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Written Testimony Submitted to the U.S. Senate Committee on the Budget
Hearing: *Beyond the Breaking Point: The Fiscal Consequences of Climate Change on Infrastructure*, entitled:

Fiscal and Economic Implications of Climate Change on Infrastructure Systems in the United States

Wednesday, July 26, 2023 / 9:30 a.m. / Room SD-608
Dirksen Senate Office Building
Washington, D.C.

I. <u>Introduction</u>

Chairman Whitehouse, Ranking Member Grassley, and Members of the Committee: Thank you for the invitation to testify on the nature of climate impacts on domestic infrastructure. My name is Jesse Keenan and I am the Favrot II Associate Professor of Sustainable Real Estate and Urban Planning and affiliate Professor of Law at Tulane University. I also maintain a visiting appointment in sustainable finance at Oxford University. My research focuses on how climate change shapes the design, management, and financing of buildings and infrastructure systems.

In my remarks today, I would like to focus on a brief survey of the mechanics of how climate-attributed physical impacts impose increasingly burdensome financial, capital and operational costs that collectively impair our capacity to deliver and maintain infrastructure. According to the most recent accounting by the American Society of Civil Engineers (ASCE), the United States faces a $2.6 trillion funding gap across all infrastructure sectors through the balance of this decade.[1] This funding gap is projected to grow by tens of billions of dollars each year due to climate change.

As now universally defined by G20 central banks and prudential oversight bodies, including the Board of Governors of the Federal Reserve,[2] I am limiting my remarks here today to *physical risk* and not transition risk to climate change.[3]

II. <u>The Direct Costs of Climate Impacts on Infrastructure</u>

The failure or degradation of interconnected infrastructural systems provides an array of transmission mechanisms for a variety of economic and financial costs. These are not just abstract macroeconomic long-term projections. These are costs paid for by taxpayers, consumers, ratepayers, and a broad array of market stakeholders. While our understanding of a range of impacts and costs across various infrastructural sectors is an active area of inquiry, it is instructive to highlight a few infrastructure sectors that are central to the social and economic welfare of this country, including the energy, transportation and water and wastewater sectors.

In the domestic electric power sector, various research has estimated that electricity demand will increase somewhere between 2% and 4% by the middle of the century. As such, the United States is facing increased production costs in the order of $50 billion a year going into the year 2050.[4] This is *roughly* equal to an unamortized and undiscounted per capita annual cost of $155, which

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[1] American Society of Civil Engineers (ASCE)(2021). Assessing America's Infrastructure Gap. In *2021 Report Card for America's Infrastructure*. Reston, VA.: American Society of Civil Engineers.

[2] Board of Governors of the Federal Reserve (2023, January). *Pilot Climate Scenario Analysis Exercise: Participant Instructions*. Washington, D.C.: Federal Reserve. Retrieved from https://www.federalreserve.gov/publications/files/csa-instructions-20230117.pdf

[3] Note: The pure distinction between physical risk and transition risk is not always so clear, as there are many points of convergence. *See*, Keenan, J. M., Trump, B. D., Hynes, W., & Linkov, I. (2021). Exploring the convergence of resilience processes and sustainable outcomes in post-covid, post-Glasgow economies. *Sustainability*, 13(23), 13415.

[4] Jaglom, W. S., McFarland, J. R., Colley, M. F., Mack, C. B., Venkatesh, B., Miller, R. L., & Kayin, S. (2014). Assessment of projected temperature impacts from climate change on the US electric power sector using the Integrated Planning Model®. *Energy Policy*, 73, 524-539.

for an average household of 2.5 persons is approximately equal to one or more months' worth of summer electricity bills at current rates.[5] As demand increases for electricity, so will the costs. While the heating and mostly cooling of buildings is a major demand factor, climate change will also increase electricity demand for vehicle charging, wastewater recycling, pumping drinking water farther distances, water desalinization, increased agricultural irrigation, and even water heating, as people tend to take more showers on hot days.[6] Additional unanticipated post-disaster recovery costs from extreme events for everything from hurricanes to wildfires are among a wide range of direct costs that will continue to be passed-on to utility ratepayers.[7]

Luckily for ratepayers, electricity retail rate projections by researchers at the U.S. Department of Energy suggest that some of these increased costs could be partially offset by decreases in fuel costs stemming from the current renewable energy transition currently well underway in the United States.[8] However, local and regional climate impacts, adaptation costs, and corresponding supply and demand imbalances are likely to continue to impose rate shocks and increase cost-burdens on ratepayers for the foreseeable future.

Researchers have begun early-stage research estimating internal climate migration in the United States and the extent to which the movement of people and industries to more moderate and lower-risk areas of the country will create supply and demand imbalances in civil infrastructure systems.[9] Domestic climate migration is currently well underway. For instance, assuming that just a quarter (1/4th) of natural disasters causing household displacement have some attribution to climate change, then the rate of annual climate displacement as percentage of the total population is comparable to the rate of displacement during the Dust Bowl from 1930 to 1940.[10] From 2023 to 2030, this cumulative climate displacement is projected to exceed an equivalent population of

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[5] Note: This is a quick back-of-the-envelope calculation intended to provide a sense of scale and should not be relied upon in lieu of a more rigorous analysis.

[6] Viguié, V., Juhel, S., Ben-Ari, T., Colombert, M., Ford, J. D., Giraudet, L. G., & Reckien, D. (2021). When adaptation increases energy demand: A systematic map of the literature. *Environmental Research Letters*, 16(3), 033004.

[7] Fant, C., Boehlert, B., Strzepek, K., Larsen, P., White, A., Gulati, S., & Martinich, J. (2020). Climate change impacts and costs to US electricity transmission and distribution infrastructure. *Energy*, 195, 116899; Voisin, N., Dyreson, A., Fu, T., O'Connell, M., Turner, S. W., Zhou, T., & Macknick, J. (2020). Impact of climate change on water availability and its propagation through the Western US power grid. *Applied Energy*, 276, 115467.

[8] Brown, P. R., Gagnon, P. J., Corcoran, J. S., & Cole, W. J. (2022). *Retail Rate Projections for Long-Term Electricity System Models* (No. NREL/TP-6A20-78224). Golden, CO.: National Renewable Energy Lab (NREL), U.S. Department of Energy.

[9] Maxim, A., & Grubert, E. (2021). Effects of climate migration on town-to-city transitions in the United States: proactive investments in civil infrastructure for resilience and sustainability. *Environmental Research: Infrastructure and Sustainability*, 1(3), 031001.

[10] Note: This is based on the author's calculations for a forthcoming publication. From 1930-1940, the domestic population displacement stemming from the Dust Bowl averaged about .2% of the total U.S. population a year. In 2023, the U.S. Census Bureau estimated that approximately 1% of the U.S. population was displaced in the past year due to natural disasters. We do not know the precise quantification between climate-attributed events and displaced households; *see generally,* U.S. Census Bureau (2023). *Natural Disaster Table 1. Displacement From Home Because of Natural Disaster, by Select Characteristics: United States.* In Week 53 Household Pulse Survey: January 4 - January 16. Washington, D.C.: U.S. Census Bureau; World Meteorological Association (WMO)(2021). *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019)*. Technical Report No. 1267. Geneva, C.H.: World Meteorological Association; Long, J., & Siu, H. (2018). Refugees from dust and shrinking land: Tracking the dust bowl migrants. *The Journal of Economic History*, 78(4), 1001-1033.

those displaced during the Dust Bowl.[11] The combination of fiscal shocks and outmigration of local ratepayers and taxpayers is a substantive concern for jurisdictions who struggle to stabilize populations following disasters. For instance, as a resident of New Orleans, my electric utility only a few years ago removed a billed surcharge for post-Hurricane Katrina reconstruction—13 years after-the-fact.[12]

In the transportation sector, physical impacts have been widely observed for everything from extreme heat waves to flood events compromising roads, tarmacs, pipelines and rail lines, with direct repair and delay costs being felt throughout the economy.[13] Annual direct damage costs for road and rail impacts alone are estimated to be just under $20 billion[14] a year by 2050 under an RCP 4.5 scenario, [15] with approximately $1.5 billion just in direct costs for bridges.[16] Under the same scenario, increased O&M expenses for the paving and resurfacing of roads is estimated to be approximately $19 billion[17] a year by the end of *this* decade.[18] None of these cost estimates and projections account for the indirect costs to consumers and market participants for increased logistical costs, fuel costs, delay costs and lost economic output.[19] For instance, when the water is too high or too low in the Mississippi River, boat traffic delays have ripple effects in domestic and international food and grain markets.[20]

For taxpayers, the economic consequences of climate impacts are particularly palpable when there is convergent vulnerability in infrastructure systems and economic markets. For instance, the interconnected vulnerabilities in flood protection, water, and transportation systems were highlighted by the Florida landfall of Hurricane Ian last fall. At the epicenter of the landfall in Lee County, direct infrastructure repair cost estimates now exceed $320 million, with another $288 million required for future hazard mitigation.[21] While these infrastructure costs equal approximately $771 for every resident in the county, it is the federal government who is

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[11] Id.

[12] Entergy (2018). *Entergy Louisiana's Katrina and Rita Restoration Costs Are Paid in Full*. Retrieved from https://www.entergynewsroom.com/news/entergy-louisianakatrina-rita-restoration-costs-are-paid-full/

[13] Markolf, S. A., Hoehne, C., Fraser, A., Chester, M. V., & Underwood, B. S. (2019). Transportation resilience to climate change and extreme weather events–Beyond risk and robustness. *Transport Policy*, 74, 174-186.

[14] Note: This is an undiscounted figure in 2018 dollars (USD).

[15] Neumann, J. E., Chinowsky, P., Helman, J., Black, M., Fant, C., Strzepek, K., & Martinich, J. (2021). Climate effects on US infrastructure: the economics of adaptation for rail, roads, and coastal development. *Climatic Change*, 167(3-4), 44.

[16] Martinich, J., & Crimmins, A. (2019). Climate damages and adaptation potential across diverse sectors of the United States. *Nature Climate Change*, 9(5), 397-404.

[17] Note: This is an undiscounted figure in 2016 dollars (USD).

[18] Underwood, B. S., Guido, Z., Gudipudi, P., & Feinberg, Y. (2017). Increased costs to U.S. pavement infrastructure from future temperature rise. *Nature Climate Change*, 7(10), 704-707.

[19] Note: For projected traffic delays from flooding, please *see*, U.S. Environmental Protection Agency (EPA)(2021). *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts*. EPA 430-R-21-003. Washington, D.C.: EPA; for disproportionate cost burden on mass transit riding cohorts, please *see*, Martello, M. V., Whittle, A. J., Keenan, J. M., & Salvucci, F. P. (2021). Evaluation of climate change resilience for Boston's rail rapid transit network. *Transportation Research Part D: Transport and Environment*, 97, 102908.

[20] Jacobs, J.M., Cattaneo, L., Chinowsky, Pl., Choate, A., DesRoches, S., Douglass, S., & Miller, R. (2018). Ch. 12: Transportation. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, Volume II. Washington, D.C.: U.S. Global Change Research Program, pp. 483–485.

[21] Lee County, Florida (2023, May). *Ian Progress Report*. Retrieved from https://ianprogress.leegov.com/pages/dashboards

disproportionately footing the bill for billion in grants and loans to expedite reconstruction of this infrastructure in Florida. Independent of the allocation of public resources, it is ultimately taxpayers and infrastructure consumers who will foot the bill for infrastructure recovery, risk mitigation, and climate adaptation.

It is not just the public sector that is feeling the financial pressure when extreme events exceed the thresholds of infrastructure performance. While the property and casualty market is widely recognized to be in a state of crisis in some high-impact states, there are other areas of the insurance market where there are signs of market dysfunction and/or failure. In part because of the billions in auto losses from last year's Hurricane Ian,[22] Florida is now the most expensive state in the country for full-coverage auto insurance at $3,183 a year—a full $1,169 above the national average.[23] Progressive Insurance, alone, had estimated auto losses in Florida of $574 million.[24] While there are non-climatic reasons for rapid premium inflation in the insurance industry across the United States and not every hurricane is attributable to climate change, climate impacts are widely viewed in the industry as a chronic stress driving premium inflation across multiple lines of insurance.[25] As such, the potential failures of flood control systems and other elements of protective infrastructure represent systemic risks to the economy.

Beyond insurance consumers, the economic impacts of climate on utilities, local governments and ultimately taxpayers in the water and wastewater sectors are estimated to be significant. Annualized urban drainage infrastructure damages are estimated to be approximately $4.3 billion a year by 2050 under RCP 4.5, with an additional $2 billion in costs associated with water quality and quantity impairments for existing municipal and industrial water supply systems.[26] However, this latter figure does not account for the untold cost of adaptations to addresses water scarcity challenges facing the western United States where reduced irrigation, additional groundwater mining, and increased reservoir storage capacity pose significant costs.[27] According to some estimates, the Southwestern U.S. faces upwards of $1.4 trillion in lost GDP between 2022 and 2050 due to the risks and costs of projected water scarcity challenges.[28]

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[22] Eaglesham, J. (2023, June 24th). Car Insurance Rates Are Soaring with Little Relief in Sight. *The Wall Street Journal*. Retrieved from https://www.wsj.com/articles/car-insurance-rates-are-soaring-with-little-relief-in-sight-66138e2a; Note: A lack of appropriate land use planning and infrastructure development to mitigate storm surge and stormwater is central to the geographic vulnerability and the spatial distribution of auto losses.

[23] Bankrate.com (2023, June). *Average Cost of Car Insurance in June 2023*. Retrieved from https://www.bankrate.com/insurance/car/average-cost-of-car-insurance/

[24] Progressive Casualty Insurance Company (2022, December 21st). *Progressive Announces Updated Loss Estimates from Hurricane Ian*. Retrieved from https://investors.progressive.com/financials/financial-news-releases/financial-news-release-details/2022/Progressive-Announces-Updated-Loss-EstimatesFrom-Hurricane-Ian/default.aspx

[25] Watkins, N. (2023, March 22nd) *Prepared Testimony of Nancy Watkins, FCAS, MAAA, Principal and Consulting Actuary, Milliman Inc*. Hearing on "Risky Business: How Climate Change is Changing Insurance Markets" United States Senate Committee on the Budget.

[26] Martinich, J., & Crimmins, A. (2019). Climate damages and adaptation potential across diverse sectors of the United States. *Nature Climate Change*, 9(5), 397-404.

[27] Brown, T. C., Mahat, V., & Ramirez, J. A. (2019). Adaptation to future water shortages in the United States caused by population growth and climate change. *Earth's Future*, 7(3), 219-234.

[28] GHD (2022). *Aquanomics: Southwestern U.S.: Home of the Megadrought*. Retrieved from https://aquanomics.ghd.com/en/swus.html

III. The Financial Costs of Climate on Infrastructure Management

As a general (but not universal) proposition, when we see a shift in the mean observations, for instance with temperatures or precipitation, there is also an observed flattening of the previously observed statistical distribution insofar as the variance in the distribution reflects a greater range for potential extreme events. In the parlance of finance and engineering, we associate this with the greater likelihood of "fat tail" events. In other words, a small shift in mean observations often corresponds with a greater likelihood of extreme events. For instance, the return period for storm surge on the scale of Hurricane Sandy in New York City, which caused billions in infrastructure damages, was approximately a 1:1,200 year event in the preindustrial period and is projected, in the face of climate change, to be somewhere between a 1:23 and 1:93 year event by 2100.[29]

Why is this relevant to our proceedings? A greater likelihood of extreme climate events means a greater measure of financial risk for infrastructure investors and owners, including the federal government. Market participants and engineers utilize our statistical understanding of observed and projected distributions in designing infrastructure systems and managing risk.[30] An investor has to evaluate a range of contingencies in the performance of an investment that could shape their internal rate of return and their return on equity over a relevant hold period. Climate analytics play an increasingly important role in evaluating a potential risk and return frontier from which expected values for any investment portfolio—including infrastructure investments—may manifest.

As a general proposition for investors, when there are greater risks, there must be a corresponding increase in financial returns. In the context of growing physical risks from climate change, this plays out in the notion of what we call a 'climate premium' in debt and equity markets. Investors simply demand a higher return to offset a risk. Although this research is at a very early-stage of development, we see climate premia being observed in real estate and mortgage markets,[31] non-U.S. sovereign bond markets,[32] financial derivative markets,[33] and corporate equity and bond markets.[34] It should be noted that a variety of factors—including everything from uneven corporate disclosures to the uneven quality of climate services technologies—have clouded consistent

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[29] Lin, N., Kopp, R. E., Horton, B. P., & Donnelly, J. P. (2016). Hurricane Sandy's flood frequency increasing from year 1800 to 2100. *Proceedings of the National Academy of Sciences*, 113(43), 12071-12075.

[30] Chester, M. V., Underwood, B. S., & Samaras, C. (2020). Keeping infrastructure reliable under climate uncertainty. *Nature Climate Change*, 10(6), 488-490.

[31] Nguyen, D. D., Ongena, S., Qi, S., & Sila, V. (2022). Climate change risk and the cost of mortgage credit. *Review of Finance*, 26(6), 1509-1549; Baldauf, M., Garlappi, L., & Yannelis, C. (2020). Does climate change affect real estate prices? Only if you believe in it. *The Review of Financial Studies*, 33(3), 1256-1295; Bernstein, A., Gustafson, M. T., & Lewis, R. (2019). Disaster on the horizon: The price effect of sea level rise. *Journal of Financial Economics*, 134(2), 253-272.

[32] Beirne, J., Renzhi, N., & Volz, U. (2021). Bracing for the typhoon: Climate change and sovereign risk in Southeast Asia. *Sustainable Development*, 29(3), 537-551; Beirne, J., Renzhi, N., & Volz, U. (2021). Feeling the heat: Climate risks and the cost of sovereign borrowing. *International Review of Economics & Finance*, 76, 920-936.

[33] Schlenker, W., & Taylor, C. A. (2021). Market expectations of a warming climate. *Journal of Financial Economics*, 142(2), 627-640.

[34] Huynh, T. D., & Xia, Y. (2021). Panic selling when disaster strikes: Evidence in the bond and stock markets. *Management Science*. doi: 10.1287/mnsc.2021.4018; Huynh, T. D., & Xia, Y. (2021). Climate change news risk and corporate bond returns. *Journal of Financial and Quantitative Analysis*, 56(6), 1985-2009.

empirical research in understanding emergent investor behavior in pricing physical risk in equity markets.[35] But, what we do know is that markets are getting more efficient and effective at pricing climate change signals and events across a variety of asset classes.

As a result, infrastructure is getting more expensive because the municipal bond market is beginning to price climate risk. In a recent peer-reviewed journal article in the *Journal of Financial Economics*, we see for the first that time that jurisdictions with greater levels of physical risk are paying higher prices for the cost of their municipal bonds.[36] More precisely, this research observed a 23 basis point increase in annualized cost for every 1% increase in measured physical risk. Within the context of an average bond issuance of $27.5 million, this means that local governments with a modest level of risk would be paying an increased annual cost of $64,350. While this figure may not sound cost-prohibitive, it is widely estimated by market participants to increase with time as municipal bond disclosures increasingly incorporate physical risk considerations at the behest of credit rating agencies and institutional investors. There are two implications here. First, higher-risk jurisdictions and/or infrastructure projects will have a higher weighted average cost of capital (WACC), and, second, lower-risk projects and/or jurisdictions who take steps to mitigate and adapt to climate change may very well have a lower WACC, as has been recently observed.[37]

This raises the fundamental question: what are investors and credit rating agencies really worried about? When local governments and infrastructure providers issue general obligation bonds, investors are concerned that a degraded tax and rate base may impact the fiscal stability of the issuer over the term of bond.[38] For example, Paradise, California has been teetering on default of its bond obligations after a wildfire destroyed most of the town and its infrastructure.[39] Default risk is amplified for revenue bonds, which are bonds that are paid-off by revenue from particular projects.[40] For instance, if a toll road is washed-out in a climate-attributed event (or any natural hazard event), then the payment of the bond may be compromised for as long as the tolls are not being paid. Recent research has highlighted that after disasters, local governments are more likely to issue revenue bonds and that these post-disaster issuances are paying higher comparative yields.[41]

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[35] Venturini, A. (2022). Climate change, risk factors and stock returns: A review of the literature. *International Review of Financial Analysis*, 79, 101934.

[36] Painter, M. (2020). An inconvenient cost: The effects of climate change on municipal bonds. *Journal of Financial Economics*, 135(2), 468-482; see also, Auh, J. K., Choi, J., Deryugina, T., & Park, T. (2022). *Natural disasters and municipal bonds* (No. w30280). Cambridge, MA.: National Bureau of Economic Research. DOI: 10.3386/w30280.

[37] Karpf, A., & Mandel, A. (2018). The changing value of the 'green' label on the US municipal bond market. *Nature Climate Change*, 8(2), 161-165; Note: However, recent research has revealed that positive benefits to yields may arise in the secondary market and not at the time of issuance; Partridge, C., & Medda, F. R. (2020). The evolution of pricing performance of green municipal bonds. *Journal of Sustainable Finance & Investment*, 10(1), 44-64.

[38] Shi, L., & Varuzzo, A. M. (2020). Surging seas, rising fiscal stress: Exploring municipal fiscal vulnerability to climate change. *Cities*, 100, 102658.

[39] Moody's Investor Service (2022, April 21st). *U.S. Municipal Bond Defaults and Recoveries, 1970-2021.*

[40] Revenue bonds that support public-private partnerships in infrastructure development often shift disaster-related risks to the public entity as a backstop. In addition, any kind of disruption in project-based revenue may also delay revenue sharing trigger events that provide a cash-flow upside to public entity partners.

[41] Yu, J., & Zhang, Z. (2023). Local Debt Financing in the Shadow of Storms: Disrupted and Destructed?. *Public Performance & Management Review*, 1-28. DOI: 10.1080/15309576.2023.2192943

Additional concerns for both investors and operators of infrastructure relate to the increased direct costs of climate impacts. As referenced herein, the borrowing costs have been observed to be increasing in response to physical risk and this increases the overall capital costs. Increases in capital costs may also be attributed to increased construction costs for incorporating engineering resilience and designed adaptive capacity within particular assets.[42] For instance, a flood mitigation system may have to build a higher levee with greater pumping capacity to accommodate future projected precipitation, storm surge, and sea-level rise design standards.[43] Unfortunately, there is no definitive cost estimate research for these incremental costs across infrastructure sectors and asset classes.

Beyond incremental capital and construction costs, operations and maintenance (O&M) costs from climate impacts are perhaps one of the most immediate cost-burdens for infrastructure providers today. Even without climate impacts, infrastructure is very expensive to maintain with any given system requiring annual O&M costs equal to anywhere between 1% and 10% of first costs. Additional costs for things like repeated road resurfacing for areas that face more ice than snow now with warming winters[44] or greater energy costs for pumping more stormwater[45] are all drags on the financial balance sheets of infrastructure providers, particularly in the context where many ratepayers are often already increasingly cost-burdened.[46]

Unfortunately, the United States. has a limited amount of convergent research and practice in the utilization of lifecycle cost accounting models to anticipate the total infrastructure costs over the lifetime of an asset impaired by the shocks and stresses of climate impacts.[47] To compound this problem, the United States is grossly behind in the codification of climate-sensitive design and engineering standards that ensure reliability, security, and maximal economic benefit.[48]

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[42] Keenan, J. M., Chu, E., & Peterson, J. (2019). From funding to financing: perspectives shaping a research agenda for investment in urban climate adaptation. *International Journal of Urban Sustainable Development*, 11(3), 297-308.

[43] See generally, New York City Mayor's Office of Climate & Environmental Justice (2022, May). *Climate Resiliency Design Guidelines*. Version 4.1. Retrieved from https://climate.cityofnewyork.us/wp-content/uploads/2022/10/CRDG-4-1-May-2022.pdf; U.S. General Services Administration (2022). *Facilities Standards for the Public Buildings Service* (P-100). Washington, D.C.: U.S. General Services Administration.

[44] Wang, T., Qu, Z., Yang, Z., Nichol, T., Clarke, G., & Ge, Y. E. (2020). Climate change research on transportation systems: Climate risks, adaptation and planning. *Transportation Research Part D: Transport and Environment*, 88, 102553.

[45] Gallo, E. M., Spahr, K., Grubert, E., & Hogue, T. S. (2022). Improving the Decision-Making Process for Stormwater Management Using Life-Cycle Costs and a Benefit Analysis. *Journal of Sustainable Water in the Built Environment*, 8(2), 04022001.

[46] Kontokosta, C. E., Reina, V. J., & Bonczak, B. (2020). Energy cost burdens for low-income and minority households: Evidence from energy benchmarking and audit data in five US cities. *Journal of the American Planning Association*, 86(1), 89-105; Cardoso, D. S., & Wichman, C. J. (2022). Water affordability in the United States. *Water Resources Research*, 58(12), e2022WR032206.

[47] Bastidas-Arteaga, E., & Stewart, M. G. (Eds.)(2019). *Climate Adaptation Engineering: Risks and Economics for Infrastructure Decision-Making*. Cambridge, MA.: Butterworth-Heinemann/Elsevier; Asghari, V., Hsu, S. C., & Wei, H. H. (2021). Expediting life cycle cost analysis of infrastructure assets under multiple uncertainties by deep neural networks. *Journal of Management in Engineering*, 37(6), 04021059; For a practical example, *see* Qiao, Y., Santos, J., Stoner, A. M., & Flinstch, G. (2020). Climate change impacts on asphalt road pavement construction and maintenance: An economic life cycle assessment of adaptation measures in the State of Virginia, United States. *Journal of Industrial Ecology*, 24(2), 342-355.

[48] Lopez-Cantu, T., & Samaras, C. (2018). Temporal and spatial evaluation of stormwater engineering standards reveals risks and priorities across the United States. *Environmental Research Letters*, 13(7), 074006; Underwood, B.

Collectively, these additional unanticipated O&M costs may steer money away from capital investment plans and they may exacerbate ongoing deferred maintenance challenges that not only threatened service reliability but may also reduce the overall useful life of an asset.[49]

As this country embarks on a new era of infrastructure investment, we have to ask ourselves some difficult questions as stewards of public and private infrastructure investments.

1. Are we designing today's infrastructure to handle tomorrow's environmental loads?
2. Are we designing today's infrastructure to handle tomorrow's demand?
3. In high-risk zones, where will be invest and where will we disinvest in infrastructure?
4. Who will pay for the increased costs to build and maintain infrastructure?
5. Are we accounting and budgeting for the anticipated increased capital costs and operational expenses?

Proper fiscal stewardship of infrastructure in the face of climate impacts requires stakeholders to work together to provide transparency and accountability. A failure to recognize and account for these costs will not only undermine the reliability of our infrastructure, it will also undermine our global economic competitiveness. Thank you for the opportunity to testify.

S., Mascaro, G., Chester, M. V., Fraser, A., Lopez-Cantu, T., & Samaras, C. (2020). Past and present design practices and uncertainty in climate projections are challenges for designing infrastructure to future conditions. *Journal of Infrastructure Systems*, 26(3), 04020026; Markolf, S. A., Chester, M. V., Helmrich, A. M., & Shannon, K. (2021). Re-imagining design storm criteria for the challenges of the 21st century. *Cities*, 109, 102981.

[49] Neumann, J. E., Chinowsky, P., Helman, J., Black, M., Fant, C., Strzepek, K., & Martinich, J. (2021). Climate effects on US infrastructure: the economics of adaptation for rail, roads, and coastal development. *Climatic Change*, 167(3-4), 44; Note: A reduction in the useful-life of an asset also represents a credit and/or capital risk to the extent that the asset may produce less revenue than was otherwise projected upon an initial underwriting. This is an analytical consideration today among credit rating agencies supporting the municipal bond market.