subject to negotiation between DOE and PG&E, the news represents another step toward the plant's continued operation.

In the context of advancements in nuclear technologies, coupled with state and utility decarbonization goals and reliability concerns, a growing number of states have started to enact policies to either explore or support new nuclear reactor development or the preservation of existing reactors. As noted, both red and blue states have enacted these policies, demonstrating that nuclear power has increasingly attained consistent bipartisan support in recent years.

Not only has the number of nuclear energy-related bills steadily increased since 2016, but the number of enacted bills has too[27]. In 2016, the National Confer-

23 "Nuclear Plant Resilience to Weather-Related Events Between 2011 to 2020," Electric Power Research Institute, Palo Alto CA, September 2022.

24 Ibid.

25 N. Rott, "California lawmakers extend the life of the state's last nuclear power plant," National Public Radio, Washington DC, September 2022.

26 "Biden-Harris Administration Announces Major Investment to Preserve America's Clean Nuclear Energy Infrastructure," U.S. Department of Energy, Washington, D.C., November 2022.

27 "Energy State Bill Tracking Database," National Council of State Legislatures, Washington DC,

ence of State Legislatures tracked 74 bills related to nuclear energy in 17 states. Of those, five states enacted nine bills. In 2022, NCSL is tracking more than 160 bills in 31 states. Of those, at least 12 states have enacted 14 bills in 2022.

And while the ideological and policy reasons for supporting nuclear power may differ, the end result appears to be beneficial to the nuclear power industry. Beyond the preservation of existing reactors, which has already been addressed in this article, these trends can be grouped into the following categories.

Clean Energy Standards

One of the more notable developments in energy policy following the 2016 presidential election was that a large number of Democratic-controlled state legislatures strengthened their support for clean energy. The primary vehicle for state clean energy goals over the past two decades has been through renewable portfolio standards (RPS) that required a certain percent of a regulated utility's retail electricity sales to come from renewable resources[28]. Prior to 2016, most standards were set at relatively modest levels—usually between 10% and 25% of retail sales by a certain date. However, those standards have evolved in two notable ways since 2016.

In the first trend, states increased the requirements—often substantially. Overall, 15 states, two territories and Washington, D.C., have increased their requirements in that timeframe. Of those, 10 states, two territories and Washington, D.C., increased their standards to 100% of retail sales with deadlines ranging from 2030 to 2050, while another three states increased their standards to 50% or greater.

The second trend is that some of those states expanded the types of resources included in their standards. Perhaps unsurprisingly, RPS have traditionally included renewable resources like wind, solar, geothermal and hydropower. Resources like nuclear power or fossil generation outfitted with carbon capture and sequestration (CCS) technologies did not quality, because the purpose of the RPS model was to support nascent technologies to bring them to cost parity with existing resources. Given that renewables are cheaper to build than most other current energy, it can be said that the RPS model has been successful[29].

However, even with that success, emissions in some markets rose with the closure of nuclear power plants as grid operators relied on natural gas-fired generation to balance variable renewable output[30]. In response to these and other concerns, lawmakers in a number of states shifted the focus slightly from supporting

November 2022.

28 C. McMichael, "State Renewable Portfolio Standards and Goals," National Council of State Legislatures, Washington DC, August 2022.

29 D. Baker, "Renewable Power Costs Rise, Just Not as Much as Fossil Fuels," Bloomberg News, New York NY, June 2022.

30 B. Storrow, "3 states with shuttered nuclear plants see emissions rise," Politico, Washington DC, February 2022.

renewable power with the side-benefit of emissions reductions, to prioritizing emissions reductions with the side-benefit of supporting renewable power.

This is where clean energy standards (CES) emerged, with at least eight states deciding to broaden the list of resources supported beyond traditional renewable resources. The focus with CES policies is on emissions reductions, so most of these policies support "carbon-free" or "carbon-neutral" technologies. In states without restrictions on new nuclear, that opens the door for nuclear power and CCS-equipped fossil-fired power plants to qualify under these programs.

It's important to note that renewables in these states still receive the lion's share of the support. CES policies have generally been enacted while strengthening the state's RPS policy. For example, California's CES policy still maintains an RPS requiring 60% renewable power by 2030; New Mexico's requires 80% renewables by 2040. However, the balance—whether 20% or 40%–must come from carbon-free resources, giving nuclear power a potential role to play in meeting state clean energy goals.

Repealing Restrictions on New Nuclear

While states like California and Oregon have enacted CES policies, both states would need to repeal existing restrictions on the development of new nuclear power before additional nuclear capacity could be used to comply with the state CES. Like 10 other states, California and Oregon have restrictions on the construction of new nuclear power facilities.[31]

In many cases, these restrictions are less about nuclear power and more about nuclear waste. Given the impasse in Congress about how to—or whether to—move on from Yucca Mountain as the nation's designated site to house a deep geologic repository for commercial spent nuclear fuel, states have been reluctant to build more nuclear generation without a clear waste disposal solution. A waste solution is at the heart of restrictions on new nuclear in six states. The remaining states either require the state legislature or voters to approve a project before it can commence, while Minnesota is the only state with an outright ban on all new nuclear power facilities.

Of course, these are statutory restrictions and subject to change. Kentucky, Montana, West Virginia and Wisconsin have all repealed similar restrictions since 2016. Similarly, Connecticut enacted a partial repeal—providing for an exemption to its restrictions. While these repeals do nothing more than remove a barrier to development, it is another indication of how states have opened the door once again to nuclear—particularly in states with a historic connection to coal.

31 D. Shea, C. McMichael, "States Restrictions on New Nuclear Power Facility Construction," National Council of State Legislatures, Washington DC, August 2022.

Coal-to-Nuclear

Repurposing retired or retiring coal-fired power plants to be used for new nuclear is not a new concept. There are a number of logical similarities between nuclear and coal—the two resources that have long served as the backbone of the electric grid, providing steady, "baseload power." The scale of SMRs theoretically would fit within the parameters of existing coal sites. Existing switchyard, transmission infrastructure and water rights, could be utilized to reduce costs and regulatory hurdles. The existing labor force could be re-trained to operate the nuclear facility—after all, when you boil it down to the basics, both are thermoelectric power plants. These similarities and more have been explored in a variety of research papers, and DOE has recently added to the literature with its own study exploring the potential[32].

It is not surprising that states with historic ties to the coal industry have begun exploring this possibility. Nuclear represents a familiar industry for policymakers in these states, where an emphasis on power reliability and economic contributions—including high-paying jobs—are foundational to the debate over the energy transition.

While Kentucky, Montana and West Virginia have all repealed restrictions on new nuclear development, the two most influential pieces of legislation in this area have been enacted by lawmakers in Indiana and Wyoming.

Wyoming was the first state to pass "coal-to-nuclear" legislation in 2020. House Bill 74 directs state regulators to develop rules and regulations to authorize SMR permitting for owners of existing coal and natural gas power plants that want to replace those facilities with SMRs. The bill requires SMR developers to acquire all of the necessary licenses and permits from the NRC, while providing a streamlined process at the state level—along with the state's explicit support for such projects.

The following year, TerraPower, an advanced reactor company, announced that it had selected a retiring coal-fired power plant in Kemmerer, Wyo., as the site on which to build its first reactor. DOE is investing nearly $2 billion in the project, which has benefitted from the department's Advanced Reactor Demonstration Program[33]. Upon successful completion, PacifiCorp, an investor-owned utility operating across six Western states, plans to acquire and operate the new reactor. In October 2022, PacifiCorp and TerraPower announced plans to explore the potential of deploying up to five additional TerraPower reactors, paired with energy storage systems, in the utility's service territory by 2035.

32 J. Hansen, W. Jenson, A. Wrobel, N. Stauff, K. Biegel, T. Kim, R. Belles, F. Omitaomu, "Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants," U.S. Department of Energy, Office of Nuclear Energy, Washington DC, September 2022.

33 "Next-Gen Nuclear Plant and Jobs Are Coming to Wyoming," U.S. Department of Energy, Office of Nuclear Energy, Washington DC, November 2021.

In 2022, the Wyoming legislature enacted Senate Bill 131, which made several technical changes to the original law, including broadening its definition of qualifying reactors to accommodate TerraPower's specific design. The legislation also added spent fuel management requirements and established certain tax exemptions if the nuclear facility sources at least 80% of its fuel from domestic supplies.

Indiana enacted its own coal-to-nuclear legislation in 2022. Senate Bill 271 similarly directs state regulators to develop rules and regulations that accommodate the construction and operation of SMRs at retiring coal and natural gas facilities. However, the bill also addressed some of the financial uncertainty around nuclear development by authorizing utilities to receive CWIP financing for these projects. Other states are also exploring the potential role for new nuclear, including Montana, which approved a study to explore the feasibility of replacing coal units with SMRs.

Support for New Nuclear

For all the interest in coal-to-nuclear, this is but one distinct trend in broader support for advanced nuclear among states. Like Montana, a number of states are exploring this by commissioning studies to consider the role new nuclear could play in the energy transition. Michigan, Nebraska, New Hampshire and Virginia have all funded studies to this effect, while a handful of additional states have considered doing so.

And while studies can often be a precursor for more substantive legislation, they're not a prerequisite. Alaska, Connecticut, Nebraska and Virginia enacted legislation over the past two years that would support new nuclear development, while Missouri has also shown signs of interest.

In 2022, Alaska enacted Senate Bill 177, which aims to streamline the permitting of microreactors—defined by the statute as reactors with a generating capacity of 50 MW or less. The bill empowers municipal governments to approve microreactor projects and requires the state to develop regulations overseeing microreactor permitting.

Connecticut enacted two relevant bills in 2022. The first, House Bill 5202, would allow the state's lone nuclear power plant, Millstone, to expand and construct another reactor on-site. However, the bill does not allow that reactor to be a large, traditional reactor. While the plant operator currently has no plans to pursue an SMR, the legislation allows for that in the future. The second bill, House Bill 5200, aims to position the state as a leader in hydrogen production and generation. The role of nuclear power in hydrogen production is currently being explored through DOE pilot programs, and this legislation includes nuclear as a potential resource to consider in developing carbon-free hydrogen as a clean energy fuel.

Nebraska Legislative Bill 84, enacted in 2021, extended existing incentives for renewable energy under its ImagiNE Nebraska Act to apply to advanced reactor companies. Meanwhile, Virginia House Bill 894, enacted in 2022, directs state agencies to convene stakeholders and identify strategies and policies to promote SMR development in the state while minimizing the impact on prime farmland and encouraging investment in industrial sites.

Finally, the Missouri House passed House Bill 1684 in early 2022, which would have provided an exception to the state's ban on CWIP financing for advanced nuclear and renewable facilities of 200 MW capacity or greater. It is the second year in a row that the House passed the measure but it failed to move in the Senate. If enacted, the bill would certainly shift the conversation around new nuclear development in the state.

However, the dynamics have shifted since the Missouri Senate decided not to take up House Bill 1684 earlier this year, following Congress' passage of the Inflation Reduction Act (IRA) in August 2022. The new federal package has several provisions that could support new reactor development regardless of additional state policies. However, it seems likely that states will consider policies moving forward that leverage the federal incentives to further incentivize a broad swathe of clean technologies—nuclear among them—that are supported by the IRA and the IIJA, which Congress enacted in November 2021.

The Impact of Recent Federal Action

While state legislative action has played an important role in preserving existing reactors and laying the groundwork for new nuclear development, recent federal action is likely to have a dramatic effect across the energy sector in its scope and breadth. Congress has acted on nuclear issues in recent years—most notably in an effort to streamline the NRC's regulations and licensing procedures to accommodate advanced reactor designs. However, the IIJA and IRA are expected to have a profound effect on the energy sector, and the nuclear energy industry is widely expected to benefit through several key provisions from those laws.

The IIJA invested $73 billion in decarbonizing and improving the reliability of the energy sector. The nuclear power industry, in particular, will benefit from several provisions. Primary among those is through the Civil Nuclear Credit Program (CNCP), discussed earlier in relation to the Diablo Canyon nuclear power plant in California. The law allocated $6 billion for the CNCP program, which is modeled off state ZECs programs to provide financial support to struggling nuclear power plants through payments for every MWh of electricity generated. Nuclear power plant owners have been calling for a program like the CNCP for some time, given that many reactors operating in states without ZECs or other programs have also been at risk of premature closure. The CNCP, which is administered by the DOE, now has the potential to support existing reactors nationwide into the

2030s, with priority allocated to reactors that source their fuel domestically. DOE has recently concluded the first award cycle, conditionally awarding Diablo Canyon with up to $1.1 billion in credits. The department issued draft guidance on the second award cycle.

Additionally, the IIJA supports the DOE's Advanced Reactor Demonstration Program (ARDP), which aims to speed up the commercialization of advanced nuclear technologies. The ARDP received an additional $2.5 billion through 2025 to support demonstrations. These awards have been instrumental in developing the TerraPower demonstration project in Wyoming, along with a second project being developed in eastern Washington by X-energy, an advanced reactor company.

Several other provisions require DOE to develop a report on how nuclear energy can contribute to meeting the nation's resilience and carbon-reduction goals, and requires the development of a standard for qualifying "clean hydrogen" from a variety of sources, including nuclear power.

While the IIJA was considered beneficial to nuclear, the IRA has only increased the industry's enthusiasm for what the future may hold for advanced nuclear in the U.S. The IRA includes a number of tax credits that could be used by nuclear power facilities—particularly for developers of new nuclear facilities—including:

- Investment tax credit for owners of new carbon-free generation, worth 30% of the amount paid to build a facility;
- A new clean electricity production tax credit for any carbon-free generator that begins construction in 2025 or later, worth at least $25 per MWh of electricity generated;
- Coal-to-nuclear bonus tax credit, offering a 10% addition for new facilities sited in coal and other fossil fuel communities that are affected by the clean energy transition;
- Clean hydrogen production tax credit based on the carbon-intensity of the hydrogen production;
- Nuclear power production tax credit for existing reactors of up to $15 per MWh from 2024 through 2032 to prevent premature closure.

The IRA also addresses growing concerns over the U.S. nuclear sector's reliance on foreign-sourced fuel. The commercial fleet of nuclear reactors in the U.S. imports most of its uranium from countries like Kazakhstan, Canada, Australia and Russia[34]. In fact, the U.S. only produces 5% of the uranium used by the cur-

34 "Nuclear Explained: Where our uranium comes from," U.S. Energy Information Administration, Washington DC, July 2022.

rent reactor fleet. And that's just the raw uranium. Russia is the leading producer of enriched uranium—the form required to be used as fuel[35]. Nearly 40% of the world's supply of enriched uranium came from Russia in 2020, and the recent war in Ukraine has only exacerbated these concerns.

This is even more pronounced when it comes to the production of high-assay low-enriched uranium (HALEU) fuel, which is required for most advanced nuclear technologies[36]. To support domestic production of HALEU fuel, the IRA provided $700 million to DOE to support the development of HALEU facilities in the U.S.

The allure of the nuclear power industry—from an economic, workforce, decarbonization and grid reliability perspective—has been enhanced by the passage of these federal packages. It seems inevitable that states will spend the next several years positioning themselves to benefit from the suite of incentives provided under these new laws.

Conclusion

As the U.S. moves forward with the clean energy transition, the role of nuclear power remains to be seen. While many states are exploring its potential, the nuclear energy industry and advanced reactor companies leading the way in new technology development will ultimately need to deliver on the promise in order for nuclear to gain broad acceptance as a technology solution.

State legislative policy has been increasingly supportive of the potential for nuclear power. NCSL's bill-tracking database reveals the increased interest in this topic area, and a growing number of states have enacted legislation to support new and existing reactors. These policies have been enacted by states across the political divide, reflecting the increasingly bipartisan nature of nuclear power.

Recent federal legislation is likely to accelerate these trends. In the coming years, NCSL anticipates that state legislatures will continue to enact policies in support of nuclear power to leverage funding and financing opportunities in the IIJA and IRA.

Author Capsule Bio

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35 K. Foltynova, "Russia's Stranglehold On The World's Nuclear Power Cycle," RadioFreeEurope, Washington, DC, September 2022.

36 "What is High-Assay Low-Enriched Uranium (HALEU)?," U.S. Department of Energy, Office of Nuclear Energy, Washington DC, April 2020.

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How Advanced Nuclear Generation Technologies Support Electric Grid Resilience

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Introduction

This paper articulates the case that deployment of advanced nuclear generation technologies can and should play a major role in enhancing electric grid resilience. Before addressing specific factors in support of this broad proposition, it is necessary to define the scope of the recommendation, as well as to clarify issues to be addressed.

The term "resilience" is frequently overused. It is also applied by different audiences for different purposes, quantified by different measures to avoid a range of adverse consequences. I recently suggested an organizing framework to facilitate how industry, policymakers, and regulators could factor "resilience" into future utility investments (Mroz 2021).

This article clarifies how advanced nuclear generation technologies could be deployed to enhance the "resilience" of the electric grid and to address emerging challenges associated with current electric grid evolution. Advanced nuclear technologies could also decrease the potential for negative consequences in the aftermath of public policy aimed at accelerating grid development. While these observations are specific to the North American and, particularly, the United States electric grid, they are likely applicable in other international markets.

Grid Infrastructure Conditions and Public Policies

The condition of US electric power grid is being challenged by policies to decarbonize generation resources, including but not limited to the application of new digital technologies, anticipated two-way power flow, and expanded use of renewable energy and other forms of distributed generation. Given the current state of these technologies and the nature of current grid evolution, care must be taken to build resilience going forward.

Many of the consequences associated with grid evolution are attributable to the nature of new technologies being deployed. Some result from the transition from existing generation sources. Others relate to ensuring the continuity of electricity supply. Emerging policies addressing climate change can be expected to have particular impact on reducing historic levels of base load electricity generation from coal and natural gas fueled facilities. Other policies have emerged to widely expand the deployment of energy production from solar and wind generation.

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Avoiding Adverse Consequences on the Electric Grid

A widely recognized consequence of the expanded use of renewable generation sources, such as solar and wind, is intermittent electricity production. When the sun shines, solar generates; at night or under cloudy conditions it does not. Wind generation, whether land based or offshore, generally operates during the day but less so at night, during heavy and in other localized meteorological conditions. Additionally, demand for electricity is often greater at certain times of the day, namely early morning and at night, when generation renewable resources are not producing the power needed to meet demand.

The resulting mismatch of supply from renewable generation sources to meet demand for electricity load is regularly illustrated by the "California Duck Curve". This mismatch is the consequence of the deployment of renewables and not having other resources such as energy storage or having zero or low carbon generation sources that can follow the demanded energy load (DOE 2017).

Public policies which compel emissions reduction from electricity generation simultaneously accelerate the retirement of base load generation facilities that are powered by coal and even natural gas. While intermittent renewable resources are being deployed at an accelerated rate and load following resources are retiring, the resulting mismatch poses new reliability concerns. The emerging problem has been the subject of commentary in the Midwest (Utility Dive 2022). In California, with a policy history favoring expanded renewables, the legislature recently called for continuing operation, and suspension of the previously announced retirement, of the two-unit Diablo Canyon nuclear generation facility (*San Luis Obispo Tribune* 2022).

The evolving grid and expanded deployment of renewable energy resources has led to another dynamic with two interrelated consequences. The increased deployment of distributed resources, most notably solar and wind, and parallel movement away from central station generation has amplified the need for expanded transmission resources. The expansion of transmission resources could allow grid-scale generation which is distant from current transmission hubs to be transported across the country. However, planning and siting of multi-state transmission projects, which typically require state and local government approvals, creating a significant challenges. Further, the financial investments needed for new transmission capacity are increasing at a rapid rate.

At the same time, previously built transmission resources, particularly hubs at or near retiring fossil fuel generation locations and without replacement renewable generation, are being stranded literally and then figurately as financial assets. The consequence is that ratepayers are confronting new transmission costs while still paying the legacy costs for abandoned transmission assets.

A second consequence, which is a corollary to new transmission planning, involves the distribution grid. As more resources such as solar are deployed on the distribution grid, localized circuits are challenged to accept the new distributed load. The additional challenges associated with expanded deployment of renewable resources is the inability of the existing grid to manage two-way power flow, voltage balance, and dispatch from net metered generation (ClenTechnica 2022).

An additional consequence on grid operations involves the need to support defense critical infrastructure such as military bases. While the Department of Defense (DoD) has for many years focused on "mission assurance" of its facilities, military bases often receive electricity like commercial customers and could be placed at risk during large grid outages (Department of Defense 2012). At the same time, DoD has instituted expanded renewable energy policies similar to those previously mentioned. The consequence is that military facilities can experience the same intermittent energy supply challenges as the civilian grid if local electric or utility service is disrupted. This could impact critical military operations and cause mission assurance failure (USDOE, Stockton 2022).

The consequences presented thus far are real, and current standards for grid reliability do not adequately address the full scope of reliability challenges. Moreover, with aggressive policies for decarbonization and a concerted drive to deploy intermittent distributed generation, there is real potential for stranded transmission investments. Concerns about the ability to keep electricity flowing during wide scale disruptive events are legitimate. For these reasons, it is essential to provide solutions capable of averting major adverse consequences by ensuring continued electricity supply. Advanced nuclear power generation is poised to provide the adaptability needed.

Advanced Nuclear and Power Grid Resilience

Nuclear generation operations, particularly in the United States, have been conducted safely since the early 1950s. Technologies that are re-emerging today were founded, and in some instances proven, in experiments conducted by the Department of Energy (DOE). However, they have not been widely advanced for commercial development (Third Way 2015).

Specific nuclear technologies are not reviewed in this paper. However, in Table 1, the technologies and representative companies currently seeking to bring these projects to completion are summarized. They include the current light water reactor technology integrated into Small Modular Reactors (SMRs) that use water cooling systems as well as other reactor designs including molten salt, pebble bed with molten salt, high temperature gas, and metal reactors.

Table 1: Overview of current ANG companies and projects under development (Pillsbury Winthrop Shaw Pittman, LLP)

Design	Classification	Nameplate Capacity	Licensing Status
NuScale Reactor	Light Water	77 MWe	NRC Approved Final SER on 08/28/20. $1.4 billion DOE funding for UAMPs demonstration of 6-module reactor at Idaho National Laboratory.
GE Hitachi BWRX-300	Light Water	300 MWe	Selected for potential deployment by Ontario Power Generation (OPG) and Tennessee Valley Authority (TVA). First topical report submitted to NRC.
X-Energy XE-100	High-Temp Gas (Pebble Bed)	80 MWe	Selected for ARDP - $80 million by DOE to deploy at EnergyNorthwest site in Washington State. NRC pre-application discussions.
Terrestrial Energy IMSR	Molten Salt	195 MWe	Selected for USNRC/CNSC pilot project. NRC pre-application discussions.
TerraPower Natrium Reactor	Sodium Fast Reactor with Molten Salt Storage System	345 MWe 500 MWe (5 ½ hours) -with Molten Salt	Selected for ARDP- $80 million by DOE. Partnered with PacificCorp to construct at former coal plant in Wyoming.
Oklo Aurora	Metal	1.5 MWe	Filed a combined construction and operations license with the NRC on March 11, 2020 – licensing review suspended.
Kairos Power	Pebble Bed with Molten Salt Coolant	140 MWe	Selected for $30 million risk reduction award by the DOE.
Westinghouse eVinci	Solid Core Heat Pipe	200 kWe to 5 MWe	Selected for $30 million risk reduction award by DOE.
Holtec SMR-160	Light Water	160 MWe	Selected for $147.5 million risk reduction award by DOE. NRC pre-application discussions.

These technologies, though different in terms of fuel type and cooling processes, share attributes that can be expected to advance "resilience," especially in relation to the consequences discussed above. By virtue of being smaller, safer, and without significant risks related to used fuel, advanced nuclear technologies have important attributes that can meet resilience goals. Those attributes follow.

First, these generation units, including SMRs and microreactors, are "baseload generation" that can run twenty-four hours a day and seven days a week (24/7). They can be deployed for continuous electric or heat production, unlike renewables which by definition are "intermittent" generation resources. This avoids conditions illustrated by the "California Duck Curve," mentioned earlier. It is, therefore, not surprising that California recently decided to allow the Diablo Canyon units to continue operations.

Unlike renewables, small advanced nuclear units have capabilities to ramp up and down more quickly. Therefore, these units can be "load following" and support dispatch to meet electric demand especially rapidly. And they could be load following and even integrated with grid scale renewable resources to provide called up capacity when that renewable generation ramps down for the day (LeCroy 2021).

These units can also be a viable option to repower retiring fossil fuel plants. This builds on the ability to site units closer to population centers than before.

The Nuclear Regulatory Commission (NRC) has required a ten-mile emergency evacuation zone around nuclear plants. This was based on the prevailing science that a nuclear plume release could migrate up to ten miles. The NRC recently authorized a reduction of the emergency evacuation zone to the "fence line" of a facility with new nuclear. It was based on NRC findings that the source term or amount of potential radiation release is not of a magnitude necessitating a larger emergency zone. Thus, it is now possible to site an advanced nuclear generation unit at an existing generation site without further geographic restrictions. This would permit the reuse of existing generation sites. The resulting resilience effect is that replacement of existing fossil fuel generation will directly reduce carbon emissions of retiring coal plants while ensuring reliable generation to that location (NEI Website 2019).

An additional benefit relates to the re-use of existing generation sites which allow for continuing use of existing transmission assets. As noted, proposed new transmission projects will undoubtedly create lengthy siting and environmental impact assessments, adding to the cost for new transmission. The repowering of fossil fuel generation through advanced nuclear will minimize new transmission costs, avoid delays in the siting process, and avert other impacts to new transmission corridors (Scott Madden 2021). DOE recently issued a report identifying more than one hundred current coal generation sites that could be candidates for repowering with new nuclear (USDOE, Wrobel, et al. 2022).

Next, and as an overarching environmental consideration, nuclear has by definition zero carbon emissions. With both national and state policies calling for complete or near zero carbon emission limits, it is becoming increasingly clear that other technologies cannot provide the capacity to attain long-term goals. Industry and government officials in the United States and globally now project that most regions can likely attain about 80% of decarbonization goals. But reaching the 100% zero carbon mark may be a technological impossibility - unless nuclear is utilized to reach the final increment (International Atomic Energy Agency 2020).

Two other attributes of new nuclear designs are relevant here, but only come into play under the most extreme circumstances. They are not typically considered in assessing "reliability risks" to the grid. They become relevant if there is a catastrophic event such as widescale and prolonged grid outages otherwise known as "Black Sky" events.

Under such a circumstance, the grid would need to be restarted. The resources necessary to ramp up or "Black Start" are still being evaluated. Most industry and other commentators do not believe that the United States has sufficient Black Start resources in place. Smaller advanced nuclear units could provide a foundation for the capability to restart the grid (Greene 2020, Stockton 2018).

At the same time these discussions are occurring, there has emerged a focus on defense critical infrastructure and the ability to have uninterrupted power supply for continuity of military operations and mission assurance. While the military has considered the use of onsite generation including renewables at defense critical facilities, the need for 24/7 generation is crucial to meeting such goals. Advanced nuclear generation located on the premises of a defense critical facility such as a military base may be a viable option for meeting this critical need (Yachanin 2016). Recent recognition of this benefit was the announcement by the Department of Defense that advanced nuclear will be developed on the premises of Ellison AFB in Alaska (Department of Defense 2021).

Conclusion

As the national electric grid continues to evolve, the nation is faced with resiliency challenges associated with new policy initiatives and technological developments. Unless these challenges are addressed, the ability to attain aggressive climate goals and achieve grid reliability may be restricted. There are also implications for national security. Resilience is defined as the ability to avoid risks but to respond and recover quickly from adverse consequences if they occur. For the reasons detailed herein, the deployment of advanced nuclear generation technologies including small modular reactors and microreactors offers an important opportunity to enhance overall grid resilience.

Author Capsule Bio

Richard S. Mroz is an independent consultant and is an advisor to the Coalition for Advanced Reactor Energy Solutions (CARES). He is the former President of the New Jersey Board of Public Utilities (NJBPU), was Chair of the Critical Infrastructure Committee of the National Association of Regulatory Utility Commissioners (NARUC), served as NARUC liaison to the Electric Sector Coordinating Council, and was chairman of the Organization of PJM States, Inc.(OPSI). During his years at the NJBPU, he oversaw implementation of numerous resilience initiatives including post Superstorm Sandy investments in hardening and modernizing the New Jersey infrastructure in the electric, gas and water sectors. He also presided over the issuance of the NJBPU order requiring the regulated companies in the State to establish cybersecurity protocols, which order was the first such directive from a public utility commission in the country to require specific cybersecurity measures. Also, during his tenure at NJBPU, Mr. Mroz managed the negotiations for the State, the product of which ultimately resulted in legislation, regarding the Zero Emission Credit (ZEC) program supporting the existing nuclear generation fleet. Mr. Mroz is Senior Advisor at Protect Our Power, Inc, a Corporate Fellow with the Global Resilience Institute at Northeastern University, and an appointed member to the USDOE Electric Advisory Committee.

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Editorial

The Energy Transition: Advanced Nuclear Needed but Address Climate Change Vulnerabilities Now [1]

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Abstract

The term "Energy Transition" is an attempt to capture an elaborate set of activities related to the modernization and decarbonization of energy grids. Performed concurrently and often in an ad hoc manner across local, state, regional and national boundaries, it is bringing chaos to what should arguably be one of the most conservatively managed of all critical infrastructure sectors. What's more, with climate change producing an increasing tempo of extreme events, confidence in the intended resilient and redundant structure of the electric grids is likely to ebb. Even without these climate induced stressors, the nation's electric grid was built for an earlier century.

In addition to a drive towards greater efficiency via digitization and a continuing price decline in distributed energy resources (DERs), one could argue that climate change concerns are the primary driver of the energy transition. Non-CO2 emitting generation sources like wind and solar have become an important part of the overall generation fleet, albeit ones that cannot be counted upon to provide dispatchable power. Current projections indicate deployment of even larger percentages of DERs in coming years. Until far better storage capabilities arrive, the variability of wind and solar, inconsistent performance of traditional thermal generation plants, and energy delivery failures associated with natural gas pipelines will reinforce mounting reliability concerns. This pertains to both electric transmission and distribution.

The recent shuttering of nuclear power plants in Germany, Japan, the US and elsewhere are also putting more downward pressure on dispatchable generation. Russia's attack on Ukraine has roiled

1 As an Editorial, views expressed herein are those of the author do not necessarily reflect those of the *Journal of Critical Infrastructure Policy* or the Idaho National Laboratory

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energy markets worldwide and forced some countries to return to coal as a primary fuel.

In view circumstances such as these, it is essential that significant changes be made to policies and planning criteria, and to the standards and code on which they are based. Given the accelerating pace of extreme weather events, this needs to occur as soon as possible.

Keywords: grid reliability, extreme weather, decarbonization, resilience, regulation

Introduction

Calling what the US grid is going through "The Energy Transition" is like calling the migration that accompanied the great midwestern dustbowl a population transition. What may sound smooth as modern, cleaner forms of energy generation and delivery replace higher carbon emitting approaches, is proving anything but smooth. This is accentuated by the fact that alternative generation sources fluctuate with the rising and setting of the sun and with other far less predictable natural phenomena. What's more, with the exception of hydropower, thermal plants being shuttered have formed a stable foundation for grid planners to count on to deliver baseload. In other words, these have been the primary, predictable sources of reliable electricity on which nations depend. The North American Electric Reliability Corporation (NERC) calls them "firm" resources.

"Transition" also invites conjuring winners and losers. Some may imagine new clean energy millionaires being minted while coal barons and oil sheiks are forced to trim their profligate spending. The trajectory appears to be that as industries like solar, wind, and energy storage proliferate, stakeholders in fossil fuel extraction, processing, delivery or utilization will likely eventually decline, though that decline will be many years off.

Governance Snapshot

The interstate high voltage Bulk Power System (BPS) is under Federal jurisdiction while lower voltage assets and the utilities who own and manage them are supervised at the state level by public utility commissions (PUCs). Some federal regulations for transmission, large generation and important control centers are mandatory and are enforced with stiff penalties administered by FERC and the national Electric Reliability Organization (ERO), NERC. Distribution level matters are handled somewhat more gently by the PUCs. Trade groups play an important part in this ecosystem, rallying the collective needs and visions of their members.

These include:

- The Edison Electric Institute (EEI) for the Investor-Owned Utilities (IOUs)
- The American Public Power Association (APPA) represents the Municipal Utilities
- The North American Rural Electric Cooperative Association (NRECA) works with Electric Cooperatives

These organizations as well as executives from the larger IOUs are regularly convened by the US Department of Energy's Electricity Subsector Coordinating Council (ESCC) to discuss security and reliability challenges. Another important role is served by the National Association of Regulatory Utility Commissioners (NARUC) which convenes the PUCs in annual meetings and conveys their concerns in Washington DC and state capitals.

In addition to regulatory forces, electric utilities, whether regulated with guaranteed rates set by their PUCs, or de-regulated and operating in competitive markets, have financial incentives to be as reliable as possible. They earn revenue by delivering kilowatt-hours to their customers, so when electricity isn't flowing, funding is reduced.

To date, regulation and market drivers have tended to ensure that reliable electric service is provided nearly everywhere when weather conditions were optimal or near optimal. However, when extreme weather in the form of record-breaking heat or cold, floods and fires, and storms of increasing ferocity arrive, as they do now with increasing frequency, the grid can buckle, as it did during the recent cold snap enveloping large swaths of the nation in December 2022.

The ERO Energy Transition Warning

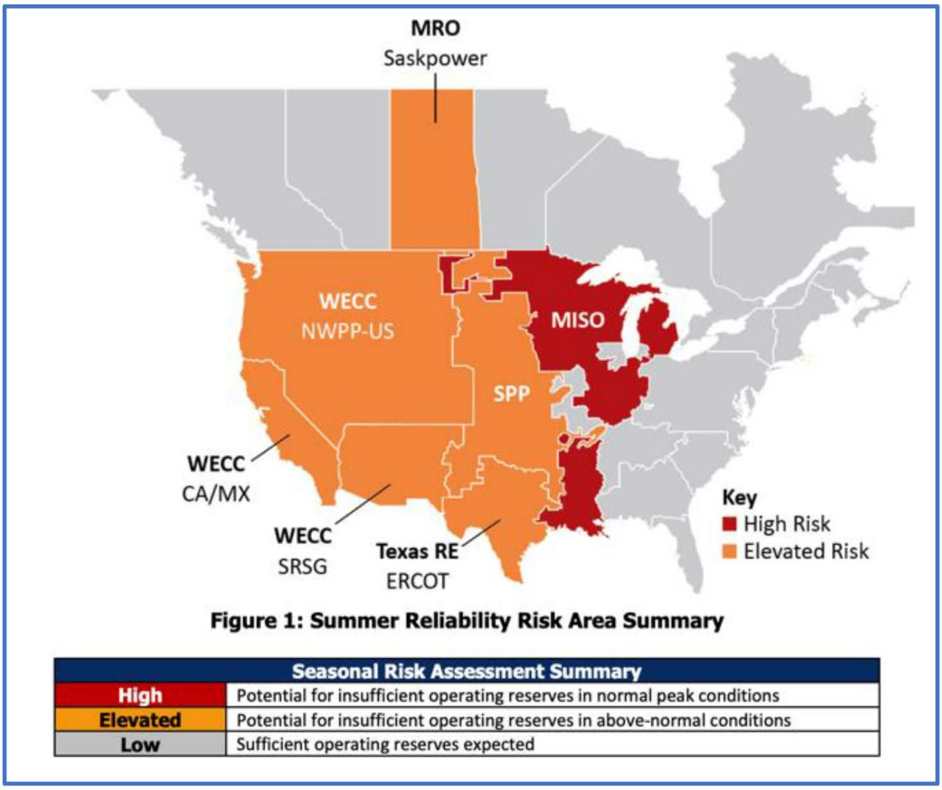
The "warning" took the form of a response to capacity shortfalls due to heat and cold in summer and winter of the past year. Specifically, in 2022, NERC issued two reliability assessments, one in the spring with cautions about summer, and one in the fall ahead of winter.

The summer reliability assessment[2] (Figure 1) painted the entire western half of the United States and the Canadian province of Saskatchewan orange indicating elevated risk of electric service interruptions due to high heat, drought and wildfire concerns. And in the middle of the US, the Midcontinent Independent System Operator (MISO) region was warned about high risk due to capacity shortfalls, largely due to the closing of baseload coal generation plants without making up the difference.

And, of course, there's Texas, which chooses to remain an island, largely separate from the rest of the US grid. In so doing, the State limits its ability to im-

2 https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SRA_2022.pdf

port electricity from other regions during extreme weather events like the deadly freeze experienced during February 2021.



Seasonal Risk Assessment Summary	
High	Potential for insufficient operating reserves in normal peak conditions
Elevated	Potential for insufficient operating reserves in above-normal conditions
Low	Sufficient operating reserves expected

Figure 1: NERC Summer Reliability Risk Area Summary

The winter reliability report[3] colored the map differently, with the MISO region still in trouble for similar capacity adequacy reasons, and Texas for its inability to import electricity when needed, across state lines. Similar to Texas, but for different reasons, New England was also assessed as risky. Among other factors, the lack of adequate natural gas pipelines to the region makes it an island of sorts as well. When sustained cold weather arrives each winter, hard choices between using gas for electricity generation or for heating homes or businesses have to be made.

December's Winter Storm Elliott arrived just in time to cause catastrophic flight disruptions before, during and after Christmas. It once again helped illustrate how the electric and natural gas infrastructures are not up to the challenges of increasing extreme weather events.

> "High winds along with the cold temperatures from the arctic blast across much of the country created equipment problems at TVA's biggest coal plant and limited power from some natural gas-pow-

3 https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2022.pdf

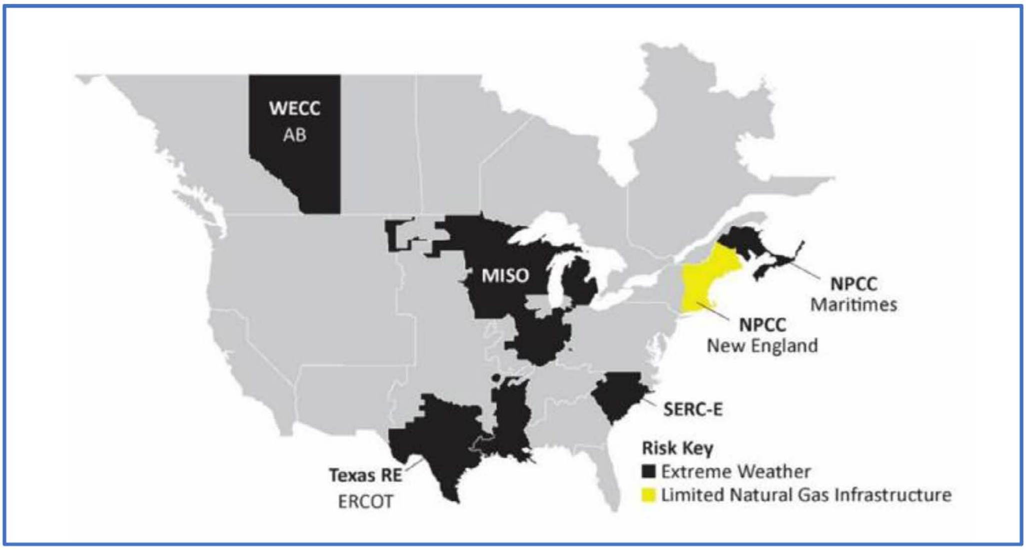


Figure 2: NERC Winter Reliability Risk Area Summary

> ered combustion turbines. At one point Friday, TVA lost more than 6,000 megawatts of power generation or nearly 20% of its load at the time, with both units at TVA's Cumberland Fossil Plant offline and other problems at some gas generating units."[4]

Just before year's end 2022, FERC and NERC filed to open an investigation on what went wrong and to possibly generate proposals for better performance in the face of future extreme winter weather events.[5] It should be noted that after every extreme heat, extreme cold or extreme storm event, utility representatives seem to suggest that they were unforeseeable.

NERC's Longer Look

Looking further out, NERC issues ten-year lookaheads intended to inform the next round of planning cycles. The most recent Long Term Reliability Assessment (LTRA) cites five trends that NERC perceives as having likely impact on grid performance on both good and more challenging days:

- Integration of inverter-based resources
- Growth in distributed energy resources
- Generation retirements
- Flat transmission growth
- Increased demand growth

4 https://www.timesfreepress.com/news/2022/dec/24/power-outages-tfp/

5 https://www.tdworld.com/overhead-distribution/article/21257108/ferc-nerc-to-open-joint-inquiry-into-winter-storm-elliott

Any one of these factors, if not monitored closely and adapted, could mean a North American grid that is less reliable than we expect it to be—and that we ought to we require it to be.

Add other eventualities that even the most prescient grid regulators and planners cannot foresee are events such as major war breaking out among countries with substantial energy market roles, or a global pandemic. Another contingency, however, is the future deployment of new forms of nuclear power generation that might meet both the demand for clean power with the urgent need for a firm baseload.

Is Help on the Way?

After stagnating for decades, enthusiasm for nuclear energy is rapidly growing. According to a mid-2022 report from the Pew Research Center:

> Despite longstanding safety concerns, many state leaders and some environmental groups say climate change poses a greater risk than reactors.[6]

According to former NERC Chief Security Officer Tim Roxey, there are two factors that should guide decision-makers and planners when it comes to developing new generation resources in 2023 and beyond: capacity factor and carbon footprint. "Taken together these two knowable factors can help policymakers sort through the societal demands for clean, available energy that is climate sensitive."[7]

While these factors can prompt significant debate among various renewable energy and thermal energy stakeholders, the Department of Energy's (DOE's) Office of Nuclear Energy claims that "nuclear has the highest capacity factor of any other energy source—producing reliable, carbon-free power more than 92% of the time in 2021. That's nearly twice as reliable as a coal (49.3%) or natural gas (54.4%) plant and almost 3 times more often than wind (34.6%) and solar (24.6%) plants."[8]

At Idaho National Laboratory and many other research facilities in the US and globally, new nuclear power plant designs are being developed and tested at a pace not seen until very recently.[9] Many of advanced designs use physics-based passive safety strategies to ensure that even when electric power is lost, nuclear fuel will remain cool. Such was the case in 2011 when a tidal wave hit Japan's Fukushima plant, swamping backup generators leading to a partial meltdown. With truck-transportable small modular reactors (SMRs) ranging from 50 Mega-

6 https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2022/06/15/climate-change-is-shifting-state-views-on-nuclear-power

7 Via personal communications

8 https://www.energy.gov/ne/articles/what-generation-capacity

9 https://inl.gov/trending-topic/small-modular-reactors/

watts to 800 Megawatts, and microreactors from 1 to 50 Megawatts, we may find ourselves in approximately a decade having the ability to build out a low-to-no carbon, load-following baseload that can then support larger amounts of wind and solar generation than is currently deployed.

Climate Change and Energy Transition Risks

The simplest way to frame this is that with weather increasingly getting more extreme, instead of reinforcing the North American grid to be able to handle it with confidence, we are inadvertently weakening it due to an overriding desire to decarbonize. Decarbonize, since emissions are what scientists agree are making the weather more extreme.[10]

One multi-state Southern utility, now fully aware of this situation, is poised to act:

> "Entergy Louisiana … filed its proposed Phase I Entergy Future Ready resilience plan with the Louisiana Public Service Commission. Phase I seeks approval of the first five years of a 10-year resilience plan that would aim to accelerate the restoration of power and reduce the costs associated with doing so following major storms … Although the company has successfully invested in its electric system for years, it is important to review the pace at which these efforts occur because the threat of weather events has increased at a time when the demand for power is expected to grow significantly to decarbonize the local economy and create a more sustainable future."[11]

While there are varying degrees of confidence and skepticism about the accuracy and precision of the perils global climate models show are coming, one need only turn to the international news. Or better yet, in one's own backyard to see that, depending on geography, significant changes to seasonal and other weather patterns are well underway. These conditions portend profound changes in both generation capacity and load, all which must be managed by utility operators and reliability coordinators.

Physical Risk Vulnerability Assessments Getting Underway

In January 2020 the Biden administration set the wheels in motion for the US Federal government to begin taking stock of climate change-borne risks to its own

10 From a technical and multi-disciplinary standpoint, Chris Nelder's "Energy Transition Show" is a dynamic information source for readers: https://xenetwork.org/ets/about/

11 https://www.tdworld.com/overhead-distribution/article/21256752/entergy-louisiana-files-proposed-10year-entergy-future-ready-resilience-plan

missions with the issuance of Executive Order 14008. Section 211 includes requirements for all US agencies and departments to:

> "Submit a draft action plan to the Federal Chief Sustainability Officer … that describes steps the agency can take to bolster adaptation and increase resilience of its facilities and operations to the impacts of climate change."[12] It continues, "Action plans should, among other things, describe the agency's climate vulnerabilities." And, "after submitting an initial action plan, the head of each agency shall submit to the Task Force and Federal Chief Sustainability Officer progress reports annually on the status of implementation efforts."

Two years later, DOE, for example, received the first round of reports in from its national laboratories and other sites in response to the Department's Vulnerability Assessment and Planning (VARP) guide.[13] Beginning in 2021 and over the next several years, the VARP requires each DOE entity to:

- Identify Critical Assets and Infrastructure
- Characterize Climate Trends and Events
- Characterize the Likelihood of Climate Change Hazards
- Characterize Current and Projected Impacts of Climate Change Hazards on Assets and Infrastructure Systems
- Characterize Vulnerabilities with a Risk Matrix
- Identify and Assess Resilience Solutions
- Develop and Implement a Portfolio of Resilience Solutions
- Monitor, Evaluate, and Reassess the Resilience Plan

At approximately the same time, FERC[14] and the SEC[15] have begun promulgating similar reporting requirements to the large number of energy and other organizations over which they have governance authority. Most of the corporate and governmental climate change activity to date has focused on emissions reductions. However, by the mid-2020s we should anticipate that every organization of consequence will examine climate change risks to both its mission and key assets. Furthermore, these organizations will update their resilience, business continuity

12 https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

13 Vulnerability Assessment and Resilience Plan Guidance v1.2 (Updated)

14 https://www.federalregister.gov/documents/2022/06/27/2022-13471/transmission-system-planning-performance-requirements-for-extreme-weather

15 https://www.sec.gov/news/press-release/2022-46

and adaptation plan accordingly. In truth, many have already begun this process, such as AT&T.[16]

Conclusions

Throughout history, there have been storms and floods, freezes and fires. Some arrive slowly, like drought and sea level rise, while others appear suddenly. Despite having experienced a similar if less intense weather system ten years prior, in February 2021, Texas was impacted by a wave of cold weather for which it was not prepared. Many died, and $100 billion dollars of physical and financial damage resulted. Amidst a tremendous amount of finger pointing, prominent US utility CEO Tom Fanning of Southern Company summarized the peril that befell Texas and that, without swift action, awaits utilities worldwide when he said:

> "This weather system in Texas greatly exceeded the planning criteria in which they operate ERCOT (Electric Reliability Council of Texas)."

What does it mean when for infrastructure as essential to economic security and public health as the power grid, utility planners misunderstand risks to reliable operations that their stakeholders expect? What are the criteria used based upon? Perhaps one aspect of this is undue reliance on historic conditions to project dynamic future circumstances. In the case of climate change, that may no longer be a responsible approach. Making the best use of downscaled appropriately calibrated global climate modeling data is the soundest approach from this point on.

Though its projections typically lag observed reality due to a conservative, consensus-driven approach, the Intergovernmental Panel on Climate Change (IPCC), in its sixth round of reports published in 2021 and 2022, largely removed qualifying language about what the world can expect to experience in the coming years.[17] A few takeaways:

- The world will probably reach or exceed 1.5 degrees C (2.7 degrees F) of warming above the industrial baseline within the next two decades.
- No region will be left untouched by the impacts of climate change, with enormous human and economic costs that far outweigh the costs of action. Southern Africa, the Mediterranean, the Amazon, the western United States and Australia will see increased droughts and fires, which will continue to affect livelihoods, agriculture, water systems and ecosystems.

16 https://www.forbes.com/sites/esri/2020/10/19/four-lessons-from-att-on-climate-resilience-and-business-continuity/?sh=6133f9523f94

17 Intergovernmental Panel on Climate Change, AR6 WG1. "Climate change widespread, rapid, and intensifying. 2021. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

- Changes in snow, ice and river flooding are projected to impact infrastructure, transport, energy production and tourism in North America, the Arctic, Europe, the Andes and more.

- Many consequences of climate change will become irreversible over time, most notably melting ice sheets, rising seas, species loss and more acidic oceans.

In many ways, a dawning national recognition of the urgent need to address climate threats to critical infrastructure mirrors how cyber threats to these essential national assets were slowly recognized and then acted upon. Major climate change impacts on critical infrastructure are now drawing increased attention. It is arguable that far less time will be required to respond to this threat than the approximately two decades that it took for the full scope of cyber infrastructure threats to fully register. In short, the longer government regulators, reliability coordinators and utilities take to adjust their "planning criteria" and to update their adaptation and resiliency measures, the more we can expect grid reliability and performance metrics in both the energy and related critical infrastructure sectors to decline.

Author Capsule Bio

Andrew Bochman is Senior Grid Strategist for Idaho National Laboratory's National and Homeland Security directorate. Mr. Bochman provides strategic guidance on topics at the intersection of grid security, the Energy Transition, and infrastructure climate resilience and adaption to senior U.S. and international government and industry leaders. A Non-Resident Senior Fellow at the Atlantic Council's Global Energy Center, in 2021 he published *Countering Cyber Sabotage: Introducing Consequence-based Cyber-Informed Engineering*. He began his career as a communications officer in the US Air Force, and prior to joining INL, was a Senior Advisor at the Chertoff Group and the Energy Security Lead at IBM. Mr. Bochman received a BS from the U.S. Air Force Academy and an MA from Harvard University. With national laboratory colleagues, he is developing a decision support tool for government and industry planners and regulators. You can read more about its prioritization, data and workflow model here.[18]

18 https://resilience.inl.gov/icar/

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Abstract

Led by the Pennsylvania State University a coalition of academia, national laboratories and industry have formed the Post-Industrial Midwest and Appalachia (PIMA) Nuclear Alliance to harness firm carbon-free energy from nuclear while educating and training the future energy workforce. The PIMA Nuclear Alliance will facilitate nuclear research, critical infrastructure, policy, community engagement, education, and workforce development to augment the country's dependency on non-renewable energy resources to more resilient, sustainable, high-capacity sources of energy. Advanced nuclear technologies including microreactors (aka nuclear batteries), small modular reactors and fusion reactors are opening opportunities for non-carbon firm sources of energy that are dispatchable and versatile to meet difficult-to-decarbonize sectors of the economy. From the standpoint of sustainable economic development and a just clean energy transition, nuclear-based technologies offer safe, secure, and reliable energy while abating the impact of fossil fuels to our climate and local regional communities. The long-term vision of the PIMA Nuclear Alliance is the establishment of a technology corridor for manufacturing advanced nuclear microreactors at scale. The goal is to enable a future where 10's to 100's of thousands of reactors are manufactured in the region resulting in a "tera factory" (i.e. 100,000*10MWe = 1 TWe) transforming a high-tech supply chain for advanced reactors in the world. The PIMA Nuclear Alliance has a holistic approach with three primary aims: 1) to establish a research, develoment & deployment (RD&D) microreactor platform for end users and stakeholders to test energy conversion systems to their applications, 2) to engage communities and end users in participatory practices for the adoption of advanced nuclear technologies, and 3) to innovate enabling technologies (e.g. digital twin, advanced manufacturing, AIML,

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etc.), as well as regulatory and policy frameworks to accelerate and scale deployment of advanced reactors in the US and abroad.

Introduction

The impact of climate change and the geopolitical landscape placing greater emphasis on energy security and resilience, requires a broader multi-faceted approach than currently exists for the transition to a carbon-free energy economy. Energy markets are complex and dynamic with changes influenced by multiple factors including policy, global production trends, macro and microeconomic forces, geopolitical conflicts, and many more. One can look at some general trends regarding global energy and electricity consumption. For example, the global final electricity consumption in 2019 reached about 23,000 TWh or roughly a total of about 2.6 TW [1]. Roughly about 80 percent of this electricity is provided by fossil fuel-based sources such as coal and natural gas. Energy transition away from fossil fuels, however, not only consists of reducing carbon emissions from electricity. In the United States, electricity is only one third of total greenhouse gas emissions with the other two thirds coming from industrial processes and transportation [2]. Therefore, energy transition must examine versatile sources of energy that are not only resilient but can be adopted in sectors of the economy that demand large amounts of power such as manufacturing and heavy-duty transportation.

Multiple studies have examined energy transition pathways with many considering a diverse mix of energy sources including renewables (e.g. wind, solar) and nuclear. However, to reach an energy transition that is economically viable when transitioning from fossil fuels, a combination of firm energy sources such as nuclear and carbon capture and storage (CCS) must complement intermittent sources such as solar and wind [3]. In addition, challenges such as battery technology cost and lack of scale, land access, and resilience, make renewable technologies limited to specific energy transition scenarios and may not necessarily provide the firm and sustainable energy sources required for reliable low-cost decarbonization scenarios [4]. Transition strategies from fossil fuels must also consider the current pace of energy demand outpacing carbon-free sources such as renewables. For example, a recent report found a 5 percent rise in electricity demand in 2021 with almost half the increase met by fossil fuels [5]. By 2040, the energy demand in modern nations will grow on average between 20-30 percent. However, energy demand will also be driven by emerging and under-developed economies. This is due to the fact that close to about half of the world population lives in economically vulnerable conditions (e.g. living on average $12-120 per day). As they transition to emerging economies, faster development will be triggered, which, combined with climate change, will cause energy demand to continue growing at non-linear rates [6,7].

Given these factors we find that nuclear technology, would not only need be a part of the energy solution, but a significant one with the promise of a sustainable and resilient source of energy for electricity and other energy sectors, [4,8]. Roughly about 14 TW of reliable energy will be needed by end of this century to keep up with demand, and at the rate of current conventional nuclear fission reactor construction and aggressive renewable and CCS deployment, a shortage of about 8 TW is conceivable [4,9]. There are many examples where advanced nuclear technologies can address important gaps in energy transition towards reliable (e.g. base-load), resilient, and sustainable energy sources. For example, microreactors and small modular reactors could find opportunities in multiple energy sectors including hydrogen generation, water desalination, industrial process heat used in steel or concrete manufacturing, co-generation of district heat and electricity on microgrids, synthetic liquid fuel generation, thermal storage to complement intermittent energy sources such as solar and wind, transportable power units with applications in natural disaster and military applications, and as energy sources for mining and critical mineral extraction from brownfield and former coal sites [4]. These advances will result in a drastic reduction of carbon-free energy costs.

Microreactor technologies can vary from 1MWth (e.g. "MWth" means Megawatt of *thermal* power) to about 40 MWth and small modular reactors (SMRs) are currently being designed in the 60-80 MWe (e.g. "MWe" means Megawatt of *electrical* power) up to 300 MWe range. Similar to SMRs, nuclear fusion reactor technologies with large private capital investments in the last few years, can provide thermonuclear magnetic confinement energy reactors ranging from 100-500 MWe using hydrogen isotopes as fuel with self-sustaining breeding systems and low-level radioactive waste generation [10]. Both SMRs and fusion reactors are considered as options for baseload power to an electric grid with a larger footprint (~ 10 acres) but significantly smaller than conventional nuclear reactors (footprint ~ 640 acres). On the other hand, microreactors are small enough to be manufactured in a factory and transported by truck to the point of use. In fact, their footprint is less than an acre. They can be integrated with other renewable power sources, such as solar or wind power, in microgrids to support communities without access to reliable energy due to location or natural disaster. Their compact size has driven the use of the term of either "nuclear batteries" or "fission batteries" to refer to these small nuclear power reaction systems. They are highly mobile, reliable, with standardized designs that can be factory-produced, can be installed, and operated at any location with limited site development, secure and safe while unattended and autonomously operated, and economically competitive. These characteristics makes it easier to remove after use and can be replaced quickly and relatively cheaply, if needed [11].

PIMA Nuclear Alliance – The Vision

The Pennsylvania State University, a $7B economic powerhouse contributing more than $11.6 billion to the state's economy and supporting, directly and indirectly, more than 105,000 jobs across Pennsylvania in FY 2017 [12] is Pennsylvania's only land-grant university, with 24 commonwealth campuses providing access to training, education, and research to over 88,000 students. Penn State founded the PIMA Nuclear Alliance in May 2022 to address carbon emission reduction goals and energy transition at the regional scale, and bring forth economic development, innovation, and transformation to the region. Penn State has a long history with nuclear technology. Penn State is home to the Breazeale nuclear reactor, a 1MW TRIGA light-water research reactor, that provides a platform for neutron science and technology since the mid-1950's [13]. The PSBR, which first went critical in 1955, is the nation's longest continuously operating university research reactor.

The Alliance goal focuses on a multi-institutional collaboration to support the siting of a microreactor research, development, and deployment (RD&D) platform at the Penn State University Park campus in central Pennsylvania supporting nuclear technology and workforce development as well as maturing the technical and societal readiness levels of advanced nuclear reactors. The Alliance will actively include local and regional colleges and universities and make sure that they have prominent roles, not just from a research perspective, but also from training the next generation workforce in nuclear technology. Training will focus on the current and future workforce generation across the heartland of America providing new skills, high-paying jobs, and careers that can sustain the economic growth of these communities. The alliance will also engage with other green-tech initiatives and look for effective synergies.

The vision of the PIMA Nuclear Alliance is a transformational change to the region, mitigating the climate crisis and fostering economic development by introducing micronuclear reactors across difficult-to-decarbonize industrial sectors enabling a sustainable, just, and resilient clean energy transition in the PIMA region at scale. Penn State with its 24 commonwealth campuses throughout Pennsylvania serves as an important demonstration hub for advanced nuclear technology supporting research, development, deployment, and community economic development. With large and diverse urban centers in Philadelphia and Pittsburgh and a rural population in between, Pennsylvania is a microcosm of the US and an ideal setting to establish a holistic approach at research, development, and deployment of advanced nuclear with our strategic university partners across the Midwest and greater Appalachia in the PIMA Nuclear Alliance. These partnerships will be supported with strategic National Laboratory and industrial partners providing for an advanced nuclear battery development ecosystem.

In addition, this initiative is envisioned to seed and nurture a robust domestic supply chain of nuclear and advanced materials technology in the greater Appalachia region and the post-industrial Midwest. The PIMA Nuclear Alliance will bring emergent technologies in additive and advanced manufacturing of conventional and novel materials, digital innovation, advanced computing, and combine multi-disciplinary and transdisciplinary collaborations leveraging initiatives in law, policy, and technology interfaces. The vision of the PIMA Nuclear Alliance is a collective effort with rural, micro-urban, and urban communities in the region empowered to support the energy transition with the goal to drastically reduce carbon-free energy costs in difficult to decarbonize sectors, helping support advanced manufacturing of microreactors at scale, leading to a truly transformative change for how we power society.

The PIMA Nuclear Alliance has strong support from the leadership at Penn State. For example, Lora Weiss, Senor Vice President for Research, recently stated that "The breadth of the PIMA Nuclear Alliance speaks to the critical role it is filling as we explore how to efficiently power our future — literally and figuratively." She went on to state "With trailblazing experts, state-of-the-art facilities and a strong community in varied environments across the Commonwealth, Penn State is well situated to both understand the challenges of developing sustainable energy and lead the innovations needed to solve them [14]." In addition to support from the Penn State University leadership, the PIMA Nuclear Alliance receives support from a diverse and broad collective of departments, colleges, and institutes, including the College of Engineering; Smeal College of Business; the College of Earth and Mineral Sciences; the Materials Research Institute; the Institute of Computational and Data Sciences; the Social Science Research Institute; the Center for Energy Law and Policy; the Law, Policy and Engineering initiative; the Radiation Science and Engineering Center which houses the Breazeale Nuclear Reactor; Pennsylvania Technical Assistance Program; the Office of the Senior Vice President for Research, and the Office of Physical Plant, which recently supported a Carbon Emissions Reduction Task Force and published a report in December 2021 on carbon net zero strategies for Penn State University [15].

PIMA Nuclear Alliance is also a diverse collective of institutions and organizations. Alliance members include foundational partners University of Michigan Nuclear Engineering and Radiological Sciences, University of Tennessee at Knoxville, and the Westinghouse Electric Company. Additional partners include Pennsylvania College of Technology, Idaho National Laboratory, Los Alamos National Laboratory, Argonne National Laboratory, Sandia National Laboratories, Oak Ridge National Laboratory, Morgan Advanced Materials, Pittsburgh Technical, Energy Driven Technologies, and Reuter Stokes. Faculty from University of Central Florida, California Polytechnic State University, West Virginia State University, and Cornell University are also participating.

These collective efforts are anticipated to accelerate technology adoption and provide the framework for similar transitions across the U.S. and the world. Transformation of these regions means leveraging nuclear technology with microreactors to generate hydrogen, decarbonize steel and concrete factories, food processing, and innovate ways to provide green energy to high-value critical mineral extraction from coal [16]. In addition, microreactors will be designed to innovatively couple to renewal or other advanced reactor technologies (e.g. small modular reactors, compact fusion reactors, etc..) for optimum resilience and an environmentally just energy transition.

Recent developments from both the federal and private sectors are providing opportunities for initiatives that support advanced nuclear reactor development and deployment. For example, the Department of Energy's Advanced Reactor Demonstration Program and the privately funded Breakthrough Energy Ventures are both investing hundreds of millions of dollars into advanced nuclear development and energy innovation at scale. Penn State University is in a unique position with several potential venture firms and industry partners that have interest in advanced nuclear technology and deployment in the PIMA region.

A result of a strategic private-public partnership has been the Penn State and Westinghouse collaboration on research and development efforts focused on exploring and applying nuclear engineering and science innovations to societal needs. A memorandum of understanding detailing the partnership — the first one between Westinghouse and a university in the United States — was signed at Westinghouse's headquarters in Cranberry on May 18, 2022. The partnership entails exploring the siting of Westinghouse's eVinci micro-reactor, a next-generation, small modular reactor designed to address sustainable power needs from immediate use in large communities to decentralized remote applications, at University Park. The current focus is a RD&D platform as discussed earlier with the long-term goal of supporting Westinghouse in deployment of first-of-a-kind (FOAK) units that could be adopted as an alternate energy source of heat to the campus.

Both Penn State and Westinghouse have a long history and significant experience in the realm of nuclear energy: Penn State houses the Penn State Breazeale Reactor — the longest continuously operating research nuclear reactor in the United States — and Westinghouse established the first commercial nuclear reactor in the country. Both are uniquely positioned to cultivate microreactor technology to provide safe and sustainable energy. Westinghouse, with a 130-year history distributing electricity, produced the country's first commercial reactor in Shippingport in 1957, just two years after Breazeale reached full power. Now, Westinghouse has established and helps oversee more than 430 nuclear reactors around the world.

Penn State and Westinghouse share a common vision for the potential of micro-reactors to revolutionize industry and energy globally, micro-reactors are smaller and safer than conventional reactors (note: conventional nuclear reactors are extremely safe) since they produce less power, require less fuel, and have fewer moveable parts. The eVinci micro-reactor can produce sustainable carbon-free energy and integrate with other renewable power sources, such as solar or wind power. It is also small enough for factory fabrication and truck transportation, meaning it can be built and implemented to support communities without access to reliable energy due to location or natural disaster. Its compact size minimizes the physical footprint and allows for construction and installation in as few as 30 days. "eVinci is a game-changing nuclear battery that can play a critical role in reducing the carbon intensity of the global energy sector," said Mike Shaqqo, Senior Vice President of Advanced Reactors at Westinghouse. "Westinghouse and Penn State share a long history of leadership in the nuclear industry and will build on that legacy through this program."

Penn State will leverage its established nuclear capabilities — such as the Breazeale reactor, multi- and interdisciplinary experts in power conversion systems, thermal hydraulics, detection and safeguards, high-temperature nuclear materials, advanced manufacturing, nuclear energy policy, nuclear safety, technology adoption and community engagement, and more. The aim is to support basic and translational research development to establish a micro nuclear reactor prototype platform to drive technology advances and support wide adoption and deployment of advanced nuclear technologies in the PIMA region and across the country in a safe and sustainable way. In addition to advancing the eVinci micro-reactor for broad applications, the team plans to explore how the platform can contribute to displacing carbon-generating energy sources at Penn State.

"Such a platform for research and development would help establish a clean technology corridor in Pennsylvania and beyond, as well as help strategically position our teams to partner with experts across the University in multi- and interdisciplinary scientific fields, as well as in social sciences, business and law on focused projects supporting micro nuclear reactor study and deployment," said Geanie Umberger, associate vice president for research and director of industry research collaborations at Penn State,

The Penn State College of Engineering, Office of the Senior Vice President for Research, the Office of the Physical Plant, among others, will be deeply involved in preliminary discussions with Westinghouse about the feasibility of siting the eVinci micro-reactor at University Park, including potential locations. The micro-reactor platform would be subject to all federal safety rules and reviews by the U.S. Nuclear Regulatory Commission, from approving the safety and operations plans and design to conducting regular inspections. The Penn State Breazeale Nuclear Reactor, which has been in operation at University Park since 1955, underwent the same initial approval process — although the regulations have evolved over the last 67 years — and now receives regular reviews to ensure compliance with modern standards.

The role universities can play in the deployment and adoption of advanced nuclear technologies cannot be overstated. Universities such as Penn State have significant expertise in many of the emerging technologies supporting advanced nuclear such as novel materials, advanced manufacturing, and digital innovation. Land grant universities also have beyond their mission of education and research, their role in economic development of the region. It is on this premise that the PIMA Nuclear Alliance was established.

Recently multiple efforts are aimed at establish R&D platforms and the siting of advanced nuclear (i.e. microreactors or small modular reactors either on campus or in the region) including University of Illinois, Purdue University, Abilene Christian University, and several others [17]. The collective efforts of these universities is of critical importance to regional deployment of advanced nuclear technology, its adoption, and public acceptance as efforts to continue to communicate the benefits of microreactors to energy transition demands. The hope of the PIMA Nuclear Alliance is that multiple consortia support deployment of microreactor technologies. The ingalliance is focused on an overall strategy and plan summarized in the next section.

PIMA Nuclear Alliance – The Plan

The first phase of the initiative will focus on: (1) energy market evaluation in the region for microreactors from industrial processes to other applications, (2) engagement with community, nonprofits, and local government stakeholders, (3) expanding industry and academia partners to our alliance and, (4) flesh out the details of the research platform at Penn State addressing the needs of all our partners. These activities will also help to establish strategic partnerships with key players leveraging major government and private sector financing to establish the RD&D platform, technology deployment strategies, and ultimately help support the establishment of a global technology corridor supply chain for advanced reactor high-volume manufacturing in the PIMA region. Penn State along with their academic partners will also help establish new nuclear engineering programs in the region and collaboratively support workforce development jointly with industry and local governments. This will help sustain a resilient microreactor "Tera" factory (i.e. 100,000*10Mwe ~ 1 TWe) vision for the PIMA region described earlier.

The plan is illustrated in Fig. 1 showing a technology roadmap supporting development of a FOAK design collaborating with Westinghouse and in parallel supporting the design of a RD&D platform. Collaborations among PIMA Nuclear Alliance members would focus on de-risking RD&D platform design and certain aspects of a FOAK. Ultimately the RD&D platform will benefit NOAK (nth-of-a-kind) microreactor designs when cost and scale play a critical role in market adoption. The roadmap in Fig. 1 also illustrates collaborative translational research by alliance members across multiple technical areas including but not limited to advanced power conversion systems, molten salt reactor technology, advanced detection and safeguards, high-temperature nuclear materials, advanced manufacturing of high-temperature components, nuclear energy policy and regulatory innovation, social adoption of nuclear technology and many more.

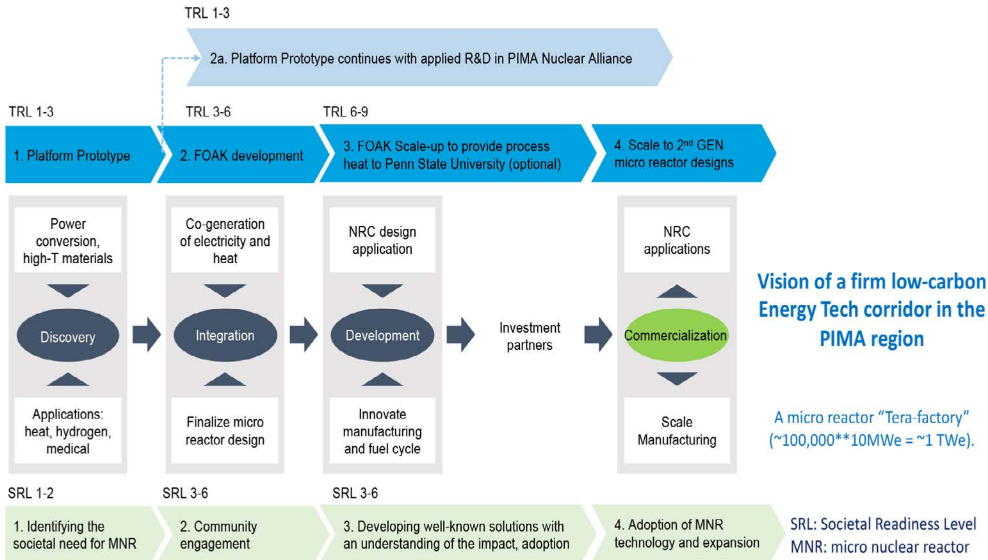

Figure 1: Vision for strategy of a microreactor RD&D platform at Penn State University. A technology roadmap that links enabling technologies such as advanced manufacturing to scale microreactor deployment.

Fig. 2 illustrates the diversity of expertise leveraged at Penn State University from its multi-disciplinary institutes. For example, scientists from the Social Sciences Research Institute (SSRI) would work closely with those from the Institute of Computing and Data Sciences (ICDS) developing enabling technologies such as virtual reality tools to communicate how microreactors work to regional communities.

The PIMA Nuclear Alliance plan has three major goals:

1. To support basic and translational research development in a nuclear battery prototype platform enabling use for licensing, testing, and validation. The prototype platform will provide modular connections to enable study of applications of process heat (e.g., hydrogen generation and low-carbon concrete) and neutron irradiation (e.g., medical isotope production and high temperature materials testing). It will bring both technical and non-technical experts to study all aspects of advanced nuclear technology adoption in the Midwest and greater Appalachia region. Focus areas will include supporting a resilient and "green" mining value chain, high-value critical mineral extraction from coal, carbon-based advanced materials, co-generation, hydrogen generation, medical radioisotope fabrication, industrial and district heating, and renewable energy resilience.

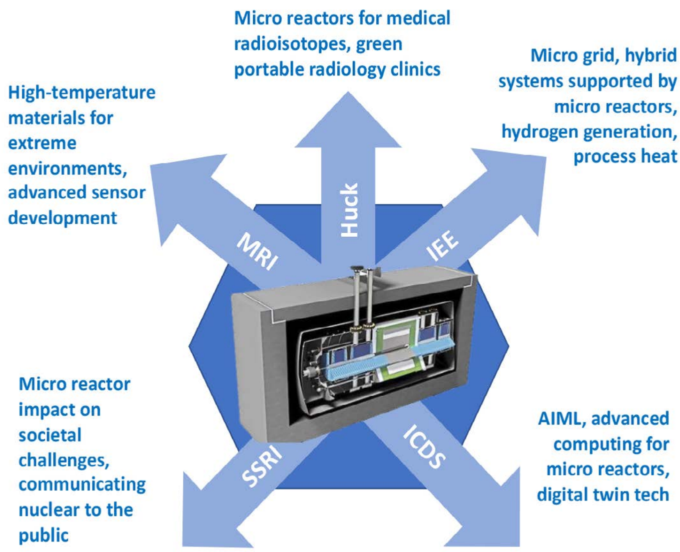

Figure 2: Research areas enabled by microreactor RD&D technology platform at Penn State leveraging PSU multi-disciplinary institutes.

2. To support development and siting of eVinci micronuclear reactor First-of-a-kind (FOAK) deployed on the Penn State University campus that can supply district heating; and other advanced nuclear technologies in the long-term.

3. To leverage development and innovation in #1 and #2 to develop n-th generation nuclear battery technologies that can scale massively with innovative manufacturing for a variety of energy-intense applications (e.g. terawatt-factory).

The alliance also supports bridge programs to provide K-12 and beyond students an affordable, achievable path to obtain education and training in nuclear engineering and science, such as non-traditional models for students unable to reside at University Park to still obtain their degrees in nuclear engineering. This initiative is supported via the Nuclear Sustainability Fund, which was established by the Penn State Nuclear Engineering Alumni Society.

Although the PIMA Nuclear Alliance was established in October 2020 during the pandemic, the collective work of collaborating members began in June 2022 (see the PIMA NA website: https://sites.psu.edu/pima/). The PIMA Nuclear Alliance kickoff workshop took place at the University Park campus in the Invent Penn State Innovation hub, which more than 60 participants from multiple universities and national laboratories attended. The PIMA Nuclear Alliance was highlighted at the Clean Energy Ministerial in Pittsburgh, PA in September 2022 The second workshop was held Oct. 4-5, 2022 in Pittsburgh at the Westinghouse headquarters and included a tour of the eVinci microreactor facilities at Waltz Mill. Attendees included several potential microreactor end users, including oil and gas company NOV and the Saskatchewan Research Council, among others.

Engaging PIMA Communities

The PIMA Nuclear Alliance strategically positions technology teams to collaborate with experts in social sciences, business, policy, and law on focused projects supporting microreactor study and deployment. These teams are organized in working group committees as shown in Fig. 3 and engage together at the PIMA NA series of workshops. Through the Law, Policy, and Engineering initiative at Penn State, a collaborative effort between the College of Engineering, Penn State Law, and the School of International Affairs, the regulatory and policy frameworks of advanced nuclear, as well as the societal effects of technology adoption and impact on communities, are explored.

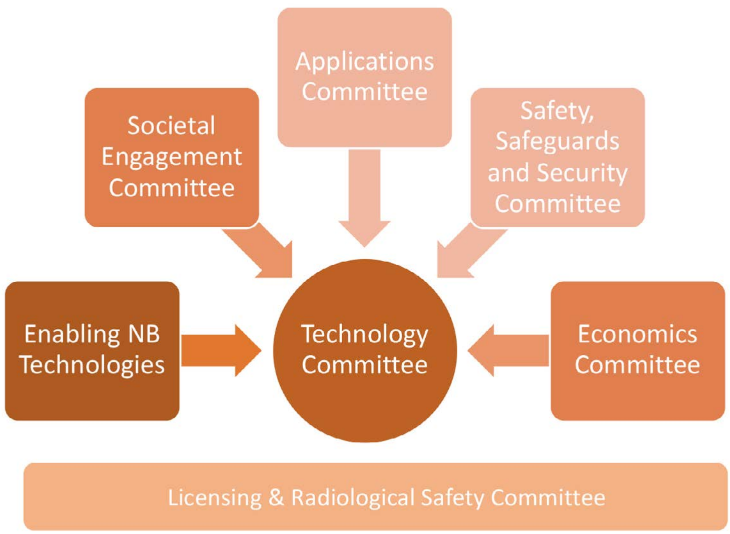

Figure 3: The PIMA Nuclear Alliance plan includes working group committees made up of faculty experts from multiple universities and national laboratories developing working project plans.

"There is a growing interest in engineering amongst young people in disenfranchised communities across this region that are looking for ways to address the urban-rural divide that has been a reality in their lives for a long time," said Aditi Verma, Assistant Professor of Nuclear Engineering and Radiological Sciences at the University of Michigan and PIMA member. "They have seen how many places in Appalachia and the Midwest have been adversely impacted by resource extraction to satisfy the energy appetite of urban America. There is now an opportunity to pursue firm, low-carbon energy generation with nuclear as a potentially viable, scalable, and reliable source of energy. Through the work of the PIMA Nuclear Alliance, we will seek to explore and demonstrate not just the technical but also the social and environmental viability of nuclear as a source of energy for this region through direct engagement with communities. This collaboration with the University of Michigan also leverages their initiative known as Fastest Path to Zero.

Developing better understanding of industries in the region that can benefit from advanced nuclear technology, such as nuclear batteries, and the needs of the region's communities is just as important as developing the technology, Community participation and engagement are at the forefront of the PIMA Nuclear Alliance. Microreactors have the potential to transform communities and spur job creation and economic development in the region. For microreactors to succeed, the regulatory and policy frameworks must evolve in tandem with the technological advancements. Comprehensive outreach and participatory frameworks in all these realms, accompanied by effective communication channels and supporting social infrastructure, is critical for communities to adopt these technologies and reap the benefits.

A great example of the impact micronuclear technology could have on a community is the city of New Kensington, PA. New Kensington in Westmoreland County is 15 miles NE of Pittsburgh, and the city is considered part of the Pittsburgh metropolitan area. It was founded in 1891 and has a population of 12,052 of which 23% live below poverty level according to the 2017 US Census Bureau. New Kensington is witnessing a resurgence in manufacturing and digital innovation that is transforming the community. In 2022 Penn State New Kensington's Digital Foundry was named one of four new Smart Manufacturing Innovation Centers (SMICs) by the U.S. Department of Energy (DOE) in partnership with the CESMII, the Smart Manufacturing Institute. One goal of the Alliance is to immerse itself in community action in the PIMA regions to find out how micronuclear reactors and advanced nuclear, as well as its supply chain, can transform industries and create not only jobs, but sustained, equitable, and resilient economic development and environmental justice. This is the reason the Alliance chose to have their third and most recent workshop on December 8-9, 2022, at the PSU New Kensington's Digital Foundry innovation space directed by Sherri McCleary. The PIMA workshop in New Kensington was impactful to see and learn about the history of the city that went from steel glory to abandoned town and is now on the rise gaining traction as a manufacturing hub.

New Kensington is witnessing a resurgence in manufacturing and digital innovation that is transforming the community. The desire of the PIMA Nuclear Alliance is immersed in community action in the PIMA regions to find out how micro nuclear reactors and advanced nuclear engineering can transform industries and create not only jobs, but sustained and resilient economic development. "We are excited to welcome PIMA and our University colleagues to New Kensington," said Kevin Snider, chancellor of Penn State New Kensington. "The goals and mission of PIMA in relation to workforce development, sustainability, education and use of cutting-edge technologies align with the vision of our future-ready initiatives, including the Digital Foundry, and we look forward to learning more during the event and being part of discussions on continued partnership." Working closely with partners such as PSU New Kensington, engaging and listening to communities, and working with potential local end users of advanced nuclear technology is precisely what the PIMA Nuclear Alliance is all about. Enabling pathways for adoption of nuclear technology as their manufacturing will create more resilient and sustainable jobs that support energy transition.

Author Capsule Bios

Jean-Paul Allain is Professor and Department Head of the Ken and Mary Alice Lindquist Department of Nuclear Engineering at Pennsylvania State University. He was Professor and Associate Head of Graduate Programs in the Department of Nuclear, Plasma and Radiological Engineering at the University of Illinois at Urbana-Champaign (UIUC) from 2013 until 2019 and was Assistant and Associate Professor in Nuclear Engineering at Purdue University from 2007 to 2013. Dr. Allain was also a staff scientist at Argonne National Laboratory from 2003 to 2007. He received a master's and a doctorate in Nuclear Engineering from UIUC and a B.S. degree in Mechanical Engineering from Cal Poly Pomona. He works in areas of surface science and plasma-material interactions with applications in nuclear fusion, plasma medicine, and advanced nanomaterials. Dr. Allain is the recipient of Argonne National Laboratory's Distinguished Award from 2003 to 2006, Best Teacher Awards in 2008 at Purdue and 2013 at Illinois, Department of Energy Early Career Award in 2010, Purdue Research Excellence Award in 2011, the Fulbright Scholar Award in 2015, Faculty Entrepreneurial Fellow in 2016, Grainger Engineering Dean's Excellence in Research Award in 2017 at Illinois, and the 2018 American Nuclear Society Fusion Energy Division Technology Accomplishment Award.

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Challenges to Implementing Microreactor Technologies in Rural and Tribal Communities

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Abstract

Microreactors are an emergent technology providing nuclear-powered energy production facilities that boast portability, modularity, robust operational capacity, and carbon-free baseload electricity generation. While the exact operational and maintenance requirements are currently unclear, most platforms aim to have similar features, such as minimal required operational staff, portability via standard shipping vectors, and high availability factors. Proposed areas for deployment include remote military installations, community disaster relief and recovery operations, and electricity resource supplementation in rural communities, among others. Successful deployment would secure critical, vulnerable infrastructures, and alleviate resource scarcity in historically disadvantaged communities. Rural and Tribal communities are uniquely poised to benefit due to increased vulnerability to—and disproportionately negative outcomes caused by—power disruptions, infrastructure gaps, and critical service disruptions. However, successful deployment to these areas will depend on the careful consideration of current barriers, opportunities, and unique impacts of energy transitions to the respective local communities; as such, implementation and technology must be considered jointly.

As microreactors have not been widely studied in multiscale policy spheres, nor as a typical context for emergent technologies, this article will examine existing regulatory scope, energy infrastructure, ecological capacity, natural resource impacts, and community buy-in as a measure of a community's adoption capability for this technology. Using the Institutional Analysis and Development (IAD) Framework introduced by Elinor Ostrom, we will provide a context for micro- and meso-scale adoption of this technology that is reliant on the nested federal political, social, economic, and

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regulatory climate surrounding the use of nuclear technology, microreactors, and their deployment to address climate change and its associated needs at the local scale. We will address municipal, county, state, and Tribal perspectives; current policies; and ongoing efforts, as well as ecological and social costs associated with transition to a carbon-free national energy position.

Keywords: Small modular reactors, SMR, energy policy, environmental justice, rural communities, Tribal communities, Institutional Analysis and Development, energy transitions, coupled human systems, nuclear

Introduction

Recent global and national disruptions of energy supply, diminished energy resources, environmental degradation, and extended controversies over energy technologies have revived interest on the topic of energy transitions. Renewables and other emerging technologies, such as nuclear energy and advanced nuclear reactors, have been advanced to address these current and expanding challenges. For their part, the nuclear energy industry has proposed the deployment of small modular nuclear reactors to support local power provision—particularly in cases of natural disasters and frequent outages.

Small modular reactors (SMRs) are portable nuclear facilities that serve the same basic function as larger scale nuclear power plants, but they produce a fraction of the power that prototypical plants can produce due to their reduced scale. According to the United States (U.S.) Nuclear Regulatory Commission (NRC), SMRs produce 300 megawatt electrical (MW_e) or less power. This reduced scale also reduces the design component options and footprint requirements in electricity generation.

Presently, the most common model for SMRs are light water reactor (LWR) facilities, but there is a catalog of alternate nuclear reactor designs using various working fluids, which includes liquid metals (e.g., sodium, sodium-potassium alloys, or lead-bismuth eutectic), high temperature gas in the form of helium, or molten salts. SMRs are intended to be scalable to meet existing or growing power demands and may even be further optimized for civilian use. The SMR concept diverges from current nuclear reactors by: (1) increasing safety and reliability through reduced componentry; and (2) reducing the overall facility size. To accommodate this technology, a community must be able to provide a skilled workforce that can operate and maintain these reactors, as well as potentially build additional reactors to meet future power demands.

Proposed Communities for SMR Deployment

Mehta (2005), Wellock (1998), Sovacool (2009), Sovacool and Valentine (2012), and Jasper (1990) all describe national nuclear policy stating that nuclear development is not merely an economic or technical challenge, but also dependent on the cultivation of broader social conditions. Conversations about proposed communities often center around urban areas with industrial colocation. However, this technology is particularly attractive to chemical and agricultural producers in rural and remote communities where a significant amount of heat, and subsequently atmospheric carbon, is currently generated through fossil fuel combustion, as an externality of agriculture. Here, these innovations aim to address critical gaps in service for rural and remote communities.

The size and modularity of SMRs allow siting in areas with common challenges in remote energy provision—particularly following catastrophic natural disasters, such as wildfires—and to provide more reliable energy service to residents and remote localities. In the presence of new technologies such as SMRs, foreseen challenges by designers and policymakers often focus on the economic viability of such technologies. However, communities at the margin—particularly U.S. rural and Tribal communities—may face more challenges in siting and implementation than their urban counterparts. This is due to the nature of their lessened capacity at both the institutional and infrastructure levels. Other issues deemed as important by marginalized communities may take precedence over new power generation using SMRs.

US Rural Communities

Rural communities are characterized by conditions that disqualify them from being classified as metropolitan areas—such as counties consisting of countryside or woodland areas where the presence of rural localities consisting of fewer than 2,500 people and urban areas with populations less than 49,999 that do not contribute to 'larger labor market areas'—or what are commonly thought of as bedroom or suburban communities (USDA ERS 2021). Resources flowing from these rural counties, then, may have some variance — with larger communities in the county being the center for shopping, medical, governmental, career, and job locations, and other services. These communities often are the county seat. For less densely populated communities of rural towns, the prevalence of infrastructure and government institutions, including street-level services such as police, fire fighting, and local representation, may have limited capacity compared to their slightly less rural counterparts (Mockrin et al. 2014).

Individual rural communities are often characterized by their close-knit populations, where 'everyone knows everyone,' their limited services, and long distances from city centers or services. Many rural communities have depended on natural resource extraction industries or agriculture to support their economies. Some of these include timber, critical minerals mining, crop farming, and fishing, among others. Rural communities across the West are often characterized by proximity to the wildland-urban interface (WUI) and subsequently studied for their challenging experiences during and after recurring natural disasters, such as wildland fire and tornadoes, among others (Mockrin et al. 2018). In past years, recurring natural disasters, such as the wildfires in California, Oregon, and surrounding states, have left rural counties with mass infrastructure damage, as well as mid- and long-term disruptions in power provision for both rural and urban localities. Other outages, such as those caused by the 2021 winter storms in Texas, or Hurricane Ian in 2022 in much of Florida, among others have exacerbated the challenges of rural communities in receiving power, water, and aid. these communities may be less accessible, have a much lower population, and have less infrastructure to tend, they are often the last ones to come back online following a natural disaster or outage (Mockrin et al. 2022).

In addition to outage experiences during catastrophic events, many rural areas are already classified as disadvantaged communities (DOE 2022a), meaning that critical service gaps in education, medical service provision, Internet, and energy, among others, exist and can be exacerbated by such events. Rural community capacity hinges on the availability of infrastructure and institutional inputs—such as those from local government, street-level bureaucrats, job opportunities, and available industry, among others. Challenges to new technology adoption may stem from the current lack of infrastructure; issues with quality provisions or the availability of food, water, and electricity; low median income and home ownership; a legacy of land or environmental degradation with resource extraction and other natural resource-based industries; and a diminished tax base from which to derive funding for capital improvements.

U.S. Tribal Communities

Across the U.S., Tribal communities—including those on or off reservations—suffer disproportionately from health impacts, food and water insecurity, housing insecurity, and energy poverty, among many other environmental injustices and disparities in social and economic wellbeing. Environmental challenges, such as a history of mining on sacred ancestral lands, unregulated waste, and failure to properly clean up natural resource extraction areas, have led to further mistrust and strained relationships between Native American peoples and current energy suppliers. These include but are not limited to industry and the U.S. Department of Energy (DOE). These challenges compound historical social injustices endured by Tribal communities during the periods of colonization and expansion of settlements across the US, but particularly in the West.

In September 2021, the U.S. Department of Defense (DoD) issued a draft environmental impact statement regarding the Project Pele Mobile microreactor and its ongoing consultations with state, local, and Tribal stakeholders—particularly insight shared from the Shoshone-Bannock Tribes of Fort Hall, ID. Due to the Tribes' deep cultural heritage and strong historical ties to the land, their insight is very valuable to the Strategic Capabilities Office.

Notably, the Land Back Movement, which has been gaining traction among Tribal communities and progressives across North America since 2020, has focused on the sovereignty of indigenous peoples over their historic lands. Centered on environmental stewardship and the rights of nature, the Land Back Movement examines the role of Tribal communities in preventing further destruction of ancestral lands and combating climate change through grassroots conservation and guardianship of the environment (NDN Collective 2020).

The Biden Administration's 2021 executive order, the Justice40 Initiative (DOE 2022b), outlines stipulate that projects funded by the federal government must consider the environmental and energy injustices experienced by marginalized communities, such as rural and Tribal communities. The Tribal experience of health disparities, food insecurity, and energy poverty, among many others, highlight the need for solutions to social science's 'wicked' problems, or large-scale, multifaceted societal challenges imposed by the current institutional structure. However, current resource extraction practices for energy provision and other infrastructure across the US has led to a history of land degradation and disruption of sacred Tribal lands, cultural resources, and biodiversity.

Community Linkages

Linkages between rural and Tribal communities are often reflected in the types of resources, community capacity, and generalizations regarding remote living and access to critical services such as education, medical care, high-speed Internet, and energy equity, among others (DOE 2022a). It is important to note that many social science studies consider Tribal entities in the studies of rural communities—particularly in the American West. Similarities between natural resources, industry, natural amenities, and environmental and energy injustices—including gaps in service — are unique to each individual community context. Studies on rurality across the U.S. necessarily strive to include Tribal perspectives, particularly since federally recognized Tribes and reservation lands as managed by the Bureau of Indian Affairs, are largely remote and rural in nature, thereby experiencing the same challenges as their other rural community counterparts. For our analysis, we will consider the resources and capacity of rural and Tribal communities to be similar, yet governed by sets of contrasting sociocultural, economic, political, and institutional norms. Citizens and other members of these communities are assumed to have a different set of values regarding their community, the land, its stewardship, and priority needs, wants, as well as for the outcomes of new technologies and interventions.

Regulatory and Licensing Processes for Small Modular Reactors

Current principles of nuclear regulation and safety have evolved due to technical understanding of the strengths and weaknesses of existing plant designs and public concerns related to the safety of nuclear power plants. The role of nuclear reactor safety regulation and licensing is for the government to review and independently verify that nuclear reactor systems perform safely with reasonable assurance that the public and environment are protected (Deutch et al. 2003). Safety functions include controlling nuclear fission, heat and coolants, and the managing of any chemically reactive or radiological materials. Additionally, licensing challenges and requirements for SMRs are derived from frameworks and features that are significantly different from traditional LWR-based plants, making the licensure case for SMRs non-standard when compared to the current nuclear power fleet.

The licensing process for new reactors, in broad terms, is the process by which a civilian organization receives authorization to conduct any or all the following activities:

1. Construct, operate, and decommission commercial reactors and fuel cycle facilities.
2. Possess, use, process, export, and import nuclear materials and waste.
3. The management and transportation of nuclear materials and waste.
4. Site, design, construct, operate, and retire nuclear waste disposal sites.

Proper execution of these activities requires forthright dealings with regulatory organizations, community involvement and support, proper engagement with reactor vendors and construction firms, and the establishment of an adequate technical workforce. Current rural and Tribal communities may not be well-suited to meet these demands, given their geographical isolation, lack of centralized infrastructure, public apprehension towards unfamiliar or external influences, etc., described in earlier sections of this paper. Providing guidance on how to overcome these challenges is a major objective of this work—particularly in the context of the adoption of advanced technologies, when disparities in accessing current technologies and historical gaps in resources and infrastructure exist today.

Challenges to Adoption of New Technologies

Tribal and indigenous ways of life, as well as rural community values and norms, may pose challenges to the acceptance of SMR adoption at a local level. Federal and state regulatory processes have been thoroughly examined. Social science may focus on market support for adoption of these technologies for supplemental, emergency, and day-to-day energy provision. There is a need for community-led buy-in for the adoption of technologies, including support for nuclear power. In addition, to an understanding of unique community conditions, needs, and wants, is crucial in the promotion of SMR adoption.

Therefore, for the adoption of SMRs and new energy transitions in general, industry should consider the ways not only that regulatory bodies and markets interpret what is allowable, safe, and innovative, but also how these new technologies align with or defy social norms, expectations, and common values at multiple scales before determining the target site for the implementation of projects. Rural and Tribal communities possess unique and localized community networks, contexts, and sets of inherent rules and norms. These exist alongside regulatory practices, infrastructure availability, and economic feasibility. This can produce unforeseen and unstudied challenges in the siting and adoption of SMRs and other energy innovations.

Literature Review

An interdisciplinary Massachusetts Institute of Technology (MIT) (Froese et al. 2020) study on the future of nuclear power linked the "limited prospects for nuclear power today" to "four unresolved problems: Costs, Safety, Waste, and Proliferation" (Deutch et al. 2003). It is important to note that these problems are ultimately social in origin and the recognition by nuclear reactor vendors that these are problems to be dealt with reflects popular struggles (Ramana and Mian 2014). The social science literature on many of these restrictions about nuclear technology proliferation is vast. For example, Ishiyama (2003) analyzed an environmental justice study evaluating long-term nuclear waste, Greenberg (2014) studied trust in nuclear institutions, Greenberg (2009) focused on risk perception to understand the public preferences for risk perception in the U.S., and Downer (2014) and Hagmann (2012) questioned the risk complexity and problematic nature of the production of 'expert knowledge' about reactor accidents.

At a micro-level of analysis, adopting more pro-environmental choices and behaviors is possible, but this adoption is not occurring to the extent necessary to stem the increasing flow of greenhouse gases and other environmental damage because there are limits on the part of individuals that prevent the widespread adoption of new technologies (Gifford 2011). Some barriers are recognized in psychological research, but others are considered only marginally (Kollmuss and Agyeman 2002; Lorenzoni et al. 2007).

Additionally, communication is critical for community support for nuclear technology adoption. A social comparison between one house and its neighbors is one of the most efficient ways to change energy use. The way a message is delivered can influence how people react and behave, according to Thaler and Sunstein (2008). In this way, the authors' ideas about nudging and behavioral economics are critical. They demonstrate how one of the most common economic models are wrong in predicting what people do. Cognitive limitations, information bias, emotions, and an unknown future are commonalities among individuals who try to make decisions related to the environment and energy conservation.

The authors present a series of experimental results based on Kahneman (2011) regarding how people sometimes prefer the certainty of a decision even when the final benefit of that decision measured in monetary values is smaller than other options. In other words, monetary incentives are not the only ones that matter.

Health and environmental messages are vital to consumer buy-in, particularly in areas of environmental injustice and critical service gaps in healthcare, broadband, and in areas of land degradation and natural resource extraction. In the literature, there is not a common agreement regarding the reasons that lead people to accept specific technologies or innovations over others. However, vast literature exists regarding measurable psychological factors that could explain 'consumers' decisions, but only considers quantifiable factors, rather than qualitative data or robust sentiment analyses. The rapid development of new technologies makes it impossible for consumers to adapt quickly enough. In addition, researchers have yet to develop a model understanding the adoption behavior of consumers (Boserup 1981; Rezvani, Jansson, and Bodin 2015).

Adoption behaviors of communities vary, including both subjective and objective reasoning, measurable and quantifiable behaviors, and those currently unobserved. A significant share of the current empirical behavioral analysis is inclined to measurable factors. The most classical model includes aspects that can be measured numerically, narrowing its scope. An excellent example of this is Froese et al. (2020), Locatelli et al. (2014), and Macdonald and Parsons (2021). Furthermore, most studies focused on a limited quantitative set of psychological factors, thus failing to include a comprehensive set of critical factors influencing technology acceptance. If variables cannot be measured quantifiably, they are not included in the analysis. It is critical to note that a vast share of studies only considers factors that can be formalized in mathematical terms.

Thus far, there is no consensus on what framework to use to explain technology acceptance and consumer behavior related to new technologies such as SMRs. In a recent survey conducted by the Pew Research Center (2022), a third of U.S. adults (35%) said the federal government should encourage the production of nuclear power, while about a quarter (26%) said the government should discourage it. Another 37% said the federal government should neither encourage nor discourage the production of nuclear power. (The authors note that the survey was fielded before the 2022 Russia's military invasion of Ukraine and following discussions related to nuclear safeguards and security.)

Specifically, we argue that there are more important social restrictions than NIMBY opposition concerning the deployment of SMRs. Specifically, cultural, psychological, and political barriers (Sovacool 2009) affect the deployment of new energy technologies. Additionally, at the micro-level, behavioral psychology and communication play a role in public policy related to energy. Many psychological scientists now assume that emotions are a dominant driver of meaningful decisions in life (Lerner et al. 2015; Keltner et al. 2014; Keltner and Lerner 2010; Ekman 2007). And as we described before, energy decisions have been critical through human history, its evolution, and quality of life. Furthermore, the importance of emotions relating to energy decisions cannot be ignored.

Another vital attribute of SMRs to be considered is concern about risks. Most of the energy technology developed in the last few decades has some degree of risk and diverse consequences on natural systems. A significant share of these technologies also has destructive potential on both human and natural systems. From a broader perspective, a nuclear plant is imbued with complex and interrelated human and natural systems where we cannot think about technological artifacts in isolation. Pritchard (2013) argues that government regulators and industry officials often focus on fixing the technology in question and attempting to reduce the likelihood of future human error. A complementary approach should ask about whose goals these technologies serve, as well as the needs of the communities they will serve. The implementation of new technologies could be disruptive and radical for an entire socioeconomic system due to interdependence among actors and technologies.

In terms of nuclear reactors, due to complicated technological designs, we cannot anticipate all the possible interactions or inevitable failures (Pritchard 2013). The solutions to addressing these risks are unclear because of the varied types of system failures like design, equipment, procedures, operators, material input, and environment. Uncertainty about a safety outcome fosters social rejection (Kahneman 2011). Additionally, Perrow (1984) states that risks seem to appear faster than the capacity to reduce risks. Barriers include limited cognition about the problem, ideological worldviews, sunken costs and behavioral momentum, and dis-credence towards experts and authorities, among others. It is critical to note that engineers often evaluate the safety of a design using the Probabilistic Risk/Safety Assessment/Analysis (PRA/PSA) methodology. However, a risk assessment is not enough to reach a successful deployment of SMRs and a widespread implantation of this technology across different scenarios. Compounding this issue, the general population, which may be hesitant to adopt nuclear technologies (Boudet 2019), may not fully grasp the intricacies of PRA/PSA, thus escalating challenges in influencing positive sentiments to adoption of SMRs or other energy advancements not reliant on fossil fuels—particularly post-Fukushima and the war on Ukraine, where news media and conversations interacted with the perceived lack of safety and reliability of nuclear power, rather than statistical probabilities of incidents related to day-to-day operations.

Even so, behavioral studies aimed towards the adoption of new energy technologies may not capture rural and Tribal values and norms, or those uniquely held by close-knit communities such as these. Additionally, the traditions of both rural communities and Tribal entities may present challenges that go beyond those quantifiably measurable. Studies regarding the adoption of nuclear technologies center around the public's environmental and safety concerns for operations and waste, regulatory challenges, and economic feasibility. However, additional challenges exist at the periphery, particularly in elements of rural and Tribal communities' potential issues regarding the externalities of SMR siting and implementation. For example, issues of greater priority might be more prudent to address – such as equitable provision of education, food, and water, among others and resistance to government and institutional interventions in tight-knit and localized social networks—both formal and informal.

Policy Framework

Traditional economic frameworks following a rational choice model assume that all parties have perfect information about the context in which decisions are made. Pure economic theory dictates the examination of prediction of future supply and demand of individualized or collective systems to predict outcomes related to these energy markets. However, unobserved, or non-quantifiable factors (i.e., historical, sociocultural, psychological, and inter and intrapersonal factors of community members and environments) may not be examined in the proposal and adoption of new technologies.

The Institutional Analysis and Development (IAD) Framework (Ostrom 2007) has been used to examine both formal and informal rules that govern decisions and outcomes both within and among institutions. This framework has commonly been employed in public policy spheres to understand how institutions operate and interpret situations and actions of themselves and one another at multiple scales. Institutions, here, are regarded as any type of collective decision-making and acting body, such as local communities, government, industry, non-governmental organizations (NGOs), schools, and interest groups, among others.

As economic and regulatory models may not capture a community's true willingness-to-adopt these new technologies, and while formal regulations govern siting and operations, other aspects of implementation—localities are often governed by informal networks of community leaders, influence, social norms, and collective values (Fishler 2017). However, their desired implementation at the micro-scale—specifically in municipal, Tribal, or rural contexts localities—necessarily depends on the analysis of local sociocultural, economic, environmental, and political contexts, as well as the presence and quality of proximal infrastructure.

In studies of energy policy, particularly in the context of SMRs, a comprehensive review of both regulatory processes and projected market demand is critical to understand the processes by which innovative technologies are implemented in communities. However, in policy studies, the need to acknowledge the multiple actors, sectors, and factors exist that play in certain spheres, including local community development and acceptance of new policies, norms, and infrastructure.

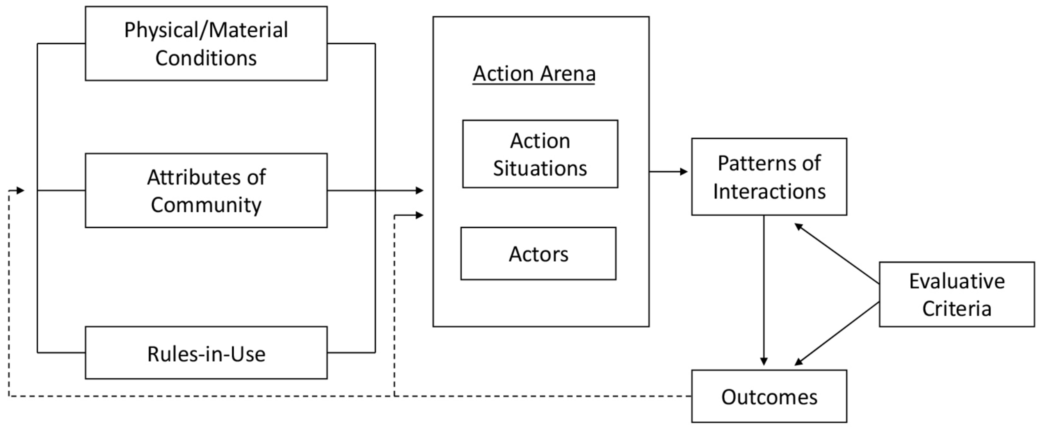

Figure 1: **A Framework for Institutional Analysis**

Adapted from E. Ostrom, Gardner, and Walker (1994). From: Institutional Rational Choice, (Ostrom 2005), in Theories of the Policy Process, Paul Sabatier

In Ostrom's IAD, as observed in Figure 1, physical and material conditions in accordance with attributes, demographic elements, social norms, inherent and implied rules in use, and current institutional capacity determine actions and decisions for the adoption of new policies, norms, and technologies. These decision-making spaces (e.g., action arenas) are the spaces in which the actors within institutions and communities consider conditions, attributes, and rules of their contexts alongside new or changing policies, infrastructure, technologies, and other proposed communal change-agents.

The resulting patterns of interactions relate to how these proposed alterations will be interpreted, simultaneously with existing beliefs, attitudes, and criteria regarding the evaluation of that which is proposed. This is relevant to the determination of willingness-to-adopt these new or changed policies or technologies within their unique contexts. It is important to note that outcomes are inherent agents of shifts in attributes, rules, and conditions of a community (Ostrom 2007; Fishler 2017).

Here, actors and stakeholders in communities may not necessarily act in a rational or formal manner, as they are acting based on sociocultural norms of their communities as decision-making bodies. For those that act according to economic principles/rational choice model of utility maximization, the decision to adopt new technologies or new sets of norms should not only consider the tradeoffs between goods and services, but also established inherent rules and values governing their patterns of interactions both within and outside their communities.

Discussion

Most studies of emergent technologies, like disaster mitigation, focus on one point in time adoption of innovations through an economic and technical lens (Mockrin et al. 2016). These studies may consider the availability of current infrastructure, resources, and challenges with program management, mitigation techniques, and practices meant to support adoption and deployment strategies as they relate to initial siting and implementation. In this context, regulatory challenges are navigated through formal decision-making bodies. However, while formal governance structures are certainly present in both rural and Tribal communities, it is misleading to assume that the same institutional resources and capacity exist within these types of communities as they do within those of higher capacity, greater population, greater infrastructure locales with numerous formal decision-makers, enforcers, and economic, policy, and technological spaces among other complexities. Tribal communities are often set within rural contexts, particularly in the case of federally recognized Reservations, and present further disenfranchisement by way of institutional capacity, infrastructure, funding, citizen resources, and greater disparities in health, socioeconomics, and quality of life (DOE 2022a). It may be beneficial for innovators in industry and government to understand the barriers and opportunities for SMR adoption in Tribal communities. These advanced technologies are aimed at addressing energy needs, including peak hour cost, availability, and accessibility for the disenfranchised. The creation of tailored approaches toward SMR implementation in Tribal communities—many of which are considered the most disadvantaged in the US—may be scaled upward to ensure success in additional areas, especially those communities or localities with less disadvantages, greater resources, and greater capabilities to adopt to these innovations.

Thus, the consideration of economies-of-scale are critical in understanding how communities and the institutions embedded within them will adopt new policies, technology, and infrastructure (Ostrom 2007). The study of civilian microreactor implementation exists largely within regulatory spaces at the federal and state levels, and at the meso-level and macro-economic scales. Current studies of these technologies focus largely on market demand, economic feasibility, and regulatory policy conditions that may create barriers or opportunities for adoption in the broad sense.

However, for rural and Tribal communities, policy research and environmental justice critiques, would indicate that there are complex sociocultural and informal considerations that this emergent industry may wish to consider prior to SMR siting and deployment. The goals of SMR implementation outside of military contexts may not necessarily align with the adoption of other new technologies, and not simply in urban areas. A new more nuanced frame may be needed for rural and Tribal communities, where populations may be hesitant to accept the influence of outsiders, industry, and federal government interventions.

With criticism of adoption of these technologies in urban areas, citing safety and waste concerns (Boudet 2019), the challenges in deploying SMRs in civilian context may go beyond these aspects. In truth, rural and Tribal communities often lack capacity and institutional availability that their metropolitan, suburban, and exurban counterparts may hold. The lessened institutional capacity, as well as remote geography, have inherently exacerbated challenges to rural and Tribal qualities of life—including decreased access to quality food, hospitals, education, Internet/broadband access, safe drinking water and water treatment provision, and the availability of affordable efficient home energy service, among other critical service gaps.

Because proposed communities for SMR adoption vary widely in their contexts, norms, composition, environment, and available institutions for governance checks and balances, there is a need for consideration of future challenges to adoption at the institutional level. Institutions, here, are defined as informal or formal decision-making bodies—including federal, state, and local governments (formal), as well as community groups, norms and beliefs, and conditions of the environment (informal), among others (Fishler 2017). Additionally, these institutions, their rules, standards, norms, culture, as well as material and physical conditions, are nested within one another. This implies a scaffolded approach to how regulations, changes, and operations are determined and interpreted within and among institutions (Ostrom 2007), as shown in Figure 2.

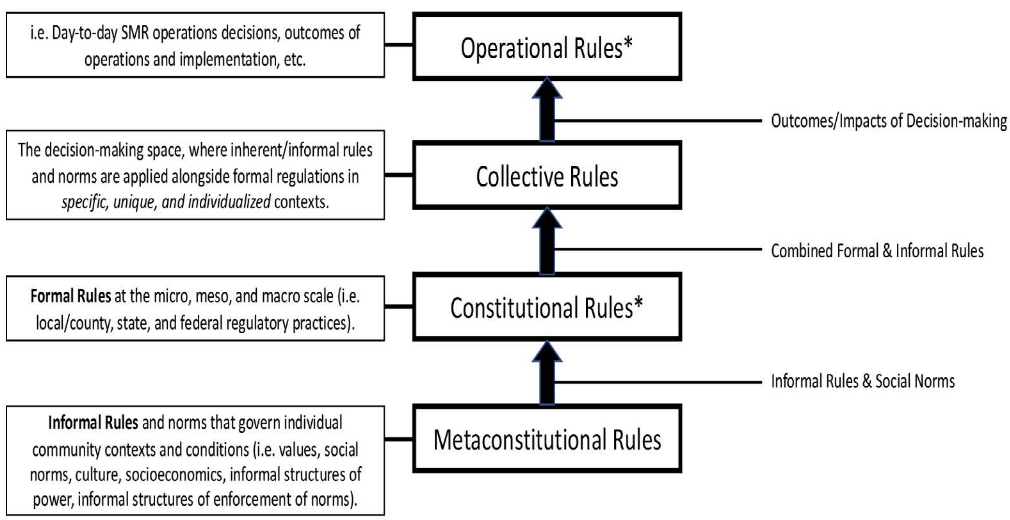

Figure 2: **Multiple Levels of Analysis – Scaffolded Rules-in-Use**

Adapted from E. Ostrom, Gardner, and Walker (1994). From: Institutional Rational Choice, (Ostrom 2005), in Theories of the Policy Process, Paul Sabatier.

Most current studies rely on notions of formal institutions or quantifiable data related to marketability and conditions under which SMRs are feasible under federal and state regulations, as well as economic feasibility. Additionally, they often depend on economics for social science determinants of adoption of these technologies. However, the process by which communities accept and adopt new technologies are more nuanced than these aspects (Boudet 2019).

Since all rules here are assumed to be nested within one another, these define how the previous set of rules will be interpreted or changed. While rules may be fixed, they may be interpreted differently by varied actors, sectors, agencies, and stakeholders. In the context of SMRs, this means that the community in which A facility is to be sited may view the introduction of new technology in a different light than industry professionals. Metaconstitutional rules provide the basis upon which all other rules are interpreted, adjudicated, and understood. These refer to those which are not commonly studied in policy spaces, as they rely on qualitative accounts of values, norms, culture, socioeconomics, inherent and contextual structures of power, and community context and the environment. Here, either informal or implicit rules based on the day-to-day experiences of living within the community and the beliefs and patterns-of-interactions between residents and street-level bureaucrats are of primary interest.

Informal rules flow upward to constitutional rules of operation, implying formal rules and regulations at the micro-, meso-, and macro-scales. In the context of SMRs, these may relate to local/county, state, and federal regulations surrounding the siting and externalities of these facilities and their implementation. In studies of SMR feasibility, the focus often draws in on federal and state regulations as nested within one another, yet, divorced from metaconstitutional rules and norms that may govern the regions and communities in which new technologies are introduced.

This framework can be used to examine a community's physical and material conditions—including existing infrastructure, availability of storage, and landscape and available space, among others. In previous studies of feasibility or willingness to adopt, the foci for this technology have existed largely in this space, as well as the formal rules employed for siting and certification purposes. These formal rules may relate to federal and state laws for reactor safety and operations, as well as economic feasibility.

Policy studies related to institutions, however, should consider attributes of the community as a crucial aspect of willingness-to-adopt. Oftentimes, these attributes are not or cannot be measured nor analyzed in quantifiable ways—yet they have impacts on the patterns of interactions between institutions, decisions of actors within these contexts, or the Action Arena itself, as seen in Figure 3. The nuances may not be captured in quantitative studies but may be observed in qualitative and social science research considering the context of the resulting impacts of sociocultural norms, environmental conditions, socioeconomics, familiarity with technology, political and policy views, and values, priorities, and genialness to and acceptance of influence from outsiders or institutions external to their communities or localities.

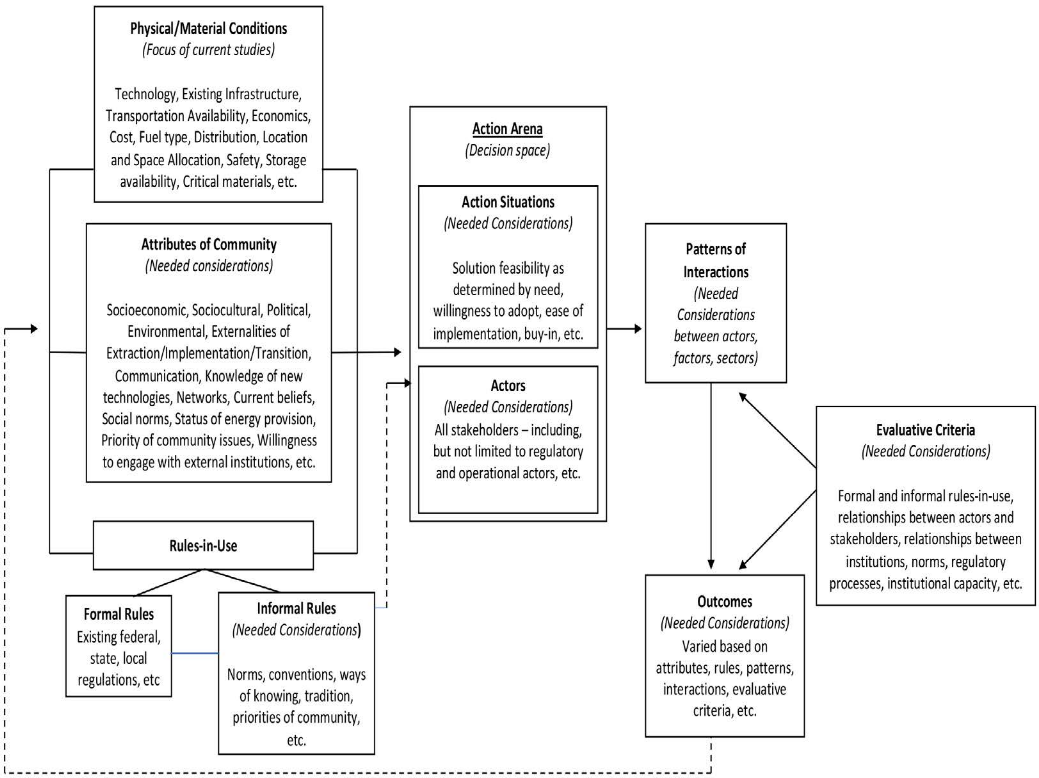

Figure 3. **Institutional Analysis of Small Modular Nuclear Reactors: Needed Considerations**

Adapted from E. Ostrom, Gardner, and Walker (1994)

Formal Regulatory Practices vs. Informal Rules and Norms

Current efforts towards examining willingness-to-adopt of these technologies does discuss the need for partnerships between government stakeholders in both local and regional contexts, as well as local government decision-makers. However, due to the limitations of institutional bandwidth and lack of willingness for most rural and Tribal communities to accept formal rules and regulation from those outside their communities, in addition to a lack of infrastructure enabled to implement and enforce these formal governance structures, there may be additional challenges that have previously not been considered in these spaces.

Research shows that the prevalence of informal networks in these tight-knit communities are the most effective forms of political and sociocultural influence—

particularly in rural and Tribal communities (Fishler 2017). Here, social norms and identity, including neighbor-to-neighbor relationships, are often the determinants of success in both street-level citizenship and stakeholder engagement. In areas where there are current service gaps and a lack of infrastructure, grassroots organizations of informal leaders who may self-select based on their connectedness in the community can often complement and have as much influence as formal regulators, governance structures, or business owners and other stakeholders. In areas where enforcement of formal regulations at the county and local level are lacking due to the challenge in resource provision for such street-level bureaucratic processes, these communities may rely on a kind of informal network-driven approach to determining and enforcing social norms and accepted behaviors, as observed in Figure 4.

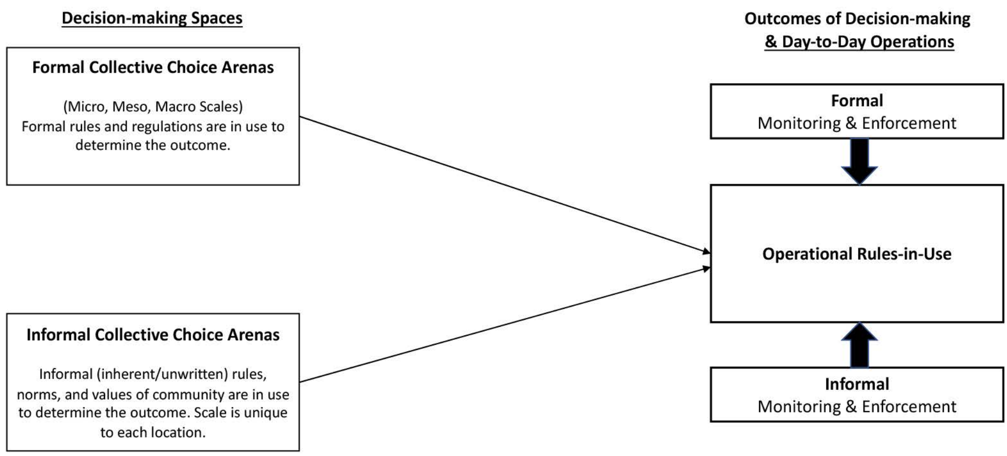

Figure 4. **Relationships of Formal and Informal Collective Choice Arenas**

Adapted from E. Ostrom, Gardner, and Walker (1994)

Formal institutions are the typically involved in analyses of SMR civilian deployment—such as regulatory bodies like the NRC, state governance, and local policies—regarding aspects of SMRs and their externalities (e.g., waste removal, water usage). They are geared more towards conformity to the norm, engaging the populace, and information provision to the commons (Ostrom 2007).

Formal collective choice arenas and decision-making spaces at the federal, state, county, and local level—or macro-, meso-, and micro-scales—include those agencies, bodies of governance, and other organizations where formal and explicit rules are used to describe and determine outcomes. At this time, those designing and siting SMRs are focused largely on overcoming only barriers located in the formal arenas to bring them to market.

However, informal collective choice arenas, where varied groups, cultures, inherent and unwritten rules, values, and norms are upheld should be a focus of siting and understanding potential barriers to community buy-in, willingness-to-adopt and willingness-to-pay, as well as availability of current infrastructure and community bandwidth. Informal monitoring and enforcement of these values will inherently align with proposed energy solutions that connect with community values, culture, norms, and the prioritized wants and needs as a precursor to formal regulations. These include legal operations, regulatory processes, and physical and material conditions. Here, the rules of day-to-day operations and successful implementation of SMRs in rural and Tribal communities should consider these informal and formal rules in tandem, which are checked and balanced not only by regulatory bodies, but also by keepers and enforcers of rules and norms within the localized context.

Safety

Safety practices and certifications are not necessarily enough to assuage community challenges in acceptance of nuclear technologies. In many cases, the distrust of nuclear technologies may stem from historical knowledge of nuclear disasters, environmental concerns about waste generation and storage, and the snowballing nature of negative sentiments surrounding the use of nuclear power, as well as the role of for-profit industry in communities. Some research suggests that education to increase awareness of reactor technologies and their inherent safety mechanisms may lead to greater social acceptance and willingness to adopt emergent and advanced technologies like SMRs (Choi et al. 2020). However, the hazards literature may indicate that education programs on best practices for safety and mitigation may not achieve long-range outcomes (Gil-Rivas and Kilmer 2016; Mockrin et al. 2018), while psychology studies suggest that acceptance of public education efforts depend on pre-existing attitudes about the particular topic, and therefore, may not assist in changing minds (Choi et al. 2020; Cho and Choi 2010).

Existing Critical Service Gaps

The prevalence of existing gaps in service and environmental and energy injustices in rural and Tribal communities may reduce the willingness to adopt new energy technology such as SMRs. Critical service gaps such as the lack of adequate medical care, Internet service provision, availability of nutritious food, proximity to disaster-prone landscapes, inequitable education, and lack of or unsafe/deteriorating infrastructure, may take priority over acceptance of new infrastructure that is time- and resource-intensive. If the immediate benefits of SMRs to the public are not clear, it may be especially challenging for these localities and groups to accept the benefits of energy transitions. It may not appear that the time-intensive and high-resource needs of SMRs will improve th quality of life for all members of the community. Since current environmental and energy injustices exist, particularly for these two community types, SMRs may not necessarily create the greatest impact on the largest number of people—particularly those that are currently disadvantaged because of existing infrastructure. Additionally, for existing disadvantaged communities, SMRs may not guarantee relief from energy and its cost burden, particularly in marginalized spaces, where the most vulnerable may still be at risk from resource extraction, space acquisition, and externalities of SMR deployment and implementation.

Rural Communities

Rural communities prefer that local governance, institutions, and rules enforcement be informal, depending mostly on their social norms. While rural residents are often subject to local building and zoning codes, they may put great stock in expressions of freedom (Kim and Marcoullier 2016; Miller and Rivera 2010; Mockrin et al. 2018; Nigg and Tierney 1993; Sumner 2005). These rural communities may value individuals embedded in the community creating and uplifting their networks, rather than acceding to the influence of outsiders or their formal rules. Additionally, because rural communities more heavily rely on informal networks than their urban counterparts (Gifford 2008; Gifford 2011; Sumner 2005), they may challenge the enforcement of formal rules that appear to violate community social norms. Achieving buy-in and support for new rules, institutions, and infrastructure may be grassroots-based through a bottom-up decision-making structure (Kapucu and Garayev 2011). The presence of an outside industry and an influx of "bureaucrats" to ensure compliance may not necessarily preserve agreed-upon social norms and conventions of these rural communities.

Tribal Lands and Community Values

The preference for local governance of rural communities also apply to Tribal communities, but other pertinent factors can deter the willingness to adopt new or unfamiliar industries or technologies. For example, efforts toward the preservation of Tribal lands, resources, and values have become more mainstream since the media focus in 2015 on the Keystone XL Pipeline. This led to a call across North America for the restoration of traditional native lands and the protection of natural resources, biodiversity, and Indigenous ways of life—particularly through the Land Back Movement. In relation to SMRs, required critical materials, disruption of historic lands through extraction, standing up the facility, the use of water and water treatment, space needed for coolant storage, etc. may be at odds with Tribal values such as conservation and environmental stewardship.

At the same time, increased energy provision and the reduction of energy costs on Tribal lands—particularly on American Indian Reservations—are often needed in remote locations. The introduction of new industry within these communities, compared with sacred beliefs about the role of people on the land, may necessarily present tradeoffs that create misalignment in the retention of values and norms in the pursuit of SMR implementation in Tribal communities.

As previously noted, federally recognized Tribes are considered sovereign nations with their own governance bodies and decision-making. In addition to informal networks, industry and Federal entities should consider a government-to-government approach in the development of plans for the implementation of new technologies and infrastructures.

Governance and Social Networks

A focus on federal and state policies on nuclear energy to determine marketability may overlook informal governance structures driven by the public, particularly in arenas where community decision-making practices are determined by small groups of publicly minded residents. Local decisions may rely on complex social norms including groups of influential neighbors, rather than local ordinances (Aldrich and Meyer 2015; D'Agostino and Kloby 2011; Fishler 2017).

Energy and Environmental Justice

Under the Biden administration's Justice40 Initiative (DOE 2022b), 40 percent of funding is projected to impact disadvantaged communities experiencing environmental injustice under current infrastructure. Priorities for research and development under DOE prioritize the alleviation of service gaps and energy poverty. However, current data tools and collection may miss indicators and data points due to the lack of current institutional capacity to capture these underserved populations. Determining measurable success for alleviating energy poverty may inherently rely on robust community engagement strategies. These are consistent with traditional scholarship on environmental justice, which emphasize grassroots, community-driven action to meet a population's basic needs while abating environmental injustice (Mohai et al. 2009).

These challenges have been highlighted in publicly available databases, including DOE's Disadvantaged Communities (DAC) Reporter, which identifies areas where communities and quality of life indicators rank below median benchmarks for the country. It should also be noted that challenges exist in using this tool since the ability to undertake data collection and reporting varies between communities. Rural and Tribal regions may or may be challenged in this regard. Ongoing research efforts are aimed at quantifying potential shortcomings to identify meaningful solutions for incomplete data sets (DOE 2022a; Ross et al. 2022).

Importantly, true service gaps, particularly those related to energy provision, may not be adequately reflected in the data. This may pose challenges in determining the actual value of new technologies as well as quality-of-life improvements they may allow. Standard assessments of market demand in these contexts may not reflect actual ground level community benefits of technologies like SMRs.

Additionally, the presence of multiple informal decision-making networks and stakeholders that may influence formal actions and policy adoption by regulating bodies. This may further complicate a true understanding of the willingness to adopt regulatory processes and market demand. This follows traditional formal economic policy and rational choice models.

Other Externalities and Additional Considerations

Traditional micro-economic theory considers externalities to be inherent to the interplay of supply and demand of goods and services. However, the IAD favors viewing externalities as outcomes of the policy, decision-making, or adoption process. They may inherently change physical and material conditions, attributes, and rules in communities (Ostrom 2007). This feedback loop can influence future decision-making of actors and sectors, including amplifying challenges, decisions, and future externalities.

In the context of SMR implementation in rural and Tribal communities across the US, as presented in Table 1, we consider the complexities of resource provision for such technologies, implementation, and the resulting challenges that these localities may likely experience.

Table 1. Micro-scale community externalities of SMR implementation

Externalities	**Description & Additional Considerations**
Environmental	
Waste Disposal	Availability space and location for safe disposal of waste with least impact to humans and environment.
Water Quality/ Quantity	Available water for SMR use that may impact agriculture, drinking water availability, etc., in record drought areas.
Coupled Human-Environmental Systems	Potential impacts to environment and ecology from implementation of new infrastructure and/or resource extraction.
Natural Hazards	Future natural hazards and priority of remote community access.
Resource Extraction	Potential environmental and health hazards related to resource extraction for use in SMRs, including critical minerals. Potential degradation of historic Tribal lands. Impacts to other local and marginalized communities associated with mining and development.
Infrastructure	
Transportation	Available routes of transportation for SMR components, including to remote locations.

Water Treatment	Water treatment needs for SMR operations, including needed upgrades and upkeep of facilities, water reuse, and runoff, etc.
Location & Space	Available development space for SMR and associated infrastructure.
Existing Infrastructure	Existing power grid infrastructure and power distribution.
Existing Service Gaps	Gaps in energy or public utility provision that may take precedence over the desire for new technologies.
Socio-Cultural	
Tribal Resources	Potential impacts to biodiversity, historical/sacred Tribal ancestral lands, resource extraction, further development on Tribal lands, Issues of land sovereignty/Rights of Nature/Sacred resources.
Tribal Values	Tradeoffs between development of land, resource extraction, perpetuation of systemic environmental and energy injustices.
Rural Values	Tradeoffs between sustained power provision/costs/systems resilience and attitudes about government and industry interventions, attitudes towards outsiders.
Informal Networks	Power of citizen-led and street-level bureaucratic advocacy coalitions and/or influence over other residents, formal bodies of government.
Prioritized Needs	Potential conflict surrounding focus on new technologies as opposed to addressing current systemic environmental and energy injustices, as well as critical service gaps.
Economic	
Job Availability	Tradeoffs between current and/or previous industries in rural and Tribal areas, and limited available, family-sustaining jobs of SMR operations at the implementation site.
Benefits to Community	Area of opportunity for broader impacts to community development, rural, and Tribal energy and environmental justice.

Policy Recommendations

The following recommendations for institutional buy-in at the local level in rural and Tribal communities recognize the challenges and tradeoffs discussed above. These policy recommendations are non-exhaustive and may not apply to their urban counterparts, although environmental justice, water provision, and prioritized needs should be considered, where relevant, in all SMR sites and proposed projects.

Recommendation 1: *Embed local leaders in all planning, siting, and implementation phases, as well as in other deliberations as warranted*

Stakeholders should focus not only on regulatory processes, siting, safety, and storage and waste disposal, but also on the development of relationships with community leaders and high-profile members having influence with other residents—either formally or informally. Many infrastructure projects enable community engagement and outreach planning at the beginning and end phases of building or implementation. Involvement throughout the life cycle of the project and its day-to-day operations is also important. Community engagement and its willingness to adopt new technologies, particularly those that may disrupt the status quo or business-as-usual, may benefit from community residents becoming stakeholders and assisting the determination of benchmarks for success. In lieu of formal bureaucracies or institutional capacity in rural and Tribal environments, citizen-based qualitative data regarding current critical gaps and communal challenges can also assist in the alignment of stakeholders and community members. This is important where data is lacking on existing experiences of environmental and energy injustices under prevailing energy provision methods (Lach et al. 2003).

Recommendation 2. *Consider Tribal communities to be sovereign nations and use government-to-government style communication and negotiations in developing buy-in*

A critical aspect of developing new infrastructure on Tribal lands and with Tribal partners, is for industry and others to respect the sovereignty of indigeneity and its values. These values may align or misalign with efforts to deploy new energy technologies. External partners should consider Tribal resources, lands, and biodiversity as inherent in these government-to-government interactions and should support the retention and sharing of this value. In addition to a government-to-government approach to value and information-sharing, allowing Tribal entities to have the option to engage on their terms is important. And respecting their style and willingness to communicate is a critical step in trust- and relationship-building. As Tribal communities identify barriers and opportunities to implement SMR projects and other advanced technologies, stakeholders should avoid prescriptive solutions. Collaboration should reflect the needs and wants defined by the community. The objective can be to take an integrated approach for energy provision while respecting the communities particular culture, values, and lived experiences.

Recommendation 3. *Understand current community needs and existing critical service gaps that may take precedence over the desire for new technologies*

Industry and government stakeholders should consider that community buy-in may not be easily won, and that they may need to contend with issues that have gone unaddressed or are of larger importance to community members. Additionally, the roles of influential informal leaders in the community – and their ability to garner support or opposition to changes in their community structure and norm – should not be ignored. Rather, these informal governance models and community groups should be considered to be members of an advocacy coalition that can influence official policies and changes within their localities. In the introduction of new technologies, those proposing projects should go beyond traditional economic models. Deliberations can reflect the view that SMRs can benefit the community, align with local values and needs, and can support an integrated-systems approach to energize community development through SMR deployment. In these communities, data-driven approaches to address important service gaps may transcend available data, since institutional capacity for data collection may be limited. This, in turn, can create challenges in the deployment of value-added integrated energy systems (Ross et al. 2022). Adequate data is fundamental to enabling individual communities integrate emergent technologies. Tools such as the DAC Reporter reflect qualitative and social science approaches that permit the identification of community priority needs under current infrastructure. It provides systematic approach to measure the needs of disadvantaged communities at a micro scale and in a sensitive manner while facilitating external financial investment.

Recommendation 4. *Consider energy and environmental justice, and develop a robust mitigation plan, including tradeoffs for sourcing materials and siting facilities*

SMRs have the potential to restore environmental and energy justice, particularly in times of uncertainty about energy provision and concern about adverse environmental impact. Project stakeholders have a role to play in addressing the unique challenges that exist within affected communities. This includes knowledge of current natural hazards, water provision, and strains on the community and its resources. Additionally, the development of a mitigation plan is critical for addressing issues that may be exacerbated by the introduction of new infrastructure and industry in the area. Relevant parties should base mitigation plans not only on quantitative data—noting that data collected in rural and Tribal areas may be incomplete or inadequate due to resource strain. Qualitative and social science data should capture the lived experiences and hardships of community members and recognize institutions at the local level. To create the desired impacts within disadvantaged communities, developers and stakeholders should seek to integrate multi-solution implementation of technologies that bring additional or value-added benefits to marginalized groups. These may include access to high-paying jobs, healthcare, and more equitable opportunities for education, among many others.

Recommendation 5. *Strategize with local communities on what successful energy transitions look like, and implement benchmark success measures that incorporate community values, wants, and needs*

Critical to a willingness-to-adopt and ongoing buy-in for new infrastructure, is the engagement of rural utilities, utility boards, and local actors, factors, and sectors to determine the roles of industry as outsiders to the community. Their role in stewardship of the area, and potential for service to the region in which SMR facilities are implemented are important. Outsider consideration of community members and garnering an understanding of demographics, trends, and qualitative data about the community may assist in the development of projects where community values are determinants of success. Additionally, treating these action arenas as unique locations with their own attributes, rules in use, and aspects of community will ensure responsible consent-based siting. A cardinal objective should be continued engagement of community members throughout the process, rather than simply the initial phases. Finally, in implementing these projects, industry and other stakeholders should consider a community development plan where citizens at large define the challenges and metrics for success. These would typically include creating more opportunities for community residents, particularly in disadvantaged communities. Care should be taken to avoid prescriptive solutions. Stakeholders can have a role in continually empowering communities to make decisions on behalf of themselves in addressing problems identified by community members.

Conclusion

Ostrom's IAD framework may provide insight in examining the actors, factors, and sectors involved in responding to challenges exacerbated by climate change. These include energy provision and transitions to a carbon-free economy. While SMRs are considered carbon-free, their inputs rely on a set of existing or developed systems to ensure their success in day-to-day operations. In SMR development, particularly in the rural and Tribal contexts, industry, and stakeholder partners should carefully consider the unique aspects of communities including current gaps in service, environmental and energy injustices, coupled human systems, and how the implementation of this technology can be used as an integrated solution to multiple community needs.

No matter the context, advanced technologies like SMRs rely on a set of resources for their componentry and deployment. Additionally, any new technology or transition from current infrastructure will inherently impact the environment. This includes physical and material conditions of the community in which it is implemented. Rural and Tribal communities may be disadvantaged and experience environmental and energy injustices, among other socio-economic disparities. This can compound challenges such as willingness-to-adopt in the implementation of SMRs. Where other equity gaps persist – such as an absence of critical services, the presence of food deserts, lack of quality education, limited access to medical care, issues with job availability, among others – a community's desire for immediate needs to be met ahead of energy transitions is an important consideration for developers.

While further research is needed on the relationship between rurality or Tribal-identification and views on SMR adoption, some research suggests that a lack of knowledge or mistrust of outsiders can create embedded challenges in the proposal of new energy infrastructure (Boudet 2019). As stakeholders consider a community's willingness to adopt and buy-in to SMRs, formal regulations and governance bodies should not be the sole players in decision-making related to energy transitions. Rather, informal networks of governance, citizen groups, and the inherent values, social norms, and cultural beliefs of each locality should be intentionally examined. This type of robust engagement and outreach can avert roadblocks in a mutually beneficial way.

By analyzing these rural and Tribal communities, including their values and norms and how their internal processes influence how formal regulations are interpreted and enforced, SMR developers can maximize the probability of project success. Messaging and solutions that acknowledge the unique conditions and attributes of these areas, make it easier to garner support from the community and create more willingness to implement solutions for equitable energy provision across a spectrum of local contexts.

Acronyms and Abbreviations

COL – Combined License

ESP – Early Site Permit

DAC – Disadvantaged Communities Reporter

IAD – Institutional Analysis and Development Framework

ITAAC – Inspections, Tests, Analyses, and Acceptance Criteria

LWR – Light Water Reactor

NRC – U.S. Nuclear Regulatory Commission

PRA – Probabilistic Risk Assessment/Analysis

PSA – Probabilistic Safety Assessment/Analysis

SMR – Small Modular Reactor

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Stormwater Capital Improvement Planning: A Framework for Project Identification and Prioritization for Pluvial Flood Mitigation

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Abstract

More frequent and disruptive non-disaster declared pluvial flooding[1] events have brought to the forefront a heightened awareness of climate change and the ever-widening gap between infrastructural needs, community capacity, and the availability of resources. Environmental Justice (EJ) as well as hazards and resilience literature has identified capacity limitations of underserved and communities of color to cope, adapt and recover from pluvial flooding events attributed to climate change. EJ advocates have long recognized the disproportional impact of climate change on the underserved and communities of color and have emphasized the principles of unequal exposure, the importance of community voice, and capacity building as tools for increasing the resilience of this population.

To improve the technocratic system that identifies prioritizes and determines the distribution of urban drainage infrastructure fundamental changes are needed. Provisions that reflect society's social justice views and climate change awareness should promote 1) ownership of climate adaptation and infrastructural needs that benefit all populations; 2) increased resilience and the empowerment of communities to petition for climate adaptation and infrastructural needs; 3) increase the coping, adaptation and recovery capacity of underserved and communities of color; 4) provide more transparency to the allocation of stormwater provisions. Using the principles of EJ and adaptive resilience as underpinnings, this article articulates a conceptual framework for a new multi-dimensional component-level resilience rating and indexing system. Called the Urban Drainage Resilience Index System (UDRIS), this conceptual framework outlines a methodology meeting two objectives. The first objective is to quantify the level of resilience con-

1 Pluvial flooding refers to surface water accumulation resulting from intense rainfall saturating urban drainage systems, where excess water cannot be absorbed.

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tained within urban drainage infrastructure and the population impacted by subsequent pluvial flooding. The second objective is to formulate a risk communication tool that empowers and serves as a mechanism for the underserved and communities of color. This tool allows stakeholders to engage in the identification and prioritization of urban drainage infrastructural needs that may anticipate, prepare, and reduce the harms of pluvial flooding events.

In addition to the UDRIS primer, this article provides insight into the application and integration of UDRIS into the existing decision-making and planning frameworks such as stormwater capital improvements planning, comprehensive planning, and Hazard Mitigation planning. The integration of UDRIS into these frameworks will strengthen a culture of hazard preparedness amongst government officials, planners, engineers, and the public.

Keywords: stormwater infrastructure, adaptive resilience, environmental justice, pluvial flooding, infrastructure planning

Introduction

With the increased prevalence of non-disaster declared pluvial flooding and the availability of funding contained in the Bipartisan Infrastructure Law for urban drainage systems, many counties, cities, and towns are evaluating the adequacy of their aging urban drainage infrastructure (ASCE, 2021; DeAngelis et al., 2019). Under the provisions of the National Pollutant Discharge Elimination System (NPDES) program, permittees of urban drainage systems also known as municipal separate storm sewer systems (MS4) in federal regulations are required to implement stormwater management programs. These programs are obligated to address the six minimum statutory requirements for limiting the total maximum daily load (TMDL) and total suspended solids (TSS) contained within stormwater that discharges into the waters of the United States (EPA, 2016; PG Environmental, 2017; Ross & Associates, 2012). These six minimum statutory requirements for each stormwater management program are: 1) Public education and outreach, 2) public participation and involvement, 3) illicit discharge detection and elimination of construction site runoff control, 4) post-construction runoff control, 5) pollution prevention and 6) good housekeeping.

In January 2019, the Water Infrastructure and Improvements Act amended the CWA to include the 2012 Integrated Municipal Stormwater and Wastewater Plan Framework. This framework placed additional emphasis on the linkage between capital improvement programs or planning (CIP) and the public participation statutory requirement (Water Infrastructure Act, 2018). Although voluntary, this framework was designed to synchronize community goals and CIP activities to assist municipalities in prioritizing their capital investment needs to achieve their long-term CWA objectives. The 2012 Integrated Municipal Stormwater and Wastewater Plan also recognize the increased pressure local governmental units (LGUs) are faced with balancing competing interests caused by changing climatic patterns, population growth, aging infrastructure, and limited financial resources (Ross & Associates, 2012).

In general, CIP is a multi-phase process that focuses on the planning, financing, and construction of prioritized capital investments using planning-programming-budgeting theory. This theory is used to optimize the allocation of a limited amount of resources for maintaining or improving the quality of life of citizens (DeAngelis et al., 2019; Grigg, 2012). Capital improvement programs are a multi-departmental and transdisciplinary process that requires input from multiple stakeholders and governance boards for the identification, prioritization, and approval of resources for the identified capital expenditures. CIP in the context of urban drainage systems has grown in the last twenty years because of more stringent regulatory requirements, increased urbanization, and more prevalent pluvial flooding and drainage complaints(NASEM, 2019).

Climate Impact Framing

With the expected increase in heavy rain events and its relationship with greenhouse gases and human activities associated with increased urbanization, it is predicted that urban drainage systems will become frequently overburdened. The inability to convey stormwater runoff that results in the accumulation of water on the ground surface is defined as pluvial flooding (ASFPM, 2019; Butler, 2018; NASEM,, 2019; Zhou, 2014). According to the Intergovernmental Panel on Climate Change (IPCC), climate change will continue to present added risks and stressors to all populations, interconnected systems, and infrastructures that are already compromised by pre-existing conditions and under-investment. Various climate studies and models have predicted a 20-80% increase in climatic events of heavy rain depending on the geographical location and the prediction model utilized (Butler, 2018; IPCC, 2021; Zhou, 2014).

Climate change is not simply a sequence of events with known impacts to populations and geographical locations but creates a dimension of uncertainty and risks that challenges the perception of the interaction between the environment, urbanscapes, and society (Friend & Moench, 2013). Urbanscapes by their very nature, are dynamic artifacts of human design that embody ingenuity, creativity, and social stratification that's reflective of societal values and relationships (Friend & Moench, 2013). The US Environmental Protection Agency (EPA) has defined climatic events of heavy rains as rain events that substantially exceed what is considered statistically normal for a specific geographical location. This increase in heavy rains has resulted in more frequent non-disaster declared pluvial flooding (ASFPM, 2019; Blessing et al, 2017; NASEM, 2019; Sarmiento & Miller, 2006; EPA, 2016).

Most communities are aware of the inherent flood risks associated with developing in or adjacent to Special Flood Hazard Areas (SFHA) as delineated by the Federal Emergency Management Agency (FEMA). These areas are primarily defined along riverine features and coastal areas to indicate the probability of floodwater inundation that triggers governmental-sanctioned loss mitigation and prevention measures at the community and household scale. Non-SFHAs are defined as areas outside of the FEMA-delineated SFHA boundary which primarily consist of the areas where we live, work, and play. This distinction is critically important because the hazards and Environmental Justice (EJ) literature has noted, non-disaster declared pluvial flooding occurs predominately in non-SFHAs where flood insurance coverage is less prevalent (Association of State Flood Plain Management, (ASFPM, 2019; NASEM, 2019).

Most of the urban drainage infrastructure in the United States has been noted as being overwhelmed and has surpassed its useful life due to deferred maintenance, poor land use policies, and infrastructure planning practices (American Society of Civil Engineers, 2021). This has resulted in the degradation of stream water quality and increased pluvial flooding risk to all populations. The more prevalent, non-disaster declared pluvial flooding events make all populations more vulnerable due to the non-availability of Federal and State governmental resources for the recovery efforts. This leaves the impacted population including the underserved and communities of color, to heavily rely on local governmental or self-produced resources for the recovery efforts (ASFPM, 2019; Blessing et al., 2017; Boone, 2013; O'Hare & White, 2018a).

Stormwater Governance

Stormwater governance is hierarchically structured in the US with most regulations created at the Federal and State governmental levels with enforcement provided by LGUs (Finewood et. al., Michael H, 2019; Government Accountability Office, 2017; Smith, et al., 2018). Over the last 20 years, US disaster policy has begun to evolve from reactionary to a more sustainable proactive system of hazard mitigation. Even with the changing attitudes at the Federal level towards hazard mitigation policy, inadequate resources and support are provided to LGUs for lower-level non-disaster declared pluvial flooding events. These events tend to occur outside of the SFHA and are not of a magnitude that triggers Federal or State Disaster Declarations due to the resources and management capabilities of LGUs are not exceeded (FEMA, 2017; NASEM, 2019; Smith et al., 2018).

FEMA's premier disaster preparedness grant program, Building Resilient Infrastructure, and Communities (BRIC) provides financial assistance to LGUs and Tribal Governments for mitigation activities designed to strengthen the United States' efforts to bolster a culture of preparedness that incentivizes public green infrastructure projects (FEMA,2020b). While the intentions of the program are admirable, the requirement for having a federal disaster declaration under the Stanford Act within the past seven years is a major barrier to the utilization of this funding opportunity (FEMA, 2020a; FEMA, 2020b). In addition to the federal disaster declaration requirement (Smith and Vila, 2020), a survey of State Hazard Mitigation Officers identified insufficient attention at the Federal and State level to the technical capacity of LGUs. This inattentiveness results in an additional barrier to smaller LGUs, which are mostly rural communities, from obtaining Federal and State funding due to their inability to provide resources for preparing " winning" proposals against resource-rich communities.

Existing CIP Decision-Making Process

An important link between stormwater governance and long-term planning is the stormwater capital improvements planning (CIP) process. This process plays a key role in assessing and determining a community's resilience to pluvial flooding and the distribution of pre-flood event resources (DeAngelis et al., 2019; Hendricks & Van Zandt, 2021). The CIP process assesses urban drainage infrastructure needs within the entire jurisdictional boundary of an LGU over a defined timeframe. At the end of the assessment phase, the identified urban drainage infrastructure needs are then benchmarked against the overall community goals and objectives as identified in long-range comprehensive plans that improve or sustain a community's quality of life (DeAngelis et al., 2019; Savage et al.,2012). Many LGUs have adopted the balanced scorecard method as a tool for describing, communicating, and implementing strategies for effectively providing benefits to the governed (Kaplan, 2010; Sharma & Gadenne, 2011).

The balanced scorecard method developed by Kaplan, 2010, in the early 1990s is a performance evaluation method that uses financial and non-financial performance measures for evaluating tangible and intangible assets that play a key role in achieving an LGU's core social and economic mission and objectives (Kaplan, 2010; Sharma & Gadenne, 2011). A major criticism of the balanced scorecard methodology is its failure to consider some of the most vulnerable stakeholders. In doing so, this limits the socio-economic benefit to a small subset of stakeholders with socio-political infrastructure and unmuted voices which is counter to the principles of EJ (Bullard & Wright, 2009; Campanella, 2006; Schlosberg, 2013; Sharma & Gadenne, 2011). "Socio-political infrastructure" as coined by Eakin et al., 2017 refers to the social and political norms, values, rules, alliances, and relationships that provide the underpinnings and institutional structure to the numerous decisions made by public and private political players, which define the roles actors play in forming and shaping the urbanscape.

For most LGUs, a small percentage of the overall CIP program budget is allocated for small-scale pluvial flooding and drainage concerns for publicly maintained urban drainage systems. This requires the LGU to internally identify and prioritize a non-comprehensive set of candidate pluvial flood mitigation projects. These projects in most cases are derived from citizen-reported flood/drainage concerns or data collected through very limited means which perpetuates a system of inequality, misrecognition, and exclusion. The prevailing literature suggests most hazard mitigation decision-making practices and governmental policies do not adequately acknowledge, provide inclusivity and provisions for the underserved and communities of color who are less able to recover from pluvial flooding events (Cutter et al., 2013; Cutter et al., 2008; Flanagan et al., 2011; NASEM, 2019; O'Hare & White, 2018).

Environmental Justice Framing

Environmental Justice (EJ) is broadly defined by the United States Environmental Protection Agency as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (EP, 2016). The concept of EJ is associated with the unjust siting of a PCB landfill in a rural underserved community of color in Warren County, North Carolina (Bullard & Wright, 2009; Schlosberg, 2013). Since then, EJ has evolved over the years to include a broader definition for both "environment" and "justice" to align with society's changing perspectives of injustices (Bullard & Wright, 2009; Colten, 2007; Jerolleman, 2019; Schlosberg, 2013). The current environmental and economic justice movement, formerly known simply as the environmental justice movement, now reverberates more to the interrelationship between vulnerability, disadvantages, and the environment (O'Hare & White, 2018a; Schlosberg, 2013).

This broader definition of the "environment" is important because it encompasses all aspects of the environment from the urbanscapes "where we live, work and play" to natural and created landscapes (Bullard & Wright, 2009; Schlosberg, 2013). The expanded definition of "justice" is also critically important to the movement because it provides a basis for critical academic inquiry into the principles of equity, recognition, and participation which are key aspects of the movement (Bullard & Wright, 2009; Schlosberg, 2013; Walker & Burningham, 2011). These broader definitions to key aspects of the EJ movement led Mohai et al (2009), to outline three empirically linked interrelated causal factors that provide additional foundational support for EJ beyond the underlying response of racial inequalities. The identified interrelated causal factors identified were 1) the exploitation of the economic condition and situation of the vulnerable and their environment for the economic gains of others; 2) governmental and empowered players seek the path of least resistance coupled with the notion that vulnerable populations make easier targets; 3) distinct forms of disenfranchisement are associated with underserved and communities of color with regards to pollution. Schlosberg, 2013, concludes that if any or all these causal factors are present, a systemic culture of misrecognition, exclusion, and inequities will exist.

Resilience Framing

Resilience is still a broad aspirational concept with positive connotations that are used to frame scientific, political, and social discourse around the ability of a system to rebound from external shocks, recover and adapt to new circumstances while preserving key components and relationships(Cutter et al., 2008; Linkov & Palma-Oliveira, 2017; Wardekker, 2018; Yamagata & Sharifi, 2018). The concept of resilience in the academic literature can be traced back to the 1973 C.S. Holling article, Resilience, and Stability of Ecological Systems (Rodina, 2019). Since publication of this groundbreaking article, three major theories and epistemologies of resilience have emerged from the disciplines of engineering (engineering resilience), ecology (ecological resilience), and social sciences (adaptive resilience, also known as social-ecological resilience) (Linkov & Palma-Oliveira, 2017; Yamagata & Sharifi, 2018).

In urban drainage system applications, resilience is often viewed from the perspective of engineering resilience. This places emphasis on creating systems that can withstand anticipated stressors by adding robustness and resistance to the physical system (Yamagata & Sharifi, 2018). When systems experience failure from anticipated stressors that exceed pre-established thresholds, engineering resilience will enable the system to rapidly recover to pre-disruption conditions. However, the robustness and resistance of the system have minimal effect on the system's ability to cope, adapt, and recover from unanticipated stressors. Looking at resilience through this lens results in a single equilibrium-focused approach that fails to capture the behavior of complex dynamic systems such as urbanscapes (Yamagata & Sharifi, 2018).

Climate Change has evoked uncertainty within urbanscapes which has led counties, cities, and towns to employ principles of adaptive resilience to better prepare for future conditions (Rockefeller Foundation 100 Resilient Cities, 2013-2019). Adaptive resilience is defined as the ability of a complex system to absorb unanticipated stressors with the capacity to explore new opportunities through evolutionary learning techniques to adapt to changing conditions across varying temporal and spatial scales(Birkmann et al., 2013; Kim & Lim, 2016; Wardekker, 2018; Yamagata & Sharifi, 2018). Since urban drainage systems have a useful life span of 50-plus years, a different epistemology of resilience is necessary to quantify the coping and adaptation capacity of urbanscapes to absorb and recover from unanticipated stressors associated with climate change (Kim & Lim, 2016; Wardekker, 2018; Yamagata & Sharifi, 2018). Integrating adaptive resilience principles into urban drainage design practices and decision-support models is a novel concept that diverges from the epistemology of engineering resilience (Oulahen et al., 2019).

New Multi-dimensional Resilience Rating and Indexing System

Overview: Urban Drainage Resilience Index System (UDRIS)

The theoretical concept of UDRIS is centered around the operationalization of pluvial flood resilience which depicts the interaction of the environment (natural and built) and society's ability to cope, adapt and recover from pluvial flooding events. UDRIS is a transdisciplinary communication, analysis, and decision-support model that quantifies the pluvial flood resilience of urban drainage systems. This is achieved through the analysis of urban drainage systems from the perspective of adaptive resilience and EJ principles that are integrally linked to the Disaster Risk Management's disaster cycle. To operationalize and quantitatively measure the level of pluvial flood resilience of populations and places, three basic conditions must be present, 1) pluvial flood hazards (natural condition), 2) exposure (man-made condition), and 3) adaptive capacity (human condition), as shown in Figure 1.

In the Figure 1 equation, pluvial flood hazard is suggestive of the occurrence probability of pluvial flooding events which are directly connected to land use policy, urban drainage infrastructure design practices, and heavy rain precipitation events. Events of heavy rains as defined by the EPA as precipitation events that substantially exceed what is statistically considered normal for a geographical location that tends to overwhelm the urban drainage infrastructure (EPA, 2016). Climate change research has noted that some geographical locations are experiencing increased pluvial flood risk because actual rain events are more frequently aligning and, in some cases, exceeding the synthetic storms use for the design of urban drainage systems (Moore et al., 2016; Butler et al., 2018; NASEM, 2019; Konrad, 2003; Brody et al., 2013).

Figure 1: Conceptual Equation of Pluvial Flood Resilience

The exposure element in equation-1 is suggestive of the temporal and spatial susceptibility of populations and places to unanticipated pluvial flooding events that result in substantial physical and/or economic impacts. These relationships and the natural variability associated with urbanscapes and precipitation events fundamentally expose all populations and places to pluvial flood risk. However, the level of pluvial flood risk populations and places experience can increase or decrease over time unbeknownst to said population due to upstream urbanization, diminished infrastructure maintenance, and overall system life cycle, which is further influenced and degraded by the effects of climate change (Moore et al., 2016; NASEM, 2019; Konrad, 2003; Brody et al., 2013; Butler et al., 2018).

The adaptive capacity element in both equation-1 and equation-2 (Figure 2) is suggestive of the dynamic interaction between urban drainage infrastructure and society's ability to smoothly transition between long periods of stability and short periods of chaotic change without losing its integrity and functionality. This relationship between urbanscapes, society, and climate change is characterized as a complex dynamic social-ecological environmental system that changes at different spatial and temporal scales to achieve and maintain equilibrium. To operationalize this complex interaction, the integration of prevalent adaptive resilience principles is required. UDRIS embraces the overarching adaptive resilience principles of diversity, stability, equity, foresight capacity, resourcefulness, and adaptability to 1) lessen potential damages, 2) create evolutionary learning opportunities, and 3) communicate pluvial flood risk (Linkov & Palma-Oliveira, 2017; Yamagata & Sharifi, 2018; Kim & Li, 2016).

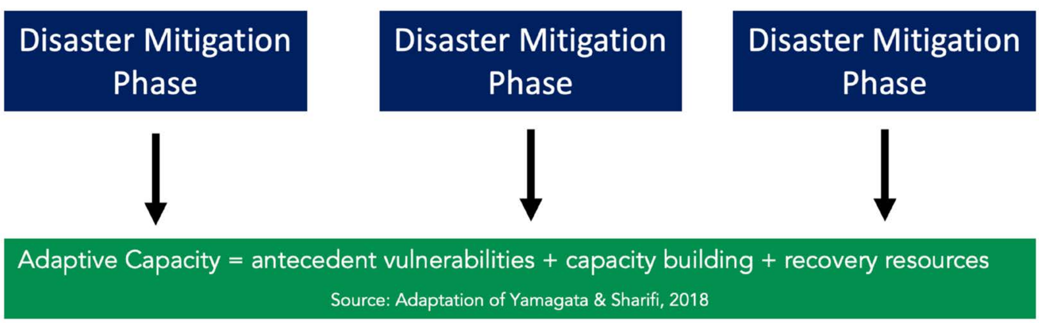

Figure 2: Conceptual Equation of Adaptive Capacity

In the equation shown in Figure 2, the antecedent vulnerabilities element is suggestive of the precursor socioeconomic characteristics of a population. This predisposition of susceptibility is inherent to all populations but underserved and communities of color are fundamentally more socioeconomically vulnerable. This stems from years of governmental and societal-sanctioned exclusionary practices such as Jim Crow laws, redlining, urban renewal, segregated housing, exclusionary zoning & annexation practices, gentrification, and urban revitalization (Bullard et al., 2008; Bullard & Wright, 2009; Chakraborty et al., 2019; Hendricks & Van Zandt, 2021). These exclusionary practices tended to push underserved and communities of color to undesirable low-lying land or high-density urban areas with deficient urban drainage infrastructure provisions(ASCE, 2021; Bullard & Wright, 2009; Heck, 2021; Hendricks & Van Zandt, 2021).

The *capacity-building* element in equation-2 provides a linkage to the role LGUs and community-based organizations play in providing educational, financial, and technical resources for mitigating the negative socioeconomic impacts of pluvial floods. In this element, the educational, financial, and technical resources are indicative of the actions that promote community voice recognition and authentic engagement through a capacity-building framework such as VCAPS (Vulnerability, Consequences, and Adaptation Planning Scenarios), the EPA's Collaborative Problems Solving Model, or Community Action Roadmap. These frameworks provide a systematic approach for: 1) identifying community needs; 2) identifying existing community resources and capacity; 3) creating alternative & solution discovery and discourse; 4) identifying capacity building & resources needed for solution implementation; 5) solution implementation; 6) assessing the long-term impact of the solution. The implemented solution should have tangible outcomes such as equal access to and awareness of flood insurance policies, flood risk awareness, wealth creation, financial literacy, and community economic development opportunities. These tangible outcomes will provide additional capacity and resources to the community to counteract the negative socioeconomic impacts of pluvial floods (Jerolleman, 2019; Schlosberg, 2013).

The *recovery resources* element in equation-2 represents the level of access to and spatial availability of provisions that allow impacted populations to recover at a reasonable temporal scale. The quality and rapidity of recovery have been identified in hazards and EJ literature as one of the measurements for a successful recovery process. A successful recovery process as described in the literature is one that at a minimum returns the impacted population to pre-pluvial flood levels of functionality both physically and economically at a reasonable temporal scale commensurate with the magnitude of pluvial flood damage. (Bullard & Wright, 2009; Campanella, 2006; Olshansky, 2005). At the neighborhood scale in terms of the boots-on-the-ground impact, there is no significant distinction between disaster-declared and non-disaster-declared pluvial flood events.

Generally, pluvial floods tend to be very disruptive to the impacted population and usually result in the substantial expenditure of financial resources for recovery efforts. The main differentiation between disaster and non-disaster-declared pluvial flood events at the neighborhood scale is the timing and access to financial resources which heavily influences the quality and rapidity of recovery. With non-disaster-declared pluvial flooding occurring predominately outside of

SFHAs where flood insurance is less prevalent, the impacted population has to solely rely on self-produced, familial, and community resources (non-governmental including LGUs) for the recovery efforts (McCarthy, 2011; Olshansky, 2005). This self-dependence usually results in an extended recovery period, which for underserved and communities of color goes beyond the immediate impact of the event. This has generational impacts with the loss of financial resources and opportunities that are never recovered which puts this population in an overall more vulnerable state (Bullard & Wright, 2009; Schlosberg, 2013; Twigg, 2015).

The concept of pluvial flood resilience is further operationalized into a culture of actionable practices by providing linkages to the Disaster Risk Management (DMR) disaster cycle. The DMR disaster cycle is an easy-to-understand four-phase linear operational model for disaster interventions for technical and nontechnical actors. It is a powerful communication tool that provides a linear sequence of interventions at the disaster mitigation, preparedness, response, and recovery phases. However, Twigg, 2015, has noted the complexity and fluidity of disasters are not fully conveyed with the DRM disaster cycle model.

The *mitigation phase* of the disaster cycle is linked to the antecedent vulnerabilities element in Equation-2. This linkage is used to communicate the level of readiness afforded by activities taken by populations and places to counteract preexisting vulnerabilities. In equation-2, the *preparedness phase* of the disaster cycle is linked to the capacity-building element. This linkage is used to communicate the level of readiness provided by actions that create a continuous culture of self-improvement, prevention, and readiness due to the uncertainties created by climate change and the dynamic nature of urbanscapes.

The *response phase* of the disaster cycle is linked to the exposure element within equation 1 (Figure 1). This linkage is used to communicate the availability of resources during or immediately after pluvial flooding events to safeguard property and lives. The last and final phase of the disaster cycle, the *recovery phase* is linked to recovery resources in equation 2 (Figure 2). This linkage is used to communicate the available capacity populations have for recovery efforts.

UDRIS Model Dimensions and Construct

UDRIS is a multi-criteria decision and analysis (MCDA) model that pairs stormwater hydraulic analysis principles with social vulnerabilities. Just like other multi-criteria decision and analysis models, UDRIS allows for the straightforward conveyance of complex information for the engagement of stakeholders and policymakers to increase 1) knowledge, 2) awareness and 3) the co-creation of solutions.

An easy-to-understand UDRIS Scoring Rubric (Figure 3) was developed using a letter grade designation based on numeric scoring ranges.

Letter Grade Designation	Numeric Scoring	Definition
A	100-90	This designation indicates a high level of resilience. There is a low risk of pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event
B	89-80	This designation indicates a moderately high level of resilience There is a low risk of pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event.
C	79-70	This designation indicates a low level of resilience. There is a moderate risk of pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event.
D	69-60	This designation indicates a moderately-low level of resilience. There is a substantial risk of pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event
F	59-0	This designation indicates a very low level of resilience. There is a high risk of pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event

Figure 3: UDRIS Scoring Rubric

Disaster Mitigation Phases	Dimension	Metric	Description
Mitigation	Urban Drainage System Resilience Index	Pipe Condition Index	Represents the condition of the urban drainage system relative to system age.
		Pipe Capacity Index	Represents the vulnerability of the urban drainage system to exceed the design capacity relative to a communities' perception of a resilience (aspirational rainfall event)
		Climate Change Score	Represents the increase frequency in which high intensity rainfall events results in reported flooding events.
		Flood Damage Potential Score	Represents the potential of the urban drainage system to create a flooding event that results in damage to structural property.
		Drainage System Maintenance Score	Represents the vulnerability of the urban drainage system relative to the system maintenance policies and practices.
		Local Drainage Protection	Represents the local drainage protection policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.
		Stormwater Management Regulations	Represents the local stormwater management policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.
	Index of Socio-economic Resilience	**Metric**	**Description**
		Poverty and race	Represents the percentage of the population below the poverty line.
		Age	Represents the percentage of the population over 65 years old.
		Wealth	Represents the household wealth
		Migration and renters	Represents the percentage of renter-occupied housing units and of foreign-born citizen
		Gender	Represents the percentage of population that identify as female.
		Ethnicity -Hispanic	Represents the percentage of the population that identify as non-white
		Special needs	Represents the per capita number of community hospitals and residents in nursing homes
Disaster Mitigation Phases	**Dimension**	**Metric**	**Description**
Preparedness	Community Preparedness Rating	CIP-Flood Prevention Funds Allocated	Represents the flood prevention fund allocated through the Capital Improvements Planning Process
		Flood Protection Assistance	Represents the local flood protection assistance policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.
		Drainage System Maintenance Score	Represents the local drainage protection policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.
		Local Drainage Protection	Represents the local drainage protection policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.
		Stormwater Management Regulation Score	Represents the local stormwater management policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.
		Community-Faith Based Organizations Factor	Represents the number of community and faith base organizations.
Response	Community Response Rating	**Metric**	**Description**
		Public Safety Factor	Represents the capacity of first responders to respond during and immediately after pluvial flooding events.
		Community-Faith Based Organizations Factor	Represents the number of community and faith base organizations.
Recovery	Community Recovery Index	**Metric**	**Description**
		Flood Damage Recovery Factor	Represents the recovery capacity of a population based on the anticipated magnitude of flood damage.
		Socio-economic Recovery Factor	Represents the recovery capacity of a population post pluvial flood event.
		Wealth	Represents the wealth of a population.
		Designated Flood/Disaster Recovery Funds (Local Level)	Represents the locally appropriated funds specifically designated for flood/disaster recovery.

Figure 4: UDRIS Dimensions

To operationalize the theoretical concept of pluvial flood resilience, UDRIS uses five dimensions as shown in Figure 4, which specifies UDRIS Dimensions (Column 2) to communicate to stakeholders and policymakers, the pluvial resilience afforded by urban drainage systems and society's ability to cope, adapt and recover from such events.

The first dimension, *Urban Drainage System Resilience Rating* is the weighted sum of proxy indicators shown. This dimension measures an urban drainage system's ability to cause pluvial flooding during the aspirational resiliency rainfall event. The aspirational resiliency rainfall event is defined as the rainfall event that affords a pre-determined level of pluvial flood readiness an LGU aspires to achieve. The goal of the aspirational resiliency rainfall event concept is to reduce the financial impacts and increase the rapidity of recovery without unilaterally instituting more stringent urban drainage infrastructure design requirements.

Dimension two, the *Index of Socio-economic Resilience* is a comparative measure of a population's socioeconomic susceptibility to non-pluvial flood-related stressors. Computationally, this is defined as the is the inverse sum of weighted census track-level proxy indicators as shown in Figure 4. The purpose of the Index of Socio-economic Resilience is to identify susceptible populations for targeted capacity-building resources to increase their overall resilience to stressors. Historically, underserved and communities of color are fundamentally more socio-economically susceptible due to past and current systematic governmental and non-governmental injustices (Bullard et al., 2008; Bullard & Wright, 2009; Chakraborty et al., 2014; Hendricks & Van Zandt, 2021).

Dimension three, *Community Preparedness Rating* measures the impact of policy decisions that create a culture of prevention and preparedness for non-disaster declared pluvial flooding. Computationally, it is defined as the sum of weighted city scale proxy indicators as shown in Figure 4. Most of these proxy indicators are derived from policy implementation categories within FEMA's Community Rating System that reduce both pluvial and riverine flooding. In addition to the policy implementation categories, this dimension includes metrics for CIP funds allocated and the number of community-faith-based organizations.

Dimension four, *Community Response Index*, is a comparative measure of a community's ability to provide aid during and immediately after non-disaster-declared pluvial flooding events. The hazard and EJ literature has identified a strong correlation between social bonds and the ability of a community to organize and provide timely aid. In recognition of this, UDRIS uses the capabilities and training provided to fire rescue departments as an indicator of the response during a pluvial flooding event. To quantitatively measure the strength of social bonds and interconnections within a community, UDRIS incorporates the number of community and faith-based organizations as an indicator of the aid available immediately after a pluvial flooding event.

The fifth and final dimension of UDRIS, *Community Recovery Capacity* is a qualitative measure of the availability and access to pluvial flooding recovery resources. Computationally, this is the weighted sum of census tract-level proxy indicators as shown in Figure 2.

These selected indicators are suggestive of a population's rate of recovery which is determined by their ability to access financial resources to repair damaged assets to return to a normative state. This is powerful because it identifies spatial locations and populations where locally earmarked disaster funds could be utilized to increase the quality and rapidity of the recovery efforts.

Model Application

UDRIS is a novel approach for integrating EJ and resilient thinking principles into planning and urban drainage infrastructure policy decisions. Incorporating such principles in the decision-making process creates a culture of hazard preparedness through the direct translation of community goals with urban drainage infrastructure needs. Figure 5 illustrates how UDRIS integrates into three governmental planning processes that involve urban drainage systems (the three processes and their major elements are highlighted within the Figure 5 chart). In this illustration, the UDRIS score provides the comprehensive unbiased identification of pluvial flooding locations where populations are vulnerable during the aspirational resiliency rainfall event. This information is then used to inform and support policy decisions that would increase the resilience of the identified populations and places.

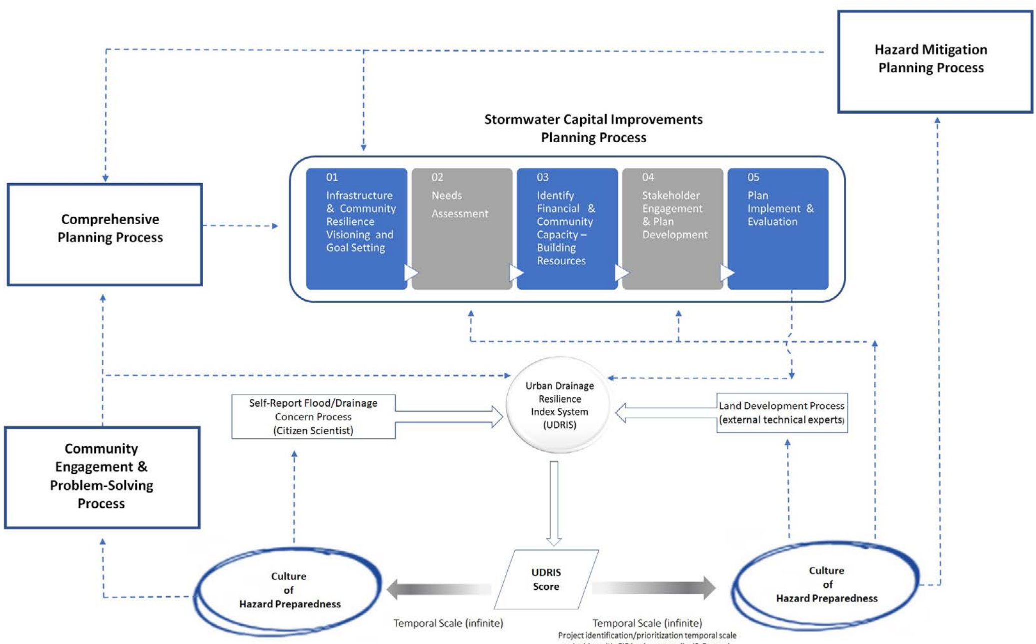

Figure 5: UDRIS Integration into the Policy Decision Matrix

UDRIS Integration into the Stormwater CIP Process

The distribution of pre-pluvial flood resources through the stormwater CIP process plays a key role in determining the degree of community flood resilience (DeAngelis et al., 2019; Hendricks & Van Zandt, 2021). As shown in Figure 5, the assessment and inventory phase of stormwater CIP is where projects to repair, rehabilitate, or replace urban drainage systems are identified to maintain an adequate level of service. In most cases, this assessment is non-comprehensive and is compiled from pluvial flooding events or drainage concerns reported by citizens with sociopolitical infrastructure. This self-report system fundamentally perpetuates bias and disparities in the distribution of pre-pluvial flood resources by narrowly defining project locations (DeAngelis et al., 2019; Grigg, 2012; EPA, 2016).

The application of UDRIS in the context of stormwater CIP is primarily an analysis and communication tool to increase transparency in the identification and distribution of stormwater resources. When UDRIS is incorporated into the needs assessment phase of the CIP process, it provides a quantitative assessment of the culpability of urban drainage systems to cause pluvial flooding and the coping, adaptation, and recovery capacity of the impacted population. This is accomplished through the calculation of a numerical score for each urban drainage system within an LGU. This numerical scoring system as identified in Figure 1.

This numerical scoring system is then used to develop a comprehensive unbiased prioritization listing of deficient urban drainage infrastructure. The deficient infrastructure that falls below the LGU's established aspirational resiliency goal should be assimilated into capital improvement projects.

UDRIS Integration into Comprehensive Planning Policy Process

Public investment in local infrastructure and community economic development is one of the most impactful and direct means communities can build capacity to address their vulnerabilities to pluvial flood risks (DeAngelis et al., 2019; Finewood et. al., 2019; McFarlane, 1999). Community economic development as described by McFarlane, 1999 is the process that promotes the holistic improvement of the communities' socioeconomic condition at the neighborhood level. This is achieved by enticing the relocation of existing businesses or the starting of new businesses to stimulate economic growth and wealth creation. UDRIS in this setting is an analysis and decision support tool for rationalizing which areas require urban drainage infrastructure investment, community economic development, and capacity-building resources. This is achieved through the letter grade designation presented in Figure 3, and in Figure 4, the Index of Socio-economic Resilience dimension within UDRIS.

In this scenario, the composite letter designation output of UDRIS provides insight into the vulnerability of urban drainage infrastructure for causing pluvial flooding within a defined spatial boundary such as the census tract. The spatial boundaries with lower letter designations such as F, D, and sometimes C, are candidate locations that need additional resources for increasing the coping, adaptation, and recovery capacity of the population. In addition to using the letter designation output from UDRIS, the Index of Socio-economic resilience and the Community Recovery Index within a defined spatial boundary can provide further justification for the allocation of capacity building and community economic development resources.

UDRIS Integration into the Hazard Mitigation & Resiliency Planning Process

Various studies within the Hazards literature (Berke et al., 2012 and Smith and Vila, 2020), have noted states' hazard mitigation plans are not well organized, technically sound, or thoroughly prepared to foster a strong commitment to bolstering community resilience. This lack of commitment results in most plans failing to pre-identify projects or comprehensively apply land use policy to reduce pluvial flood risk. The application of UDRIS in this context is an analysis, communication, and decision support tool that provides a framework for identifying levels of resources available before and during pluvial flood events. In addition to the identification of resource availability, UDRIS can also identify potential project locations for creating a culture of community awareness and hazard preparedness.

The ability of UDRIS to determine the level of resources available pre-pluvial flood events is noted within the Community Preparedness Rating dimension (Figure 4). This dimension leverages proxy indicators that are indicative of policies and practices that reduce pluvial flooding. The letter and numerical output designation from the Community Preparedness Rating can be utilized to identify and track the level of preparedness afforded by current policies and practices. Thereby the communities with low designations should review and enhance their policies and practices for increasing the overall coping, adaptation, and recovery capacity of the entire population within the designated spatial boundary.

The level of resources available during a pluvial flooding event is noted within UDRIS with the Community Response Rating dimension (Figure 4). This dimension also leverages proxy indicators that are indicative of the policies and practices that affect a community's ability to respond during and immediately after a pluvial flooding event. The output letter and numerical designation are utilized to identify and track the available response capacity during and immediately after a pluvial flood event. Spatial boundaries noted as having a low designation should review and take steps to enhance their practices and policies to increase the response capacity.

Lastly, UDRIS can be used to provide an assessment of locations with documented pluvial flood incidences within the spatial boundaries of the Hazard Mitigation Planning area (Disaster Mitigation Phases shown in Column 1, Figure 4). Urban drainage system at the identified pluvial flooding location can be further analyzed with UDRIS. The output letter grade designation (Figure 3) is utilized for assessing if drainage system upgrades are required to increase the resilience of the impacted population. Locations with a letter designation score of F, D, and sometimes C, are candidate locations for urban drainage improvement projects and should be identified within the Hazard Mitigation Plan.

Conclusions

Studies within the Environmental Justice and the Hazards literatures have begun to characterize a long lineage of governmental policies and practices that do not adequately acknowledge, provide inclusivity, or contain provisions for socially vulnerable populations pre-, during and post-pluvial flood events (Cutter et al., 2013; Cutter et al., 2008; Flanagan et al., 2011; NASEM, 2019; O'Hare & White, 2018). Restructuring and rethinking processes that embody and promote problematic practices connected to injustices may be subdued with the enactment of governmental policies that strive for the basic need for social, economic, and political equality, which transcends race and economic status (Eakin et al., 2017; Schlosberg, 2013; EPA, 2016).

Complex decisions concerning risks posed by pluvial flooding cannot be made independently but requires public involvement and the continuous input of complex technical information (Haer, Botzen, & Aerts, 2016; Rowel et al., 2012; Santos, 1990). This paper outlines a novel approach using UDRIS, a multiple-criteria decision analysis (MCDA) model to rethink and reimagine existing practices to create a more transparent and equitable decision-making process for the distribution of pluvial flood resources. UDRIS also seeks to recognize the impact of past injustices through the continuous assessment and communication of risk.

The methodology provides a systematic approach for developing a compromise between competing interests of the environment (built & natural) and society. In the policy arena, this approach is very attractive because it allows transparency and pragmatism in the comparison of needs between different locations and provides justification for the distribution of investment (Cutter et al., 2013; Heckert & Rosan, 2016). The next step is to perform a demonstration study of UDRIS to validate the theoretical concept outlined in this paper.

Acronyms and Abbreviations

ASCE	American Society of Civil Engineers
ASFPM	Association of State Flood Plain Management
BIL	Bipartisan Infrastructure Law
CIP	Capital Improvements Planning
DRM	Disaster Risk Management
EJ	Environmental Justice
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GAO	Government Accountability Office
HMP	Hazard Mitigation Plan
IMSWP	Integrated Municipal Stormwater and Wastewater Plan
LGUs	Local Governmental Units
IPCC	Intergovernmental Panel on Climate Change
MCDA	Multi-criteria Decision and Analysis
NASEM	National Academies of Sciences, Engineering, and Medicine
SFHA	Special Flood Hazard Areas
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
URDIS	Urban Drainage Resilience Index System

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Practice Advances

Outcomes of the 2022 InfraGard National Disaster Resilience Council Summit

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Introduction[1]

InfraGard is a unique partnership between the Federal Bureau of Investigation (FBI) and individuals in the private sector for the protection of U.S. critical infrastructure and the American people. As one of the nation's largest public/private partnerships, InfraGard connects critical infrastructure owners, operators, and stakeholders with the FBI to provide education, networking, and information-sharing on security threats and risks.

InfraGard's national membership currently exceeds 80,000 members. It includes corporate security managers, directors and C-suite executives, cybersecurity and IT professionals, chief information security officers, financial services executives, healthcare professionals, emergency managers, military and government officials, academia, state and local law enforcement, and more — all dedicated to contributing industry-specific insight to advance national security. Today, there are members in 77 local InfraGard Member Alliances (IMAs), represented nationally by the InfraGard National Members Alliance (INMA). Each IMA is affiliated with the FBI Field Office in its region.

InfraGard's National Disaster Resilience Council (NDRC), with approximately 2,100 members, is a cross-sector council of InfraGard. Its mission is to facilitate information sharing about hazards and ways to mitigate high-impact threats to critical infrastructures. Special emphasis is placed on power, water/wastewater and communications failures exceeding 30 days that create catastrophic, cascading conditions. One of the goals of information sharing is to help people and organizations to survive and recover more quickly and more effectively from a simultaneous nationwide or regional collapse of infrastructure attributable to an individual or combination of hazards such as a human-made electromagnetic pulse (EMP) or other major intentional or naturally occurring hazard.

The 2022 NDRC Summit

The NDRC Summit convened October 18 -19 at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland. As NDRC Chairperson, I was responsi-

1 Opinions expressed in this article are those of the author and do not necessarily represent those of the InfraGard National Members Alliance or the *Journal of Critical Infrastructure Policy*

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ble for Summit planning and execution with a registration of over 800 individuals. Summit presenters included nationally prominent leaders in critical infrastructure security and resilience protection.

A number of themes having policy or professional practice relevance emanated from Summit deliberations. They are presented below.

Critical Infrastructure Lessons Learned from the Ukraine/Russia War

A detailed, three-dimensional assessment of the War's impact on Ukrainian critical infrastructure to date was presented, culminating in five general lessons:

1. Critical infrastructure is a key target during wartime
2. Even during wartime, both sides can have incentives against attacking critical infrastructure
3. Battlefield defeats often precede infrastructure attack
4. Escalating infrastructure attacks may erode incentives against future infrastructure attack
5. A losing infrastructure strategy can negate a winning military strategy

Attacks on critical infrastructure have become an instrument of modern warfare, which has been demonstrated vividly in Ukraine. Even after NDRC's 11-year focus on electric power grid vulnerabilities, the fifth lesson was unsettling. The bottom line is that that Ukraine would not be able to win the conflict—no matter how effective they were militarily—if Russia is able to incapacitate the country's critical infrastructure. This is a wakeup call for the US, especially coupled with recent physical attacks on a number of US electric substations. Summit participants recognized that we, as a nation, need to realize and formally acknowledge the essential nature of critical infrastructures, particularly national power grid vulnerabilities. We must make the protection and security of electric power from generation to transmission to distribution a top priority. It is the foundation for all the other critical infrastructures and fundamental to national survival.

Moreover, the creation of a new international policy should be considered to make potentially catastrophic attacks on critical infrastructure a war crime, which might deter some actions. In the US, it is essential that protection of critical infrastructure becomes an explicitly stated and actively implemented policy, and it is vital that adequate funding be allocated for the protection of major critical infrastructures. Protection from threats should include natural and manmade threats, and high among these are cyber, electromagnetic magnetic pulse (EMP) and solar storms.

Foreign Incursions in the Critical Infrastructure Arena

In early 2022, the FBI released a film, "Made in Beijing: The Plan for Total Market Domination."[2] The NDRC regarded the film's release as a call to action and has been studying the Chinese "36 Stratagems" to understand how the Chinese Communist Party (CCP) actively uses them to surreptitiously undermine US values and systems.[3] The work of NDRC "36 Stratagems Working Group," presented at the Summit, included information on what US citizens can do to strengthen our country. Speakers and experts brought some of the 36 Stratagems to life and suggested countermeasures. Each of the panelists had previously analyzed at least one of the Stratagems and had presented it to a group of NDRC leaders at a weekly NDRC virtual meeting. Several InfraGard National Member Alliance Cross Sector Council leaders have also chosen a Stratagem to present along with other NDRC members.

The Summit presentation illustrated ways that the CCP is working in the US right now. This includes buying farmland near military bases, educating children in CCP values even in grade school, to stimulating US dependency on China for specific types of strategic materials, such as batteries. China captures an assortment of rare earth minerals in the world market needed for batteries, while threatening US capacity to manufacture its own batteries. CCP-backed organizations continue to compete and undercut American businesses on price. Most US citizens do not comprehend this type of hybrid adversarial action, which includes non-military, espionage, intelligence, cyber and military.

The US could help thwart this CCP threat to democracy by creating, for example, a policy to restrict the sale of land near military establishments by foreign organizations, including those which are fronted by US companies. In addition, US high schools could make civics a required course emphasizing the tenets of democratic government in order to better understand democratic values and history.

Grid-in-the-Box

Cleveland area NDRC members presented "Grid-in-the-Box", discussing how these members and partners are working to blend technologies capable of forming resilient "islands." The geographic areas involved in this work would incorporate protected power and strong internal communication capacity. The "Grid in the Box" also includes water, which is looming as a critical issue for the entire country—with draughts, floods, water aquifer depletion, and water contamination. The

2 The film may be viewed here: https://www.fbi.gov/video-repository/made-in-beijing-030722.mp4/view

3 Temin, Davia, "Ancient Wisdom for the New Year: The 36 Chinese Stratagems for Psychological Warfare", Forbes, January 2017 and "China the Next War," Strategy & Tactics Quarterly, Issue #16, Winter 2021.

presentation included discussion of water increasingly becoming an instrument of war internationally. It has been one mode of critical infrastructure attack in Ukraine.

The "Grid in a Box" presentation explained conceptually how local communities could become "resilient community islands." This was a concept that the NDRC originally presented in our 2016 book, *Powering Through: from Fragile Infrastructures to Community Resilience.* The Summit presentation discussed new technologies that could help make this a reality. The concept of an "island" is not new; it is used by the electric power industry when grid restarting is needed. The idea of a "resilient community island" is a locally defined area or jurisdiction that can stand on its own. In this context, community can be an actual community or a distinctive component such as a university campus, business park or hospital. Ideally, for example, a resilient community should have the capacity to be self-sufficient for months, providing power, water, food, and transportation within the island, thereby enabling government, business and individual survival. Security could be provided from local members of the National Guard, local first responders and also Neighborhood Watch groups. Schools are important in preserving the fabric and stability of individual communities, and parents may need to band together to ensure children's education especially if teachers do not reside in the community. Theoretically, this concept can work whether the community is large or small. The "Grid-in-the-Box" concept moves a number of theoretical ideas forward.

A bottom-line policy that all cities could pursue would be to have the ability to become a resilient community island to the maximum extent feasible. The goal would be to maximize citizen safety during a large-scale, extended critical infrastructure collapse. Once again, this need is underscored by Ukraine's experience.

Citizen Resilience

This topic was addressed in a series of presentations. An in-depth presentation emphasized the need to have a "Get Home Bag" in your car. While deceptively simple in concept, it is a complex undertaking to optimize the Bag for major disasters and other dislocative events. The purpose is to handle situations where individuals are away from home and their cars do not work post-disaster, such as a snow storm, flood, or EMP. A focus was on having the ability to walk home: a good pair of shoes, water, food, and proper clothes (e.g., in colder climates, adequate coat for weather conditions, gloves, and hat).

Considerable discussion occurred on how to be ready to support families and also get to work to support organizations. A large number of panelists shared their perspectives on "being ready." The panel then discussed the topic in relation to strategies contained in NDRC's second volume 2021 book, "*Powering Through: Building Critical Infrastructure Resilience*." Breakout sessions completed the day's emphasis on being ready, considering the roles of family and neighborhood; critical infrastructure operators; as well as first responders and emergency managers to bolster national disaster preparedness, especially during a long-term power outage.

First responders in every community could take an active role in helping their community to be prepared for long-term, large-footprint infrastructure breakdowns. For example, local policy could incorporate first responder planning on actions to take if electric power suddenly ends and all critical infrastructures are in jeopardy in a major outage extending several months. Further, emergency managers could provide community education for population preparedness. Every local area should evaluate its risk level using a Threat and Hazard Identification Risk Analysis (THIRA) from the Federal Emergency Management Agency (FEMA). Emergency managers, in creating their THIRA, should define and include threats to major infrastructure, especially to electric power, so that they can take action to mitigate the threats.

Improving Critical Infrastructure Resilience

At the national strategic level, a panel reviewed successes and failures during previous critical infrastructure breakdowns, including but not limited to those associated with natural disasters. Different analytical approaches were employed, including a new system developed by the Foundation for Resilient Societies called Grid Clue. The system includes the ability to assess each state's energy resilience level. The discussion demonstrated the limited role that solar and wind are currently playing in the generation of electric power, along with concerns about the ways power could be generated to reduce carbon emissions. Several panelists emphasized that we must concentrate on understanding real world vulnerabilities – prioritizing and mitigating them. Practical lessons drawn from past statewide and national critical infrastructure lapses were presented.

Another panel focused on the fact that we cannot accomplish everything and need to set priorities, which is important from a variety of perspectives. Specific strategy approaches were presented.

Policies for resilience emanating from the latter two panels included but were not limited to: advancing the ability of Public Utility Commissions (PUCs) in every state to include hardening the electric distribution system against manmade threats and solar storms, and acknowledging that PUCs have traditionally concentrated on protection against natural threats. In that pursuit, they could benefit from the San Antonio Electromagnetic Defense Initiative (SAEDI), whose mission is to ensure that Joint Base San Antonio (JBSA) continues military operations in a post Electromagnetic Pulse (EMP) environment. The Base has built collaborations with their electric power and water utilities along with an assortment of local businesses to protect the Base and local citizens[4]. The NDRC has worked with

4 Joint Base San Antonio Electromagnetic Defense Initiative, https://www.jbsa.mil/EDI/

SAEDI leaders on an ongoing basis. Policy development could occur to encourage all communities near military bases to protect their community and become a "Resilient Community Island."

Conclusions

Themes considered in the 2022 NDRC Summit can be used to improve both messaging and policies aimed at securing national critical infrastructures.

The US should reinvigorate national policy acknowledging that critical infrastructure is vital and provide sufficient funding and/or tax incentives to make vulnerability mitigation a reality.[5]

Local areas could consider policies to establish resilient community islands to make communities safer in times of extended disasters. Ensuring electric power, water, and food, along with communications, education, and government continuity would undergird community survival.

At the international and national levels, making massive critical infrastructure destruction a war crime could help protect all nations. Consistent with FBI public education, more widespread realization that the CCP is undermining American democracy could prompt more effective protection policies. High on the list is ensuring that children understand the values of national democracies and our form of government. Also important is protecting military installations from land purchases near individual bases by foreign countries. We need to upgrade policy to give preference to US companies in competitive situations so that US companies owned by foreign entities are not able to undercut US business based solely on price cutting.

NDRC intends to act on selected themes of the 2022 Summit. Current plans include meeting with all 77 InfraGard Member Alliance (IMA) chapters and discussing their infrastructure priorities for times of disaster, improving the ability of these jurisdictions to be secure in their homes and community. This will include best practices related to emergency bags in cars. This could also lead to planning-relevant discussion of "resilient island" concepts. In addition, NDRC intends to further elaborate the 36 Stratagems - and undertake actions related homeland security threats emanating from their use. The next NDRC Summit in December, 2023 will be held in San Antonio at the University of Texas San Antonio National Security Collaboration Center (NSCC).

5 Critical Infrastructure policy here is differentiated from the Infrastructure Investment and Jobs Act. While that legislation provided historic funding levels for transportation, alternative energy provision, water and other purposes, the Summit focused on lower probability high impact events capable of producing cascading critical infrastructure breakdowns with long-term, national consequences

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Author Capsule Bio

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The Electromagnetic Threat to the US: Resilience Strategy Recommendations

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Abstract

This article analyzes the threat of both electromagnetic pulse (EMP) and geomagnetic disturbances (GMD) to various federal agencies and the civilian population of the United States. EMP/GMD events are classified as low-probability/high-impact events that have potential for catastrophic consequences to all levels of government as well as the country's civilian population. By reviewing current literature and conducting two thought experiments, we determined that specific critical infrastructure sectors and modern society are at substantial risk from the effects of these events. Some of the most serious consequences of a large-scale EMP/GMD include long-term power loss to large geographic regions, loss of modern medical services, and severe communication blackouts that could make recovery from these events extremely difficult. In an attempt to counteract and mitigate the risks of EMP/GMD events, resilience engineering concepts prescribe several recommendations that could be utilized by policymakers to mitigate the effects of EMP or GMD. Some of the recommendations include utilizing hardened micro-grid systems, fast tracking available black start options, and various changes to government agency organizations that would provide additional resilience and recovery to American critical infrastructure systems in the post-EMP/GMD environment.

Keywords: Electromagnetic Pulse (EMP), Geomagnetic Disturbance (GMD), Resilience Engineering

Introduction

The purpose of this article is to answer two questions: how ready are the US critical infrastructure systems to withstand the effects of an electromagnetic pulse or

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geomagnetic disturbance (EMP/GMD), and what actions can be taken in order to increase the resilience of our critical infrastructure systems from such events? Using a thought experiment methodology[1] and incorporating elements of resilience engineering[2], we determined that US critical infrastructure, specifically electric power and telecommunications systems that all other critical infrastructure rely on, is relatively unprepared for a large scale EMP/GMD event. However, we also determined that there are actions that can be taken, some of which are known capabilities that exist, which have the potential to provide additional resilience to various critical infrastructure systems and to provide a level of protection against EMP/GMD events.

To some, EMP/GMD events may seem more like science fiction than reality. There are a multitude of films and books that can seem to sensationalize the effects of EMP/GMD. One book in particular, *One Second After,* provides readers with a frightening reality of what the effects of a large scale EMP attack would be like for everyday Americans as a long-term power blackout caused by an EMP attack cripples a mountain community in rural North Carolina.[3] Books like *One Second After*, while works of fiction, provide exactly the kind of thought process that can allow us to truly understand what the possible second and third order effects could be in a post EMP/GMD environment. How would large geographic areas of the country react to long-term power loss? How would hospitals provide care 96 hours after their backup generators came offline? How would people react when supermarkets are unable to provide food while first responders are either overwhelmed or non-existent? These are the types of scenarios we wanted to understand because they place enormous stress not only on our critical infrastructure systems, but on society as well. The COVID-19 pandemic showcased how low probability/high impact events can have a significant impact on our society as it sent shock waves through our supply chain, financial, and medical sectors. Unfortunately, some studies predict that a large-scale EMP/GMD event would make the COVID-19 pandemic pale in comparison.

Despite the perceived impacts of a large-scale EMP/GMD, there are few studies assessing the capacity for US critical infrastructure to anticipate and respond to such events. This is likely because GMD/EMP events are rare and there is a lack of data on their impacts as well as a lack of imagination for the perceived widespread disaster they could cause. This work is meant to help fill this gap via thought experiments intended to break out a discrete set of critical infrastructure

1 James Robert Brown and Yiftach Fehige, "Thought Experiments," The Stanford Encyclopedia of Philosophy, 2019, https://plato.stanford.edu/archives/win2019/entrieshought-experiment/.

2 John E. Thomas et al., "A Resilience Engineering Approach to Integrating Human and Socio-Technical System Capacities and Processes for National Infrastructure Resilience," *Journal of Homeland Security and Emergency Management* 16, no. 2 (May 27, 2019): 1, https://doi.org/10.1515/jhsem-2017-0019.

3 William Forstchen R., *One Second After*, vol. 1st ed. (New York: Forge, 2019).

impacts.[4] Towards this end, we present two thought experiments, one for an EMP scenario and another for a GMD scenario occurring in the near future. Utilizing data from previous EMP/GMD events as well as from recent natural disasters, these scenarios examine how the US government would respond and what the cascading effects would impact the civilian population. The article then builds on the conclusions from the thought experiments and applies paradigms from resilience engineering to help understand human and technological interactions with EMP/GMD events and provide recommendations to mitigate their impacts. The overall goal is to improve resilience of our critical infrastructure systems.

The remainder of this article is organized as follows: First, an overview is provided on EMP and GMDs are and how they can be detrimental to critical infrastructure systems. It then provides an overview of the EMP and GMD thought experiment methodology and findings and introduces how resilience engineering concepts such as Woods' four concepts of resilience[5] and the Sense, Anticipate, Adapt, and Learn (SAAL) model[6] can suggest strategies to provide both added protection and the ability for systems to rebound against EMP/GMD events. It concludes by offering recommendations to both policymakers and leaders in the private sector for how we can increase the resilience of our critical infrastructure sectors against electromagnetic events.

What are EMP/GMDs and why are they a threat?

An EMP is an electromagnetic wave generated from man-made devices, while a GMD is a naturally occurring solar radiation event that creates similar electromagnetic effects. EMPs can be produced by specialized weapons designed to emit the pulse directly, or as a wave resulting from detonating other weapons like low earth orbit nuclear missiles. In contrast, GMDs occur naturally, such as from coronal mass ejections from the sun. Coronal mass ejections (CMEs) occur when the sun emits a plasma-based emission with an intense magnetic field that can generate an enormous electric current in the Earth's atmosphere.[7] Both EMP and GMD have the potential to cause destructive health and economic impacts as they cause electronic and electrical devices to experience high-energy currents that destroy circuitry and solid-state devices. This means that any device vulnerable to electrical surge, such as computers, cell phones, servers, switchgear, lighting,

4 This work is based on a master's thesis completed by the lead author: Samuel Averitt, "The Electromagnetic Threat To The United States: Recommendations For Consequence Management" (Monterey, CA, Naval Post Graduate School, 2021).

5 "Four Concepts for Resilience and the Implications for the Future of Resilience Engineering," *Reliability Engineering & System Safety* 141 (September 2015): 5, https://doi.org/10.1016/j.ress.2015.03.018.

6 Thomas et al., "A Resilience Engineering Approach to Integrating Human and Socio-Technical System Capacities and Processes for National Infrastructure Resilience," 7.

7 Matthew Weiss and Martin Weiss, "An Assessment of Threats to the American Power Grid," *Energy, Sustainability and Society* 9, no. 1 (2019): 1, https://doi.org/10.1186/s13705-019-0199-y.

transformers, and control systems among many others, can be destroyed by EMP/GMD. Importantly, EMP and GMD can affect large geospatial regions when generated from nuclear weapons or a CME, such that infrastructure systems can be simultaneously destroyed across entire regions and countries.

There are several reasons why even a small-scale EMP or GMD event within the United States would have catastrophic consequences. All 16 U.S. critical infrastructure sectors from healthcare to the defense industrial base have an enormous reliance on the electrical grid, control and supervisory control and data acquisition (SCADA) systems, and internet-based communication which will experience immediate, direct damage from an EMP/GMD. While electric power and telecommunications systems are vulnerable, essentially all critical infrastructure systems can be affected by an EMP/GMD either through direct damage to unprotected electronic components or from cascading failures when power and communications are lost. Whether an EMP/GMD originated from an adversarial attack or from a naturally occurring geomagnetic storm, it is possible that the United States could suffer a severe degradation to its critical infrastructure and potentially experience large numbers of causalities.

EMP Specifics

The effects of EMP events on electrical systems have been well studied during nuclear testing that dates back to the 1960s, first understood by scientists during nuclear testing by the U.S. and Soviet Union in the 1960s.[8] An EMP exhibits three sequential pulses called E1, E2, and E3 that contribute to the disruption or destruction of electronic components and systems. The E1 pulse, referred to as the early time pulse, occurs immediately after a nuclear blast and creates large increases in voltage that can potentially damage standard surge protectors and send tens of volts per meter or millions of volts per kilometer throughout the affected area.[9] The E1 pulse creates conditions for an immediate effect on electrical systems which is caused by high-energy gamma rays that interact with the Earth's atmosphere and creates radiated electromagnetic fields.[10] Because the E1 pulse occurs so quickly and with so much voltage, and because most modern electrical systems lack adequate protection and resilience (e.g., high voltage transformers), many systems cannot withstand the initial phase of an EMP event.[11]

8 See, for example, US House of Representatives, Committee on National Security, Military Research & Development Subcommittee, "Threat Imposed by EMP to US Military Systems and Civil Infrastructure", July 16, 1997.

9 Mao Congguang et al., "Early-Time High-Altitude Electromagnetic Pulse Environment (E1) Simulation with a Bicone-Cage Antenna," *China Communications* 10, no. 7 (2013): 12, https://doi.org/10.1109/CC.2013.6570795.

10 Siva Kumar Pukkalla and B. Subbarao, "Evaluation of Critical Point-of-Entry (POE) Protection Devices for E1 & E2 Pulses as per MIL STD 188-125-1&2," in *2018 15th International Conference on ElectroMagnetic Interference & Compatibility (INCEMIC)* (Bengaluru, India: IEEE, 2018), 1–4, https://doi.org/10.1109/INCEMIC.2018.8704567.

11 Craig R. Lawton, *Sandia's Research in Electric Grid EMP Resilience*, ERPI 2018 EMP Resilient Grid

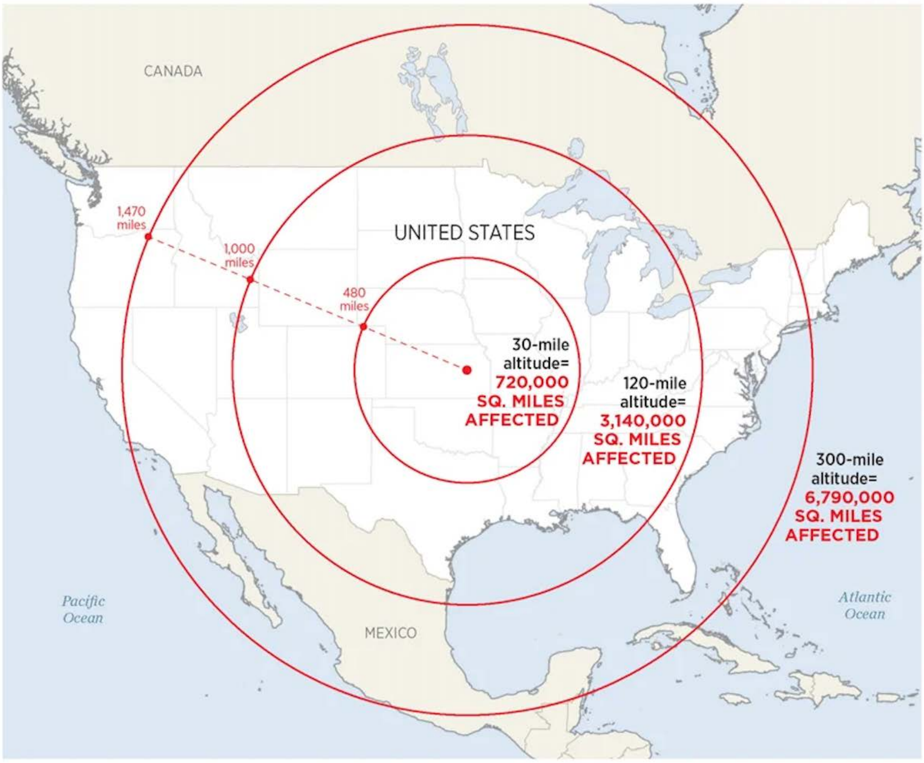

Figure 1: Continental US EMP Burst Map

Source: Threat Posed by Electromagnetic Pulse (EMP) to U.S. Military Systems & Civil Infrastructure, House Committee on National Security, July 16, 1997 from the Heritage Institute

The E2 pulse of an EMP event, referred to as the intermediate pulse, takes place milliseconds after a high altitude nuclear EMP event and immediately follows the E1 pulse.[12] The E2 pulse is comparable in waveform and strength to lightning strikes, which makes it the easiest to protect against as it is a familiar threat to modern society. It does have the potential to put out thousands of volts per kilometer and can cause significant damage to electrical systems, especially when it occurs immediately after the already disabling E1 pulse.[13]

Workshop (Albuquerque, NM: Sandia National Labs, 2018), 14, https://www.osti.gov/servlets/purl/1512391.

12 Soobae Kim and Injoo Jeong, "Vulnerability Assessment of Korean Electric Power Systems to Late-Time (E3) High-Altitude Electromagnetic Pulses," *Energies (Basel)* 12, no. 17 (2019): 1, https://doi.org/10.3390/en12173335.

13 Sirius Bontea, "America's Achilles Heel: Defense Against High-Altitude Electromagnetic Pulse-Policy vs. Practice" (master's thesis, U.S Army Command and General Staff College, 2014), 5, https://www.hsdl.org/?search=&searchfield=&all=America%27s+Achilles+Heel%3A+Defense+Against+High-Altitude+Electromagnetic+Pulse-Policy+vs.+Practice&collection=public&submitted=Search.

The E3 pulse, referred to as the long-term pulse, has significantly different characteristics from the E1 and E2 pulses as it can last seconds to minutes after the EMP event and creates power surges of tens of volts per kilometer.[14] The E3 pulse also differs in that it induces electrical fields which then produce geomagnetically induced currents (GIC)s, which have the same effect that a GMD creates from naturally occurring solar storm events.[15] Power lines can potentially carry the GICs produced from the E3 pulse to massive transformer stations, resulting in significant damage that could cause widespread power outages and greatly impede any recovery of the electrical systems and grids.[16]

Based on the characteristics and effects of the three EMP pulses, high altitude EMP events have the potential to inflict significant damage to modern electrical systems which entire populations rely on for almost every facet of society. Not only can the damage be devastating to electrical systems but depending on the height of burst the effects of the EMP can cover large geographical areas, as the figure 1 depicts.

GMD Specifics

GMD events create disturbances in the Earth's magnetic field due to enhanced solar forces that interact with the space environment that surrounds Earth.[17] A large-scale GMD occurs when a CME forms on the surface of the sun and directs high energy particles towards Earth having the potential to adversely affect GPS systems and satellite communications, and, in extreme cases, to disable power grids on the Earth's surface.[18] The National Oceanic and Atmospheric Administration (NOAA) rates solar events on a scale based on their potential impacts to space and land based systems.[19] Mild radiation events from the sun are classified as S scale events, which degrade satellite communication and high frequency radio transmissions, while a major GMD events are classified as G scale events, which have the potential to create serious impacts to power grids on the Earth's surface.[20] The most powerful G scale GMDs produce GICs that are similar to the effects to the E3 pulse of an EMP and can potentially create the same disabling effects on major power grids. The NOAA's Space and Weather Prediction Center (SWPC) can track and analyze solar activity that may result in a GMD, which can provide between a

14 Kim and Jeong, "Vulnerability Assessment of Korean Electric Power Systems to Late-Time (E3) High-Altitude Electromagnetic Pulses," 2.

15 Kim and Jeong, 2.

16 Kim and Jeong, 2.

17 Department of Homeland Security, *Federal Operating Concept for Impending Space Weather Events*, 2019 Space Operating Concept Report (Washington, D.C: Department of Homeland Security, 2019), 5, https://www.hsdl.org/?abstract&did=.

18 Department of Homeland Security, 6.

19 Department of Homeland Security, 1.

20 Department of Homeland Security, 1.

16–90-hour window of early warning before a GMD event would interact with the Earth's atmosphere.[21]

There have been several instances when GMD events occurred in the past. The earliest recorded GMD event occurred in 1859 and is referred to as the Carrington Event, based on the observations of astronomer Richard Carrington.[22] The Carrington event was observed by several early astronomers at a time when telegraph communication was becoming standard practice of most modern countries.[23] The Carrington GMD had profound and spectacular effects on Earth that included abnormally large Aurora Borealis sightings and destroying over 20,000 km of telegraph lines due to a GIC that overloaded the system.[24] Based on modern analysis and modeling techniques it is estimated that if a GMD as powerful as the Carrington event occurred today, up to 40 million people would be without power for up to two years as GICs will damage wireless communications, control systems, and large electrical transformers that generally take multiple months or years to replace.[25] Failure of these large power transformers would be especially disastrous and cause second- and-third order effects as large scale blackouts impact medical, fuel, transportation, and food production facilities.[26]

More recent events where a CME led to widespread infrastructure failures highlight the need to manage EMP/GMD risks. In 1989, the Canadian Province of Quebec experienced a GMD event that caused a massive blackout that left over five million people without power for a period of nine hours.[27] The same GMD event also had disastrous effects outside of Canada; the storm destroyed a $12-million transformer in the United States, disabled two large transformers in the United Kingdom that had to be repaired, and space agencies temporarily lost communications with hundreds of satellites.[28] Given that power grids in the United States have not been reinforced for modern EMP or GMP threats, and reliance on electrical grids has increased tremendously in the United States since 1989, with data, control, and telecommunications devices now ubiquitous across infrastructure system operations, a similar GMD event today may result in even greater damage to electrical systems.[29]

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21 Department of Homeland Security, 1.

22 Robert Giegengack, "The Carrington Coronal Mass Ejection of 1859," *Proceedings of the American Philosophical Society* 159, no. 4 (December 2015): 421.

23 Giegengack, 421.

24 Giegengack, 423.

25 Weiss and Weiss, "An Assessment of Threats to the American Power Grid," 2.electromagnetic pulse attacks (EMP

26 Mark H. MacAlester and William Murtagh, "Extreme Space Weather Impact: An Emergency Management Perspective," *Space Weather* 12, no. 8 (2014): 535, https://doi.org/10.1002/2014SW001095.

27 Mike Hapgood, "Prepare for the Coming Space Weather Storm," *Nature (London)* 484, no. 7394 (2012): 311–13, https://doi.org/10.1038/484311a.

28 Hapgood, 7.

29 Weiss and Weiss, "An Assessment of Threats to the American Power Grid," 3.electromagnetic pulse

Resilience Engineering Concepts and their Application to EMP/GMD events

Given the widespread recognition that the United States is vulnerable to EMP/GMD, resilience concepts and frameworks can assist policymakers and human operators in creating systems that are designed to survive and recover from stressful environmental events. Resilience is a familiar concept in US national strategy planning. In 2013, the Obama Administration implemented Presidential Policy Directive (PPD) 21 which stated that resilience is a key aspect of protecting national critical infrastructure against both known and unfamiliar threats.[30] The US now prepares for unexpected events using resilience concepts, especially in relation to homeland defense and security of critical infrastructure systems.[31] Resilience goals and practices are commonplace among many federal agencies that would be involved in EMP/GMD response and recovery, including DHS,[32] the Department of Commerce,[33] the DOD, and the DOE[34] among many others.

Despite widespread recognition of need for resilience among US government agencies, large-scale infrastructure failures continue to occur, meaning that systems are not resilient.[35] Alderson suggests that there are at least four barriers inhibiting national resilience to events like EMP/GMD: (1) the interdisciplinary nature of critical infrastructure systems, (2) the overemphasis of predefined threat scenarios, (3) the inability to share information about real systems and needs, and (4) a lack of understanding about resilience itself.[36] Specifically, resilience frame-

attacks (EMP

30 Barack Obama, *Presidential Policy Directive 21: Critical Infrastructure Security and Resilience*, PPD 21 (Washington, D.C: United States. White House Office, 2013), 2, https://www.hsdl.org/?abstract&did=731087.

31 John Moteff, *Critical Infrastructures: Background, Policy, and Implementation*, CRS Report No. RL5809 (Washington, D.C: Congressional Research Service, 2015), 4, https://fas.org/sgp/crs/intel/RL5809.pdf.

32 Department of Homeland Security, *Strategy for Protecting and Preparing the Homeland Against Threats of Electromagnetic Pulse and Geomagnetic Disturbances* (Washington, D.C: Department of Homeland Security, 2018), https://www.hsdl.org/?abstract&did=817225.

33 "National Critical Functions | CISA," National Critical Functions, October 6, 2021, https://www.cisa.gov/national-critical-functions.

34 Department of Energy, *U.S. Department of Energy Electromagnetic Pulse Resilience Action Plan*, EMP Pulse Report 1 (Washington, D.C: Department of Energy, 2017), 20, https://www.hsdl.org/?abstract&did=."plainCitation":"Department of Energy, U.S. Department of Energy Electromagnetic Pulse Resilience Action Plan, EMP Pulse Report 1 (Washington, D.C: Department of Energy, 2017

35 Evan Halper, "A Texas-Size Failure, Followed by a Familiar Texas Response: Blame California," Los Angeles Times, March 18, 2021, https://www.latimes.com/politics/story/2021-03-18/texas-failure-response-blame-california.

36 D.L Alderson, "Overcoming Barriers to Greater Scientific Understanding of Critical Infrastructure Resilience," in *Handbook on Resilience of Socio-Technical Systems* (Northampton, MA: Edward Elgar, 2019), 67–74.

works implemented in many federal agencies overemphasize predefined threats (barrier 2), do not improve our understanding of real systems and data sharing (barrier 3), and do not relate to a large amount of resilience theory and literature (barrier 4). Alderson argues that overcoming these barriers requires drawing upon work in resilience engineering to guide organizational policies and missions.[37]

Two frameworks developed within the resilience engineering technical community for assessing and improving current resilience practices are relevant for EMP/GMD events. First, the resilience engineering literature suggest that government agencies and utility operators can prepare for uncertain events by incorporating the sensing, anticipating, adapting, and learning process (SAAL).[38] The SAAL process describes how technological systems and human cognitive nature interact to maintain a certain level of function during stressful events that are either expected or unexpected.[39] The SAAL process incorporates:

- **Sensing**- "the process to apprehend and interpret information about a system's operations status relative to known and unknown vulnerabilities and system shocks"[40]
- **Anticipating**- "describes the processes involved with imagining, planning, and preparing for possible system changes, emergency events, and crises scenarios relative to present and future conditions of the system, which includes impacts at boundaries"[41]
- **Adapting**- "describes the process governing system responses to both known and unknown changes in stability and operating performance"[42]
- **Learning** -"integrates an open loop cycle of interrelatedness among each subgroup of process (i.e sensing, anticipating, and adapting) to inform and adjust system outcomes while retaining knowledge for future access."[43]

By understanding and implementing the SAAL process, humans can create systems and procedures that are able to quickly respond to new or changing events. The SAAL framework is useful when analyzing how to protect critical infrastructure from both known and unknown events or events which we understand but do not fully grasp the second and third order effects on our systems, such as EMP/GMDs.

37 Alderson, 76.

38 Thomas et al., "A Resilience Engineering Approach to Integrating Human and Socio-Technical System Capacities and Processes for National Infrastructure Resilience," 12.

39 Thomas et al., 6.

40 Thomas et al., 7.

41 Thomas et al., 7.

42 Thomas et al., 7.

43 Thomas et al., 7.

Second, resilience engineering literature suggests that government agencies and utility operators should aim to achieve specific resilience outcomes for infrastructure systems. Woods defines four "concepts of resilience,"[44] that categorize outcomes witnessed when systems survive unexpected stressful events. The four concepts are:

- **Rebound**- how a system can rebound from disrupting or traumatic events and return to normal function
- **Robustness**- the ability of a system to manage increasing stress while still maintaining primary function
- **Extensibility**- how a system can extend or bring additional performance and capacity while experiencing new or challenging events; and,
- **Adaptability**- a system's ability to sustain function while experiencing new or unforeseen events.[45]

Woods' four concepts can assist with the understanding and creation of resilient systems, mainly critical infrastructures, that have the ability to withstand known and unknown events and ensure that systems can continue to operate or successfully rebound after adverse conditions occur. This type of framework is vital for planning how to create electrical systems that could continue to function under EMP/GMD environments.

EMP/GMD Thought Experiments Analyzed through Resilience Paradigms

In an attempt to understand how EMP/GMD events would realistically impact modern day critical infrastructure and society we conducted two thought experiments, one for an EMP event and a second for a GMD event. Thought experiments offer a means to develop realistic, yet fictitious scenarios that reveal decision-making contexts, societal impacts, and other issues relevant for resilience. We developed thought experiments as fictional events that occur in the near future, incorporate present day infrastructure capabilities, and consider known historical societal trends. Then, we analyze each thought experiment via the SAAL and Woods' resilience frameworks to gain a better insight on how government agencies, associated systems, and the civilian population reacted to the stress of EMP/GMD events. Each thought experiment takes into consideration the federal and state level capacities in the pre-event phase, the federal response to the event, the civilian power utility response, the effects on the power grid, and effects on the U.S. population and interdependent infrastructure systems.

44 Woods, "Four Concepts for Resilience and the Implications for the Future of Resilience Engineering," 1.

45 Woods, 1–2.

Thought Experiment 1: Modern Day Carrington Event (GMD)

A GMD the size and strength of the Carrington event occurs in the near future. The oncoming GMD is discovered by the National Oceanographic Atmospheric Administration's Space Weather Prediction Center and determined to impact Earth's atmosphere in 15 hours. Once NOAA confirms the event, the SWPC issues a GMD warning alert to DHS, FEMA, DOD, and all state and local government agencies. The public is notified and elements of the DOE and public utility companies try to prepare the grid for a Carrington class GMD event, while simultaneously all federal and state government agencies execute necessary planning for consequence management and recovery operations. The federal government has no real means to respond due to the 15-hour timetable and is forced to rely on state and local governments' ability to try and mitigate as best as possible. FEMA has time to issue an abbreviated operations order to all of its field offices and state governments but has no real way to react before the 15-hour timeline runs out.

The power utility industry, with the assistance of the DOE, is forced to make significant decisions on how to best prepare the national grid for the impending GMD event. Key critical infrastructure is the main priority of protection as some parts of the national grid would be shut down. Federal, state, and local policymakers provide guidance and direction as to what parts of the country need to be sustained through the GMD event and direct the DOE to immediately disseminate orders and plans to the major power grid interconnections, which include the Western Interconnection, Electric Reliability Council of Texas Interconnection, and Eastern Interconnection who then manage the individual utility operators to prepare the grid for the impending GIC effects. As the GMD event unfolds, large portions of the grid are destroyed and federal agencies are forced to rely on the private utility companies and local governments to provide damage control.

The civilian population is forced to deal with days to weeks of no power, which has disastrous effects on healthcare, emergency response, banking, and other essential services. Both rural and urban areas are devastated by these events as mass migrations occur out of effected areas, which creates additional stress on less affected areas. FEMA attempts to set up areas with key supplies and shelter but due to the rapid timeline of the CME, it cannot deploy enough assets in the time allotted. The civilian population suffers as basic services break down; most community preparedness guidelines only call for 72 hours' worth of essential supplies per family unit, which is nowhere near sufficient in a post-GMD environment.[46] In addition, due to the early warning given to the civilian population, retail and

46 The President's National Infrastructure Advisory Council, *Surviving a Catastrophic Power Outage, How to Strenghen the Capabilities of the Nation*, NIAC-2018-0234 (Washington, D.C: The President's National Infrastructure Advisory Council, 2018), 13, www.cisa.gov%2Fsites%2Fdefault%2Ffiles%2Fpublications%2FNIAC%2520Catastrophic%2520Power%2520Outage%2520Study_FINAL.

grocery stores experience significant supply issues as many people hoard key supplies. Such hoarding behavior was experienced during the COVID-19 pandemic, suggesting that an impending GMD event may could prove to be even worse.[47]

Thought Experiment 2: Adversarial EMP Attack

For the second thought experiment we depicted a hypothetical EMP attack on the United States via a high-altitude nuclear detonation. This thought experiment utilized data from the 1962 Soviet Nuclear EMP tests that were executed in Kazakhstan in which three 300 kiloton warheads were detonated at various altitudes to determine the damage of the EMP effects on Soviet command and control networks.

An EMP attack on the United States occurs in the near future. A hypersonic ballistic missile with a 300-kiloton warhead similar to the weapon used in the 1962 Soviet Nuclear EMP test in Kazakhstan[48] is launched from a submarine in an undisclosed location in the North Atlantic Ocean. The missile is able to evade American missile defense systems, changing its flight trajectory in a rapid and unpredictable manner. The Department of Defense is able to identify and track the missile but has less than 30 minutes before the warhead detonates and has little to no time to notify key domestic agencies such as the Department of Homeland Security. As the missile progresses towards its intended target, the 300-kiloton warhead separates from the re-entry body and detonates 300 km above the Eastern seaboard of the United States. The high-altitude detonation puts thousands of volts per kilometer in the atmosphere with the initial E1 and E2 pulses, destroying most modern electrical systems instantly, including ground-based air defense monitoring stations, while the E3 pulse produces GICs that travel along powerlines and severely damage several transformers, initiating cascading effects to all sectors of critical infrastructure.[49]

Because there was little to no warning to domestic or federal agencies, local governments and communities are forced to deal with the significant effects of the post-EMP environment, which may include widespread power outages, communication blackouts, overwhelmed hospital systems that are without power, and a general state of chaos at all levels of government. Communication failure and the slow dissemination of critical supplies will diminish the abilities of key disaster agencies such as FEMA or state-level National Guard.

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47 Janni Leung et al., "Anxiety and Panic Buying Behaviour during COVID-19 Pandemic-A Qualitative Analysis of Toilet Paper Hoarding Contents on Twitter," *International Journal of Environmental Research and Public Health* 18, no. 3 (2021): 1, https://doi.org/10.3390/ijerph18031127.

48 Electric Infrastructure Security Council, "USSR Nuclear EMP Upper Atmosphere Kazakhstan Test 184," Electric Infrastructure Security Council, September 14, 2021, https://www.eiscouncil.org/Library.aspx.

49 Dodge et al., "The Danger of EMP Requires Innovative and Strategic Action," 7.

From a homeland security perspective, there will be a severe degradation in the ability to support local communities, which must depend on their own level of preparedness and ability to maintain order in the most chaotic of circumstances. Depending on the extent of the pulse, there could be serious issues with safely landing aircraft that were airborne during the EMP event and a large number of people who would be stranded at major airports, all of which may be without power. Everyday services such as food production or emergency services may not be available to a large portion of the U.S. population. This is to say, the response from the Department of Homeland Security may be non-existent in the beginning stages of a post-EMP environment.

As there was little to no warning of the EMP attack, the power utility industry will have no means of preparing the grid or taking any mitigating actions against the attack. All three waveforms of the EMP event would be detrimental to the American power grid due to the increased atmospheric voltage and unprepared nature of the grid interconnections. In short, because of the limited reaction time available during a weaponized EMP attack, there would be profound negative impacts to the electrical grid that would, at the very least, cause-long term blackouts in many regions of the U.S.

The effects of a large scale EMP attack on the civilian population have the potential to be disastrous as the level of comfort and services that most American experience in the pre-EMP environment will change dramatically. Many EMP planning documents prescribe that federal and state agencies are responsible for not only providing storage of critical medical and emergency supplies, but also for safeguarding critical infrastructure and creating hardened federal communication networks in order to maintain communications.[50] However, these documents do not consider some of the darker aspects of human nature that may occur when critical services cease to exist, such as desperation from starvation and living in an environment where rule of law may be non-existent, all of which could produce numerous fatalities.[51] In addition, when only 2 percent of the US population currently works in agriculture, and where there is a massive reliance on electric automated services, food security will be a serious concern. Food shortages will occur shortly after the onset of the event, and the ability to mass produce and distribute food will be significantly degraded until power is restored.[52] Much of the emergency distribution of key supplies will be up to state and local jurisdictions and will only be effective if prior planning for EMP/GMD events had occurred—which is doubtful.[53]

50 "EMP Program Status Report | CISA," 29 July 2021, Cybersecurity and Infrastructure Security Agency, accessed July 29, 2021, https://www.cisa.gov/publication/emp-program-status-report.

51 David Stuckenberg, R. James Woolsey, and Douglas DeMaio, *Electromagnetic Defense Task Force 2.0: 2019 Report*, LeMay Paper No. 4 (Maxwell Air Force Base, Alabama: Air University (U.S.). Press Curtis E. LeMay Center for Doctrine Development and Education, 2019), 109, https://www.hsdl.org/?abstract&did=828407.

52 Stuckenberg, Woolsey, and DeMaio, 109.

53 George H. Baker, "Electromagnetic Pulse Resilience of United States Critical Infrastructure: Prog-

As mass blackouts and absences in critical services continue to exist as a result of the EMP attack, the civilian population will be subjected to conditions that have not been experienced since the advent of the industrial age. Much of the population will be exposed to both extreme heat and cold temperatures as HVAC and air conditioning systems will be unable to function. Wastewater and sewage system failures will produce unsanitary conditions in the areas that are within the EMP blast radius and will make many areas uninhabitable for the civilian population as clean water will be harder to acquire as blackouts continue.[54] Life as most Americans know it will be changed for a very long time. The length of recovery time from a weaponized EMP attack is hard to predict, but some sources estimate recovery will last months to years as some vital electronic assets such as transformers can take many months to construct under normal conditions.[55]

Analysis of the Thought Experiments and Potential Recommendations for Mitigation

A GMD/EMP event, while rare, has great potential to inflict significant damage to our critical infrastructure systems and send cascading effects that could impact every American citizen. Having strategies to deal with post-GMD/EMP environments will not only save lives, but are necessary for America to remain secure if such an event ever occurs. Towards this end, we analyze each thought experiment via the SAAL framework and Wood's Resilience Concepts. Specifically, the SAAL framework reveals how various actors perceived the events in and the Woods' concepts inform pre- and post-event recommendations.

Overall, both thought experiments showcased that in case of a GMD or EMP event, the ability of the federal government will be severely degraded and most of the consequence management will be left to state and local agencies. In other words, the ability for various agencies to sense what is occurring was almost nonexistent in the post-event environment. It is also apparent that the ability of the civilian population to deal with these events is entirely dependent on the amount of preparation that is done at the family or household level. In both events, communities will respond based on how well they can initially operate without federal assistance. Hence, where appropriate, analyses and recommendations are provided separately federal and utility providers and civilian populations.

ress and Prognostics," *Journal of Critical Infrastructure Policy* 2, no. Spring/Summer 2021 (200AD): 38.

54 John Foster Jr. et al., *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical National Infrastructures* (McLean, VA: Electromagnetic Pulse Commission, 2008), 10, https://apps.dtic.mil/sti/citations/ADA484672.

55 Foster Jr. et al., 6.

SAAL Framework

Utilizing the SAAL framework, we created approximate timelines for both events that showcase how federal agencies and the civilian population reacted.

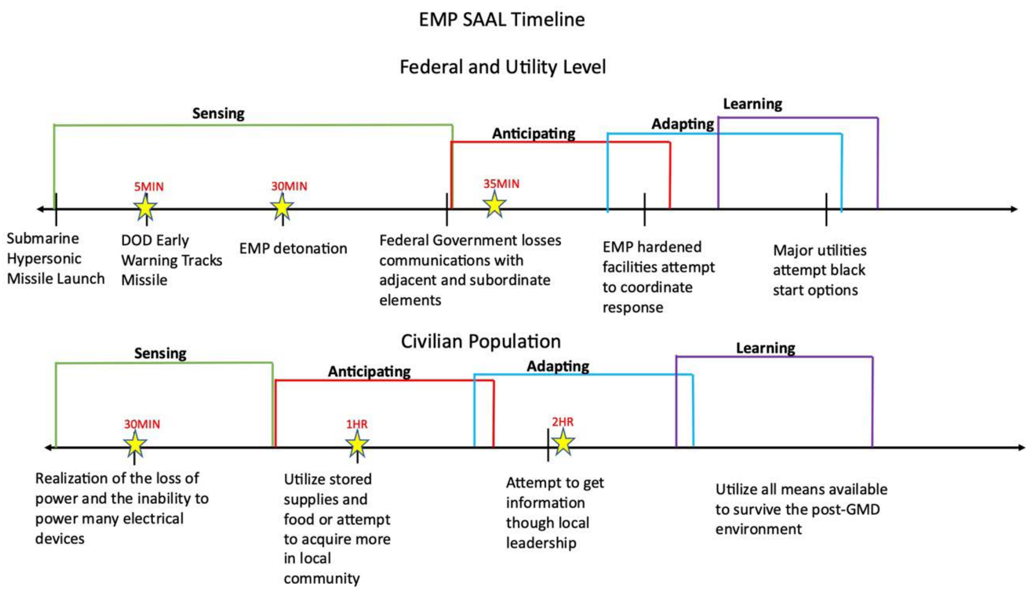

Figure 2: EMP SAAL Timeline

As seen in Figure 2, both thought experiments are broken down by each phase of the SAAL methodology for federal agencies and the civilian population. Key times are plotted on the charts to denote how much time various entities had to understand how these events were unfolding and what actions could realistically be taken. The GMD event demonstrated that NOAA was able to provide some level of reaction time to allow a limited amount of early warning to various levels of government and the civilian population whereas the EMP event had little to no reaction time, which had profound effects on both government agencies and the civilian population.

Based on the timelines created from the thought experiments, we propose a far greater level of preparedness at the jurisdiction level, better lines of communication between the DOD and domestic agencies for pre-event EMP awareness, and the incorporation of adaptable technology, such as hardened microgrids and black start options, that can provide electric power in a post-EMP/GMD environment. From a federal government perspective, the implementation of some of these recommendations may be difficult as many recent events have taken priority such as domestic terrorism, the response to COVID-19, and a return of great power competition. However, it can be argued that the basic tenets of preparedness and a sustainable, resilient grid system are extremely important in any disaster or contingency. In addition, steps should be taken in order to ensure the DOD can quickly disseminate information on adversarial EMP attacks to domestic agencies such as DHS and NOAA to ensure contingency planning can be at least initiated before large parts of the country lose power and the ability to communicate.

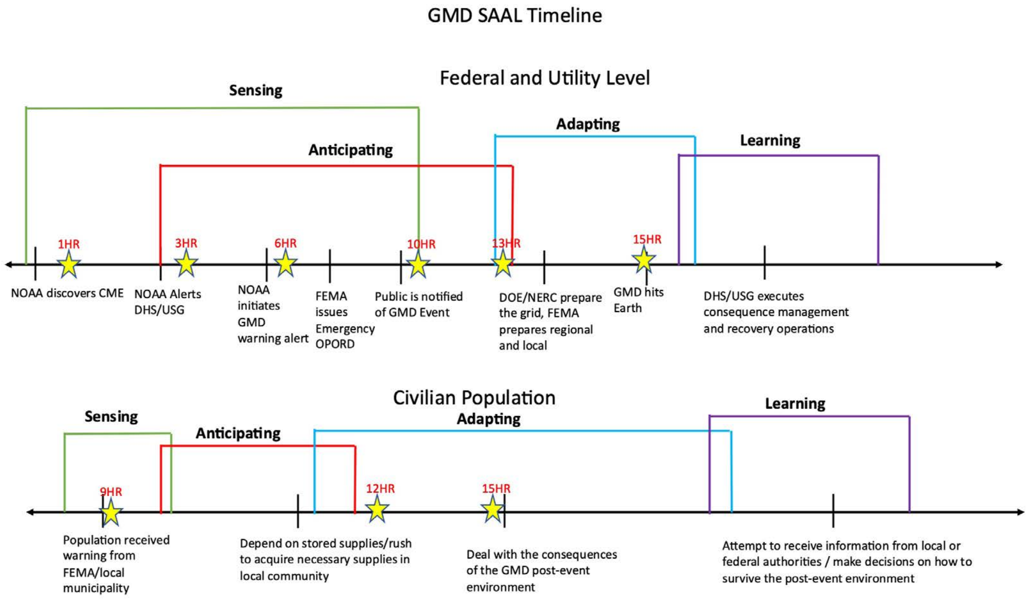

Figure 3: GMD SAAL Timeline

Woods' Resilience Concepts

Where Woods' concepts of resilience focus on outcomes, analyzing the thought experiments through this framework provides recommendations for protection and mitigation to EMP/GMD events. The pre-event recommendation is the development of hardened microgrid infrastructure that focus on robustness and sustained adaptability. The post-event recommendation involves black start recovery options that focus on rebound and graceful extensibility.

Hardened microgrids have the ability to operate off of the national grid but can also function in stand-alone island mode in order to support key infrastructure operations during an EMP/GMD event utilizing the concepts of robustness and sustained adaptability. Various microgrid systems, hardened to the MIL-STD-188-125-1 standard, provide policy makers and utility operators additional flexibility and resilience to maintain power to large geographic areas even when the electrical grid is disabled during an EMP/GMD event. Microgrids are a key strategy to mitigate the cascading and interconnected nature of both critical infrastructure systems and modern society by providing a means for communities or customers to "come off" the grid and sustain power through adverse conditions.

Modern microgrids are being constructed for three main purposes throughout the world; energy security, economic benefits, and clean energy.[56] However, the main reason for microgrid investment in the United States is added resilience and reliability of the electrical grid.[57] In an EMP/GMD scenario, massive regional power outages are to be expected which have serious implications to both other critical systems and the civilian population. However, hardened microgrid systems, capable of operating from battery or renewable energy sources independent of the national grid, helps to safeguard systems in withstanding stressful events, adapt to new circumstances, and extend their intended purpose to provide added resilience.In addition to these advantages, microgrid concepts could potentially mitigate the ever-present vulnerability of powerlines being destroyed by natural disasters by having the ability to operate without being dependent on regional or local utilities.[58]

Microgrid systems are not without challenges or controversy as these systems have specific issues that need to be addressed in order for regional or national solutions to be achieved. Microgrids are considered a grey area when it comes to legal and regulatory oversight as private citizens could make microgrids that are potentially incompatible with national grid system integration.[59] It is unknown if microgrids would be regulated by state or federal regulatory oversight as some systems could be operated or installed in an unsafe manner by commercial companies or individuals. To be most effective, microgrids need to be produced and regulated by national standards as the interconnection to the national grid could be problematic if regulations were not strictly enforced.[60] Regional interconnection utilities and federal laws would need to determine who could operate a microgrid and set specific standards as to how and when they can disconnect from the national grid and operate in island mode. It is also unrealistic for every single microgrid system to be hardened to the MIL-STD-188-125-1 standard as it is expensive and resource intensive. However, key strategic microgrid hubs that sustain critical infrastructure systems or large populations could be sufficiently hardened in order to provide resilience during EMP/GMD events.

Black start recovery options include a large system of interconnected units that can potentially re-energize the grid if a widespread power outage occurs in the United States.[61] These options are designed to respond to black sky events, which

56 Adam Hirsch, Yael Parag, and Josep Guerrero, "Microgrids: A Review of Technologies, Key Drivers, and Outstanding Issues," *Renewable & Sustainable Energy Reviews* 90 (2018): 404, https://doi.org/10.1016/j.rser.2018.03.040.

57 Hirsch, Parag, and Guerrero, 404.

58 Mishra et al., "Microgrid Resilience," 3.

59 Hirsch, Parag, and Guerrero, "Microgrids," 407.

60 Hirsch, Parag, and Guerrero, 409.

61 Sherrell R. Greene, "Nuclear Power: Black Sky Liability or Black Sky Asset?," *International Journal of Nuclear Security* 2, no. 3 (December 1, 2016): 9, https://doi.org/10.7290/V78913SR.

are defined as "outages that would span very large regions, and utilities could require weeks or months to restore power to even the highest priority customers."[62] Black start options are powered by "Black Start Units that are power generation assets that can be used independent of the national grid such as hydroelectric dams, gas turbines, or oil fired units."[63] Various black start units are coupled and wired to strategically located load centers that power local "islands" throughout the grid and can be choreographed to power larger parts and eventually bring the national grid back online.[64] Currently, most power production facilities, including nuclear reactors, are not constructed to withstand the effects of EMP/GMD events.[65] In order to utilize black start options for EMP/GMD events, the units need to be sufficiently hardened in order provide a reliable source of power. To provide adequate protection and shielding against EMP/GMD events, the U.S. military standard of MIL-STD-188-125-1 would need to be utilized. This standard requires that key facilities extensively test and provide shielding of 80 on an attenuation scale that amounts to 80mm of concrete or steel protection that includes specialized doors, grounding procedures, and enough backup power for up to 30 days of operation.[66] While the cost of hardening these facilities would have huge economic and financial requirements, such measures would ensure that the electrical grid could provide a source of rebound and extensibility for EMP/GMD events.

While there are numerous ways to initiate black start options to include fossil fuel locations such as gas turbine plants, hydroelectric dams may be the best option in a post EMP/GMD environment as the ability to produce power and water will remain intact as long as the facility is hardened as per MIL-STD-188-125-1.[67] Hydroelectric dams are generally thought of as among the Department of Energy's most reliable black start options as there is usually always enough water to activate the turbines to begin black start operations and hydroelectric dams require minimal amounts of power to operate as cooling and fuel storage is not required.[68] As

62 Greene, 5.

63 Greene, 9.

64 Mishra et al., "Microgrid Resilience," 2.

65 James Conca, "Can Nuclear Power Plants Resist Attacks Of Electromagnetic Pulse (EMP)?," Forbes, accessed November 1, 2021, https://www.forbes.com/sites/jamesconca/2019/01/03/can-nuclear-power-plants-resist-attacks-of-electromagnetic-pulse-emp/.

66 National Cybersecurity and Communications Integration Center, "Electromagnetic Pulse (EMP) Protection and Resilience Guidelines for Critical Infrastructure and Equipment," Version 2.2 – 5 February 2019 (Arlington, Virginia: National Coordinating Center for Communications, February 5, 2019), 1, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fwww.cisa.gov%2Fsites%2Fdefault%2Ffiles%2Fpublications%2F19_0307_CISA_EMP-Protection-Resilience-Guidelines.pdf&clen=7010467&chunk=true.

67 Jose R. Garcia et al., *Hydropower Plants as Black Start Resources*, ORNL/SPR2018/1077 (Oak Ridge National Labs, TN: Department of Energy, 2019), iii, https://www.energy.gov/sites/prod/files/2019/05/f62/Hydro-Black-Start_May2019.pdf.

68 Garcia et al., iv.

long as these assets are protected from the effects of EMP/GMD events, they can serve as reliable assets for getting the national grid back online.

A second, and more risky, black start option is using nuclear reactors which typically have up to a year of fuel, which surpasses most fossil fuel reserves.[69] There are a variety of dangers that occur when nuclear power plants are forced to come off the national grid after an EMP/GMD event, including nuclear meltdowns. However, various contingencies such as robust back-up power supply systems and extensive damage mitigation guidelines, developed with decades of experience from the nuclear industry and Nuclear Regulatory Council, provide some safeguards.[70] This, along with hardening techniques, could make nuclear power plants a robust black start option. Nuclear power plants in the United States are required to comply with the Nuclear Regulatory Commission's Flexible Coping Strategies (FLEX) program, which states that nuclear power plants will have large-scale diesel generators with large-scale fuel capacity.[71] The FLEX program has taken several lessons learned from the Fukushima meltdown incident and mandated that nuclear power facilities in the United States implement steps to deal with a variety of external threats, especially the loss of offsite power.[72] For example, Browns Ferry Nuclear Power Plant alone has over 282,240 gallons of diesel fuel, and diesel generators at nuclear power facilities are in enclosed underground concrete structures, providing them some protection against electromagnetic events, but they would still need to be sufficiently hardened.[73] The FLEX program was not created specifically for EMP/GMD events but could extend power to the grid as a long-term option. Depending timing and how robust the movement to deploy small modular reactors (SMRs) is, these units, if EMP hardened, have great potential to serve as black start resources.[74]

Black start frameworks can provide policy makers and private sector leaders a strategy that would provide added resilience in a variety of contingencies, not just EMP/GMD events. Coordination between the DOE and utility companies may be the only way to provide for a stable national grid system in a post EMP/GMD environment. Black start options are the only known way to re-start the grid after it experiences a catastrophic failure. Initially, black start options could be used to provide power to regional areas but could then be used to transport power to other effected areas as most grid interconnections would still be intact. Utilizing Woods' concepts of robustness and graceful extensibility, EMP/GMD hardened black start options would be a key strategy for recovering from EMP/GMD events.

69 Greene, "Nuclear Power," 16.

70 Greene, 15.

71 Greene, 14.

72 Greene, 13.

73 Greene, 14.

74 Sherrell R. Greene, "How Nuclear Power Can Transform Electric Grid and Critical Infrastructure Resilience," *Journal of Critical Infrastructure Policy*, Fall/Winter 2020.

Conclusion

The results and analysis of both thought experiments prescribed significantly higher levels of preparedness at regional and local levels and the implementation of new and existing technology to add resilience to America's electrical infrastructure. As seen in the thought experiments, the loss of the electrical grid has significant cascading effects on other critical infrastructure sectors and the civilian population. Even as these events are very rare, they have the potential to produce detrimental effects to modern society by disabling vital everyday services that we all take for granted. Recent natural disasters such as Hurricane Ida and the 2021 Texas winter power outages have had adverse impacts on the population and should lower our confidence in our critical infrastructure systems, especially when dealing with events we are truly unprepared for. EMP/GMD events could make entire regions lose the ability to produce power and provide medical assistance, and could impede food/water production, putting enormous stress on the all levels of government.

As technology has rapidly advanced, modern society has become more reliant on the services it provides for almost every aspect of modern life. The more dependent society becomes on technology, the more vulnerable we are to a fundamental surprise when the electrical grid fails to operate reliably. There is little doubt that technology has transformed most modern countries into a reality were almost anything can be found or delivered via the internet or some other form of wireless communication device. Huge parts of our critical infrastructure systems are tied into wireless internet systems and are at risk of not just cyber-attacks, but also electromagnetic events. This article does not argue that we must abandon humanity's quest for more technology; it argues that we must have systems in place in case a long-term power outage event occurs because of an electromagnetic event and that a foundation of preparedness at the lowest level will be advantageous to the recovery effort.

Despite well-studied and known vulnerabilities of some systems to EMP/GMD events, we were able to use thought experiments to identify certain decision-making factors that influence national resilience. By analyzing how EMP and GMD events occur and how we are likely to respond, recommendations were made in order to mitigate the effects of these events. Utilizing the SAAL and Woods' frameworks, we found that through a combination of policy changes, such as focusing preparedness at local levels and better communication between the DOD and DHS, together with technological innovations such as hardened microgrids and black start options, there are ways to mitigate the threat of EMP/GMD events.

Acronyms and Abbreviations

CME	Coronal Mass Ejection
DOD	Department of Defense
DOE	Department of Energy
EMP	Electromagnetic Pulse
FLEX	Regulatory Commission's Flexible Coping Strategies
GIC	Geomagnetically Induced Current
GMD	Geomagnetic Disturbance
NOAA	National Oceanic and Atmospheric Administration
SMR	Small Modular Reactor
SWPC	Space Weather Prediction Center

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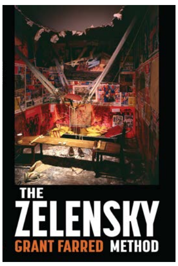

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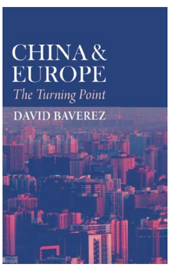
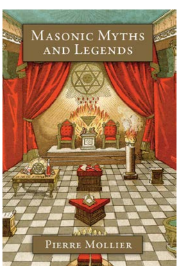
by Grant Farred

Locating Russian's war within a global context, The Zelensky Method is unsparing in its critique of those nations, who have refused to condemn Russia's invasion and are doing everything they can to prevent economic sanctions from being imposed on the Kremlin.



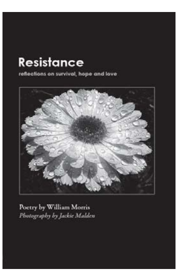
China & Europe: The Turning Point
by David Baverez

In creating five fictitious conversations between Xi Jinping and five European experts, David Baverez, who lives and works in Hong Kong, offers up a totally new vision of the relationship between China and Europe.



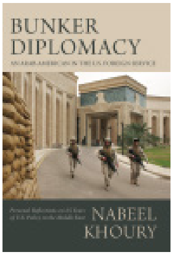
Masonic Myths and Legends
by Pierre Mollier

Freemasonry is one of the few organizations whose teaching method is still based on symbols. It presents these symbols by inserting them into legends that are told to its members in initiation ceremonies. But its history itself has also given rise to a whole mythology.



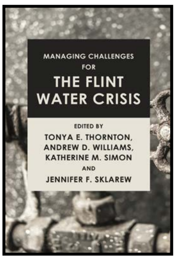
Resistance: Reflections on Survival, Hope and Love
Poetry by William Morris, Photography by Jackie Malden

Resistance is a book of poems with photographs or a book of photographs with poems depending on your perspective. The book is comprised of three sections titled respectively: On Survival, On Hope, and On Love.



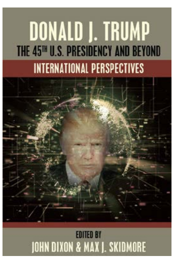
Bunker Diplomacy: An Arab-American in the U.S. Foreign Service
by Nabeel Khoury

After twenty-five years in the Foreign Service, Dr. Nabeel A. Khoury retired from the U.S. Department of State in 2013 with the rank of Minister Counselor. In his last overseas posting, Khoury served as deputy chief of mission at the U.S. embassy in Yemen (2004-2007).



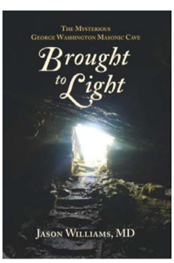
Managing Challenges for the Flint Water Crisis
Edited by Toyna E. Thornton, Andrew D. Williams, Katherine M. Simon, Jennifer F. Sklarew

This edited volume examines several public management and intergovernmental failures, with particular attention on social, political, and financial impacts. Understanding disaster meaning, even causality, is essential to the problem-solving process.



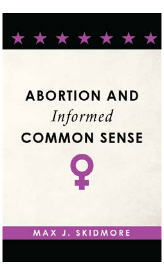
Donald J. Trump, The 45th U.S. Presidency and Beyond International Perspectives
Editors: John Dixon and Max J. Skidmore

The reality is that throughout Trump's presidency, there was a clearly perceptible decline of his—and America's—global standing, which accelerated as an upshot of his mishandling of both the Corvid-19 pandemic and his 2020 presidential election loss.



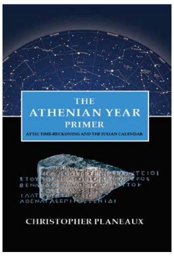
Brought to Light: The Mysterious George Washington Masonic Cave
by Jason Williams, MD

The George Washington Masonic Cave near Charles Town, West Virginia, contains a signature carving of George Washington dated 1748. Although this inscription appears authentic, it has yet to be verified by historical accounts or scientific inquiry.



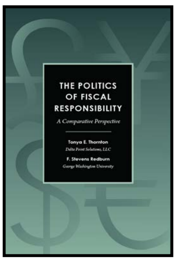
Abortion and Informed Common Sense
by Max J. Skidmore

The controversy over a woman's "right to choose," as opposed to the numerous "rights" that abortion opponents decide should be assumed to exist for "unborn children," has always struck me as incomplete. Two missing elements of the argument seems obvious, yet they remain almost completely overlooked.



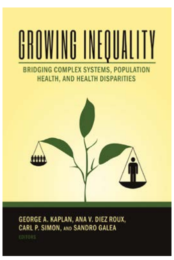
The Athenian Year Primer: Attic Time-Reckoning and the Julian Calendar
by Christopher Planeaux

The ability to translate ancient Athenian calendar references into precise Julian-Gregorian dates will not only assist Ancient Historians and Classicists to date numerous historical events with much greater accuracy but also aid epigraphists in the restorations of numerous Attic inscriptions.



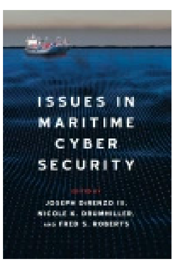
The Politics of Fiscal Responsibility: A Comparative Perspective
by Tonya E. Thornton and F. Stevens Redburn

Fiscal policy challenges following the Great Recession forced members of the Organisation for Economic Co-operation and Development (OECD) to implement a set of economic policies to manage public debt.



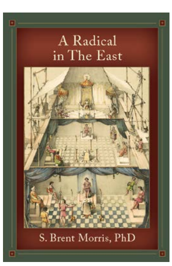
Growing Inequality: Bridging Complex Systems, Population Health, and Health Disparities
Editors: George A. Kaplan, Ana V. Diez Roux, Carl P. Simon, and Sandro Galea

Why is America's health is poorer than the health of other wealthy countries and why health inequities persist despite our efforts? In this book, researchers report on groundbreaking insights to simulate how these determinants come together to produce levels of population health and disparities and test new solutions.



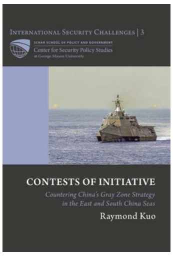
Issues in Maritime Cyber Security
Edited by Dr. Joe DiRenzo III, Dr. Nicole K. Drumhiller, and Dr. Fred S. Roberts

The complexity of making MTS safe from cyber attack is daunting and the need for all stakeholders in both government (at all levels) and private industry to be involved in cyber security is more significant than ever as the use of the MTS continues to grow.



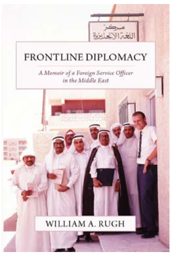
A Radical In The East
by S. Brent Morris, PhD

The papers presented here represent over twenty-five years of publications by S. Brent Morris. They explore his many questions about Freemasonry, usually dealing with origins of the Craft. A complex organization with a lengthy pedigree like Freemasonry has many basic foundational questions waiting to be answered, and that's what this book does: answers questions.



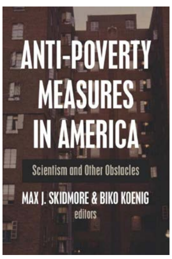
Contests of Initiative: Countering China's Gray Zone Strategy in the East and South China Seas
by Dr. Raymond Kuo

China is engaged in a widespread assertion of sovereignty in the South and East China Seas. It employs a "gray zone" strategy: using coercive but sub-conventional military power to drive off challengers and prevent escalation, while simultaneously seizing territory and asserting maritime control.



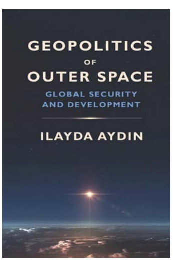
Frontline Diplomacy: A Memoir of a Foreign Service Officer in the Middle East
by William A. Rugh

In short vignettes, this book describes how American diplomats working in the Middle East dealt with a variety of challenges over the last decades of the 20th century. Each of the vignettes concludes with an insight about diplomatic practice derived from the experience.



Anti-Poverty Measures in America: Scientism and Other Obstacles
Editors, Max J. Skidmore and Biko Koenig

Anti-Poverty Measures in America brings together a remarkable collection of essays dealing with the inhibiting effects of scientism, an over-dependence on scientific methodology that is prevalent in the social sciences, and other obstacles to anti-poverty legislation.



Geopolitics of Outer Space: Global Security and Development
by Ilayda Aydin

A desire for increased security and rapid development is driving nation-states to engage in an intensifying competition for the unique assets of space. This book analyses the Chinese-American space discourse from the lenses of international relations theory, history and political psychology to explore these questions.