REGULATING TOWARD (IN)SECURITY IN THE U.S. ELECTRICITY SYSTEM

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PROLOGUE

When I was a kid we climbed radio towers. It was a low-cost, moderate-risk activity that seemed more interesting than whatever else was going on at the time. We would park off a highway, hop a fence if needed, and walk through pasture to get to a structure that was 200–400 feet high, and start climbing. Twenty-some years later, I have driven out of the city, parked the car, and have been walking through scattered woodland for about twenty minutes. The woods eventually break into a neatly mowed grass clearing that looks to be about 150 feet wide and travels to my right and left into the distance and out of sight. Interspersed throughout the clearing are familiar metal towers that look like an abstract set of open pliers, standing upright in the ground and connected by heavy hanging metal lines. This infrastructure represents the metaphorical backbone of our nation, and like the radio towers from my childhood, it is easy to access. Nothing works well without electricity, and without electricity transmission lines, everything sooner or later comes to a halt—hospitals, schools, the Internet, traffic lights.

INTRODUCTION

By design, the U.S. national electricity infrastructure stands without protection.[1] Nearly everywhere in the country, hop a fence (or not), walk a bit, and access is wide open. The leading threats to the grids[2] are not solely physical, as the twin specters of the grids infrastructure being hacked remotely or fried by an electromagnetic pulse event are recognized as being among the highest-level national security risks, well-documented by military and security analysts.[3] Nonetheless, each such

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[1] The electricity grids are not a master-designed system, their architecture evolved in response to then-applicable technological constraints applied to local needs and circumstances; however, uniform among those constraints is a need to disperse huge amounts of heat.

[2] The term "grids" rather than "grid" is used throughout as a conceptual reminder that the existing U.S. electrical systems are simply not monolithic. That there are three separate centralized grids in the U.S. is only the most obvious example that "grid" is an inapposite description. The distinction is meaningful because of the analytical tendency to find integrated system solutions when analyzing singular "things," a penchant of electricity regulatory thinking and commentary.

[3] *See, e.g.*, THE CENTER FOR THE STUDY OF THE PRESIDENCY AND CONGRESS, SECURING THE U.S. ELECTRICAL GRID 89 (2014), https://www.thepresidency.org/sites/default/files/Final%20Grid%20Report_0.pdf [hereinafter CSPC STUDY]; CNA MILITARY ADVISORY BOARD, NATIONAL SECURITY AND ASSURED U.S. ELECTRICAL POWER (2015), https://www.cna.org/CNA_files/PDF/National-Security-Assured-Electrical-Power.pdf, [hereinafter CNA STUDY]; U.S. DEP'T OF ENERGY AND ELEC. POWER RESEARCH INST., JOINT ELECTROMAGNETIC PULSE RESILIENCY STRATEGY (2016), http://www.energy.gov/sites/prod/files/2016/07/f33/DOE_EMPStrategy_July2016_0.pdf, [hereinafter, EMP STRATEGY]; TERRORISM AND THE ELECTRIC POWER DELIVERY SYSTEM, NAT'L RESEARCH COUNCIL (2012), http://sites.nationalacademies.org/cs/groups/depssite/documents/webpage/deps_073368.pdf [hereinafter RESEARCH COUNCIL TERRORISM STUDY]; BIPARTISAN POLICY CENTER, CYBERSECURITY AND THE NORTH AMERICAN ELECTRIC GRID: NEW POLICY APPROACHES TO

threat is fundamentally intertwined with the vulnerability of the physical architecture of the grids, an uneasy amalgam of a hundred year effort to manage disparate local and regional systems.[4] Efforts to "harden" select physical components of the grids in response to terrorism and other modern security threats are largely ineffectual. Such efforts are engulfed by an immense transmission[5] and distribution[6] infrastructure that is akin to a series of endless army supply convoys—long, thin, interdependent, and exceedingly difficult to protect.[7]

Despite obvious vulnerabilities, the electricity industry mainly fails[8] to evaluate[9] systemic security vulnerabilities in calculating the costs and benefits of alternate electrical grids design. As recently as, say 2010, such an omission may be forgivable,[10] as there were no economic alternatives

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ADDRESS AN EVOLVING THREAT (2014), http://bipartisanpolicy.org/wpcontent /uploads/sites/default/files/Cybersecurity%20Electric%20Grid%20BPC.pdf [hereinafter BiPC CyberSecurity].

[4] *See, e.g.*, William J. Hausman and John L. Neufeld, *How Politics, Economics, and Institutions Shaped Electric Utility Regulation in the United States, 1879–2009*, 53 BUS. HIST. 5, 723–46 (2011). Relational efforts to conceptually manage the complexity of the grids are ongoing. *See, e.g.*, THE FUTURE OF THE ELECTRIC GRID, AN INTERDISCIPLINARY MIT STUDY 39 (2011), https://energy.mit.edu/wp-content/uploads/2011/12/MITEI-The-Future-of-the-Electric-Grid.pdf*; accord* Masoud Amin and John Stringer, *Electric Power Grid: Today and Tomorrow*, 33 MRS BULLETIN 903 (2008), http://massoud-amin.umn.edu/publications/The_Grid_Amin_Stringer.pdf.

[5] Transmission is the business of shipping electricity from centralized power plants to population centers.

[6] Distribution is the business of local delivery of electricity.

[7] For a classic review of the fundamental logistical problem of protecting convoy columns *see generally* Dennis Hart Mahan, *An Elementary Treatise on Advanced-Guard, Out-Post, and a Detachment Service of Troops*, NEW ORLEANS, BLOOMFIELD & STEEL (2nd ed. 1847), https://archive.org/details/elementarytreati00maha. The rough analogy to the transmission infrastructure is simply intended to highlight the impossibility of efficiently guarding more than 450,000 miles of high(er)-voltage transmission lines, much of it located in areas that, in apparent contradiction, are both relatively remote and easily accessible.

[8] As discussed in Part III, this dynamic has been recently observed in rate cases in Arizona and Nevada.

[9] "Reliability" and "security" are frequently treated as two distinct performance metrics of electricity grids architecture (along with "resiliency"); perhaps the only meaningful difference between the two is the cause of the disruption and the magnitude of the risk. Stated differently: a grids system subject to repeated security attacks is not likely to be understood to be reliable if such attacks achieve even occasional success. For a grounding perspective on present day grids security problems, *see* Letter to President of the United States Barack Obama dated May 14, 2015, signed by thirty security and political professionals, http://highfrontier.org/wp-content/uploads/2012/09/May-14-2015-Letter-to-President-Obama.pdf. "Hardening" measures employed against natural disasters are useful although oftentimes distinct from actions needed to improve security. *See, e.g.,* U.S. DEP'T OF ENERGY, OFFICE OF ELEC. DELIVERY AND ENERGY RELIABILITY ("DOE RELIABILITY OFFICE"), HARDENING AND RESILIENCY, ENERGY INDUSTRY RESPONSE TO RECENT HURRICANE SEASONS (2010), https://www.oe.netl.doe.gov/docs/HR-Report-final-081710.pdf. The DOE Reliability Office publishes a set of "Electric Disturbance Events," a historical reference/benchmark for the (under)performance of the grids to various weather related events.

[10] The author hopes this is the case. In 2010, he produced a working series paper for what is now the KBH Center providing an overview of activities concerning the U.S. electricity grids. That paper did not discuss the potential for distributed generation sources to provide an economic alternative to a solely centralized grid architecture because the possibility seemed too remote at the time to be relevant. *See* ELECTRICITY TRANSMISSION IN THE U.S.—LEGAL ISSUES

available to the standard centralized electricity delivery structure (i.e., power plant ⇨ substation ⇨ transmission lines ⇨ substation ⇨ distribution lines ⇨ end consumer).[11] Seven surprising years later, distributed generation[12] has achieved broad cost parity with centralized electricity delivery; meanwhile, the costs of decentralized energy systems are falling rapidly and the costs of centralized electricity delivery are continuing to rise.[13] The need for reevaluation is bolstered by recent domestic attacks on the U.S. grids by both sophisticated and unsophisticated actors[14] and successful cyber-attacks by state-sponsored actors against electricity grids elsewhere in the world.[15]

This paper proceeds from an acknowledgment that an industry-wide commitment (often including distributed generation companies) to a fundamentally centralized electricity delivery system is, itself, a primary source of security risk. From a historical perspective, that commitment is understandable, as a solely centralized delivery model has been the only available economic approach to safely and reliably deliver a fundamental social good. Today, that commitment is outmoded and jeopardizes the fundamental security of the U.S. in that it distracts attention and diverts resources from the essential work of reconfiguring the architecture of the grids to be more inherently secure.

Part I of this paper provides historical background and describes conceptual aspects of the electricity grids architecture in order to provide grounding for the subsequent analysis. Part II sketches out the reasons why economic alternatives to a solely centralized grids architecture are now available. Part III describes the paradox wherein misplaced regulatory efforts reinforce the solely centralized model of electricity delivery, and thereby also increase root insecurity. The concluding

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AND TRENDS, UNIV. OF TEX. CENTER FOR ENERGY, INT'L ARBITRATION, AND ENVTL. LAW (2010), http://kbhenergycenter.utexas.edu/files/2013/11/electricity_transmission.pdf.

[11] This is a simplified schema that does not account for, as one example, consumers that receive electricity at higher voltages.

[12] Distributed generation simply refers to the generation of electricity at or near the point of consumption, without the intervening transmission and, generally, distribution infrastructure.

[13] *See* discussion in Part II.

[14] Part III reviews a well-known case from 2013 where a single individual caused material damage in the Western Interconnection by shooting cooling fans on transformers at a substation with an assault rifle; other assailants have used tractors and towing chains and other ordinary equipment to down the electrical delivery infrastructure. *See, e.g.*, CSPC STUDY, *supra* note 3, at 27–31. In a recent case, Russian malware was found on a utility-owned laptop in Vermont. *See Vermont Electric Utility Finds Malware Code Attributed To Russians*, ASSOCIATED PRESS (Dec. 30, 2016), http://bigstory.ap.org/article/7b63fe3cd3b8413d8141234b7d0ee2c2/vermont-utility-finds-malware-code-attributed-russians.

[15] As well shown by the Russian cyber-hack of the Ukrainian electrical grid in December 2015, related to Russia's hostile takeover of Crimea in 2014, that shut off power for hundreds of thousands of Ukrainians at a time of acute military threat. *See, e.g.,* E-IASC, ANALYSIS OF THE CYBER ATTACK ON THE UKRAINIAN POWER GRID 3–6 (2016), http://www.nerc.com/pa/CI/ESISAC/Documents/E-ISAC_SANS_Ukraine_DUC_18Mar2016.pdf [hereinafter UKRAINIAN GRID CYBER-ATTACK].

subparts provide guideposts and describe opportunities for reorienting regulatory focus toward the security of U.S. electricity delivery.

I. THE U.S. ELECTRICITY SYSTEM: SELECT HISTORY AND ESSENTIAL FEATURES

Like food and most other forms of centralized industrial production, the U.S. electricity grids evolved as a set of systems responding to the engineering, human health circumstances, and economic incentives of distinct time periods. The resulting modern grids system is a hodgepodge,[16] best viewed in the context of its history and essential features.

A. Select History of the U.S. Centralized Electricity System

In 1880, the population of the U.S. was only about fifty million,[17] and very few folks—mostly established shop owners and very wealthy individuals—had access to electricity from direct current coal-powered generators, located on-site and producing small amounts of energy.[18] Direct current centralized systems were ascendant in the nascent market for electricity after Thomas Edison introduced the coal-fired Pearl Street Station in 1882, providing electricity via buried copper lines to more than 500 nearby customers, including J.P. Morgan (the man) and the New York Times (the paper).[19] On November 15, 1896, a switch was flipped on George Westinghouse and Nikola Tesla's alternating current[20]

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[16] As of 2013, electricity delivery was a $320 billion dollar in annual sales business, supplied by 189 investor-owned electric utilities, 2,013 publicly-owned electric utilities, 887 consumer-owned rural electric cooperatives, with nine federal power agencies, and 218 power marketers. *See, e.g.*, AM. PUBLIC POWER ASSOC. 2015–2016 ANNUAL DIRECTORY & STATISTICAL REPORT, http://www.publicpower.org/files/PDFs/USElectricUtilityIndustryStatistics.pdf. Add to that mix several federal regulators, more than fifty state-level regulators, dozens of community microgrids, and hundreds of thousands of distributed electricity generation projects. Electricity sales is a top five industry segment in the U.S., trailing, e.g., construction and food, and leading, e.g., textiles, motor vehicles, and software.

[17] Compared to approximately 325 million people in 2016. *See* U.S. CENSUS BUREAU, U.S. AND WORLD POPULATION CLOCK, https://www.census.gov/popclock/ [last visited Apr. 2017].

[18] For context on what these changes meant for technology and society, *see* Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930*, JOHNS HOPKINS UNIVERSITY PRESS (1993), https://monoskop.org/images/2/29/Hughes_Thomas_P_Networks_of_Power_Electrification_in_Western_Society_ 1880-1930.pdf [hereinafter Hughes History].

[19] *See* N.Y. INDEPENDENT SYSTEM OPERATOR, BULK ELECTRICITY GRID BEGINNINGS (2007), http://www.pearlstreetinc.com/NYISO_bulk_elect_beginnings.pdf; *see also* Hughes History, *supra* note 18 at 41, 42.

[20] Acclaimed authors have written detailed histories of the "Battle of the Currents." For present purposes, it shall be assumed that alternating current became the standard because it was, at the time, far easier to step up alternating current voltage to transmit power over long distances and steam turbines are more efficient at scale. *See* discussion *infra* note 65.

generation plant at Niagara Falls, and true centralized hydroelectrical power was delivered twenty-six miles away in Buffalo, New York.[21]

Industry professionals thereafter set about a march to produce electricity at massive, centralized steam turbine[22] power plants positioned far from population centers,[23] and electrification expanded in near lockstep with availability.[24] Prior to the building of such massive plants, there was little functional difference between distribution and transmission of electricity.[25] Thereafter, the simple geography of centralized generation systems provided industry professionals access to two additional lines of business, shipping (transmission) and delivery (distribution).[26]

Regulation of electricity delivery systems was initially weak, as municipalities were generally not imbued with a legal authority to regulate electric operators.[27] Electric operators did, however, need

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[21] *See* EDWARD DEAN ADAMS, NIAGARA POWER: HISTORY OF THE NIAGARA FALLS POWER COMPANY (1927). The Niagara Falls plants were renamed in 1927 for Mr. Adams, an investment banker with Winslow, Lanier & Company and contemporary of J.P. Morgan, who as an early director for the Edison Electric Light Company was instrumental in the building of the plants, eventually as president of the Niagara Falls Power Company. *See Edward Dean Adams Obituary,* IEEE GLOBAL HISTORY NETWORK, http://www.ieeeghn.org/wiki/images/3/31/Adams_-_resolution_in_memory.pdf.

[22] Huge centralized power plants were adopted primarily because generation was reliant on steam turbine technology, a reliance that continues today. Steam turbines are more efficient at scale, a characteristic that is discussed *infra* note 65.

[23] For various reasons: like today, (over)building capacity permits utilities to capture most near-term finite load demand. Also, fire and explosion hazards make centralized generation near population centers a poor match. Explosions occasionally happen even today. *See* CONNECTICUT GOVERNOR'S COMMISSION RE: KLEEN ENERGY EXPLOSION FINAL REPORT 3–4 (2010) (findings on the Kleen Energy Explosion in middle Connecticut in 2010 which damaged a natural gas and oil-fired power plant and killed twenty-seven plant workers). Localized coal-fired generation was also filthy. Health impacts are outside the present scope, but for context on the problem reference the "Big Smog" event in London in 1952 which, in five days, killed over 4,000 people from respiratory issues. *See The Great Smog of 1952*, METOFFICE, http://www.metoffice.gov.uk/learning/learn-about-the-weather/weather-phenomena/case-studies/great-smog [last visited Apr. 2017].

[24] *See, e.g.*, Stephen Moore and Julian L. Simon, *The Greatest Century that Ever Was,* POLICY ANALYSIS CATO INST. 20 (1999), https://object.cato.org/pubs/pas/pa364.pdf (hereinafter *Greatest Century*). For an interesting contemporary account of rural electrification circumstances in the U.S., *see* Robert T. Beall, *Rural Electrification*, YEARBOOK OF AGRICULTURE 790–809 (1940), https://naldc.nal.usda.gov/download/IND43893747/PDF [hereinafter BEALL, YEARBOOK].

[25] The earliest centralized distribution power plants were direct-current units situated in proximity to end-consumers and generated low voltages insufficient to transmit electricity over long stretches of power lines—essentially, it was all distribution.

[26] Centralized power required high voltages, achieved through step-up substations, to transmit electricity down hundreds of miles of strung heavy metal lines to a step-down substation. Once the voltage was stepped back down, it could then be distributed to end-consumers. Most often, not always, a single utility would own each business segment of generation, transmission, and distribution. It all works in a similar way today, with voltages stepped down according to customer need.

[27] *See, e.g.*, Christopher R. Knittel, *The Adoption of State Electricity Regulation: The Role of Interest Groups*, 54 J. INDUS. ECON. 201–222 (2006), http://web.mit.edu/knittel/www/papers/elecreg.pdf; *compare* Werner Troseken, *Regime Change*

municipal approval to dig up city streets to lay copper wire or build poles to string wire across city streets, and cities used that practical bargaining power to negotiate private contracts with electric operators.[28] Those contracts were used to regulate operators and accomplish various ends, including broad and systemic corruption in favor of municipal officials.[29]

Beginning in 1900, states began to grant municipalities the legal authority to regulate utilities, and utilities undertook lobbying efforts to procure local monopolies as cutthroat competition and the requirements of large upfront capital expenditures made electric delivery a business of uncertain profits.[30] In 1907, states began to assume the regulatory mantle from municipalities through newly established statewide professional utility regulatory commissions.[31] By 1920, less than twenty-five years after Niagara Falls power was shipped to Buffalo, many states had established such commissions.[32] 1920 also marked the year that the federal government put a toe in the regulatory waters by providing oversight of federal hydroelectric projects through the newly created Federal Power Commission ("FPC").[33] The federal government further waded into the regulatory pool in 1935 by expanding the FPC's scope of power to include regulation of the interstate shipment of electricity.[34]

Apart from certain system refinements, present-day generation, transmission, distribution, and regulation trace a straight-line of development from the beginnings to today's electricity grids. The dominance of centralized generation is shown in 450,000 miles of high voltage[35] transmission lines and a distribution infrastructure that is ubiquitous in and around population centers. The original local electricity line systems have been amalgamated into three interconnections (essentially discrete grids), and ten regional markets, all reliant on centralized generation of 4.08 trillion kilowatt hours (thus, the

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and Corruption, A History of Public Utility Regulation, CORRUPTION AND REFORM: LESSONS FROM AMERICA'S ECONOMIC HISTORY (2006), http://www.nber.org/chapters/c9986.pdf.

[28] Troseken, *supra* note 27, at 261–64. In the negotiating process an electric producer might seek to limit competition from other operators, while the municipal regulators might seek wider access (to secure future votes), ineffectual price guarantees (because the price of electricity kept dropping precipitously, *see, infra*, Part II.A), and corrupt ends.

[29] *Id.*

[30] Knittel*, supra* note 27, at 207.

[31] Troseken, *supra* note 27, at 262. Massachusetts was an earlier innovator in this area.

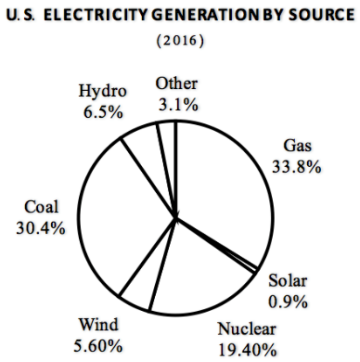
[32] *Id.*

[33] Federal Power Act of 1920, 16 U.S.C. § 791a et seq. (2017).

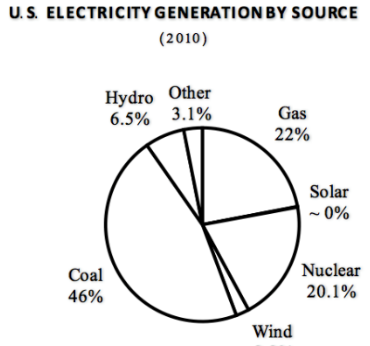
[34] Public Utility Act of 1935, 16 U.S.C. §§ 824, 824b(a) (2015).

[35] The definition of "high voltage" is subject to some disagreement. In 2013, there were over 450,000 miles of "high voltage" lines, but only a little over 200,000 miles of that total was rated at or above 230kV, *see, e.g.*, N. AM. ELEC. RELIABILITY CORP., UNDERSTANDING THE GRID (2013), http://www.nerc.com/AboutNERC/Documents/ Understanding%20the%20Grid%20AUG13.pdf; *see also* EDISON ELEC. INST., TRANSMISSION PROJECTS: AT A GLANCE (2016), http://www.eei.org/issuesandpolicy/transmission/documents/trans_project_lowres_bookmarked.pdf.

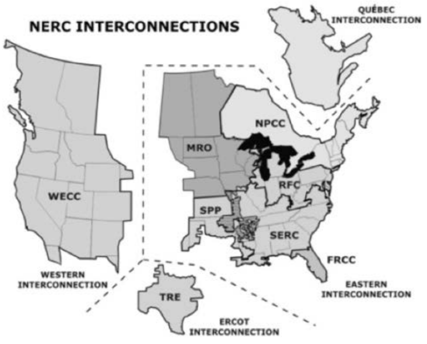
percentage changes from 2010 to 2016, shown on the charts below, represent enormous shifts in source energy generation),[36] connected here and there, or not at all.[37]



Source: EIA 2016 Data



Source: EIA 2010 Data



Source: NERC 2016

States have kept the regulatory pace—even the state of Wyoming taxes land owners for the wind blowing through their ranches[38]—and serve as

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[36] *See* inset chart. U.S. ENERGY INFO. ADMIN., PERCENTAGE OF ELECTRICITY GENERATION BY SOURCE, https://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3 [last visited Apr. 2017]. Percentages from 2010 are rounded slightly at the first decimal point due to difficulty recreating the equivalent source data set. Solar represented a negligible amount of generation in 2010, less than 1,300 thousand megawatt hours, functionally zero to the first decimal although it could have been represented as 0.1%. The EIA estimates that distributed solar systems produced approximately nineteen billion kilowatt hours of electricity in 2016, or approximately .05% of total U.S. generation.

[37] *See* inset map. N. AM. ELEC. RELIABILITY CORP., INTERCONNECTION MAPS, http://www.nerc.com/AboutNERC/keyplayers/Pages/Regional-Entities.aspx [last visited Apr. 2017].

[38] W.S. 39-22-101-111, passed in 2010, established a tax of $1 per MW of energy generated from wind facilities in the State of Wyoming. 2010 Wyo. Sess. Laws 234–38 (a subsequent attempt in 2016 to increase the tax to $3 per MW proved unsuccessful); *see, also e.g.*, Stephanie Joyce, *Legislative Committee Nixes Wyoming Wind Tax Increase*, INSIDE ENERGY

the regulators of retail electricity, performing a tri-part function of protecting consumer access, industry profits, and governmental tax revenues.[39] The FPC's successor, the Federal Energy Regulatory Commission ("FERC") today too has a far greater regulatory ambit.[40] And, in a historical bookend, the utility industry in 2005 gained federal powers for its own explicitly captive regulator, the National Electric Reliability Corporation ("NERC"), a private 501(c)(6) corporation formed by utilities, which received the explicit power to set mandatory standards and fine non-complying entities into compliance.[41]

B. Essential Features of U.S. Electricity

The consistent trend line of regulation and development of electricity, from the 1880s to present, is grounded in very few core concepts. These concepts help to define what electricity in the U.S. is, and what it is not.

(Sept. 2016), http://insideenergy.org/2016/09/23/legislative-committee-nixes-wyoming-wind-tax-increase/.

[39] Fed. Power Comm'n v. S. Cal. Edison Co., 376 U.S. 205, 216 (1964).

[40] Certain commentators argue persuasively that FERC's power is broader than even FERC generally acknowledges. *See, e.g.*, Joel B. Eisen, *FERC's Expansive Authority to Transform the Electric Grid*, U.C. DAVIS L. REV. 1783–1849 (2016). At present, FERC is explicitly tasked to: (i) regulate the transmission and wholesale sales of electricity in interstate commerce; (ii) review certain mergers and acquisitions and corporate transactions by electricity companies; (iii) regulate the transmission and sale of natural gas for resale in interstate commerce; (iv) regulate the transportation of oil by pipeline in interstate commerce; (v) approve the siting and abandonment of interstate natural gas pipelines and storage facilities; (vi) review the siting application for electric transmission projects under limited circumstances; (vii) ensure the safe operation and reliability of proposed and operating LNG terminals; (viii) license and inspect private, municipal, and state hydroelectric projects; (ix) protect the reliability of the high voltage interstate transmission system through mandatory reliability standards; (x) monitor and investigate energy markets; (xi) enforce FERC regulatory requirements through imposition of civil penalties and other means; (xii) oversee environmental matters related to natural gas and hydroelectricity projects and other matters; and (xiii) administer accounting and financial reporting regulations and conduct of regulated companies. *See, e.g., What FERC Does*, FED. ENERGY REGULATORY COMM'N, https://www.ferc.gov/about/ferc-does.asp [last visited Jan. 2017].

[41] NERC's mission is to assure the reliability and security of the bulk power system in North America, and following the Energy Policy Act of 2005, it has the power to assess severe fines on participants for non-compliance. The utility industry successfully lobbied for NERC's explicit regulatory power in the Energy Policy Act of 2005 (42 U.S.C. ch. 149 § 15801 et seq.), which required FERC to designate the then-named North American Electric Reliability Council to handle required grids standards. Superficially, the Energy Policy Act of 2005 required FERC to appoint a national Electric Reliability Organization (ERO) to provide such functions; as a practical matter, that meant designating the National Electric Reliability Council and, in fact, it was the only entity to submit an application. *See* FERC ORDER CERTIFYING NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION AS THE ELECTRIC RELIABILITY ORGANIZATION AND ORDERING COMPLIANCE FILING, DOCKET NO. RR06-1-000 (July 20, 2006), https://www.ferc.gov/whats-new/comm-meet/072006/e-5.pdf.

i. Electricity is an Essential Good

Electricity is found everywhere in the U.S. expressly because it is accepted, in regulation and practice, as an essential good.[42] It is not difficult to see why: electricity industry professionals in the 20th century, relying on wide public support, built what is arguably the most robust and democratic technological achievement in human history. Near universal social support (through subsidies, price regulation, and otherwise) for electricity is explicit today and throughout the history and development of the grids, from the regulatory justification for gifting monopolies to private and public utility companies, to the enactment of the Rural Electrification Act of 1936, which brought electricity to rural areas where it was uneconomical to do so,[43] to FERC's modern mission statement to "assist consumers in obtaining reliable, efficient and sustainable energy services at a reasonable cost through appropriate regulatory and market means."[44] Our nation's defense,[45] water, sewer, communication, shelter, health, manufacturing, and transportation infrastructures are all built on a premise of immediately available access to economical electricity, for everyone.[46]

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[42] "Essential good," as used herein, refers to a good that is recognized as a necessary benefit for the public and the functioning of an industrialized nation-state and, in such a respect, generally meets tests of non-excludability. Near universal access to electricity is necessary to the existence of an industrialized nation-state (like the U.S.) and its price is therefore regulated (and subsidized by some citizens to others) to a level so that nearly everyone can regularly afford it. More fundamentally, even if a citizen of the U.S. does not pay a monthly electric bill, that person benefits from public lighting, sewer and water services, and all the other attendant benefits of an industrialized society built on electricity.

[43] *See, e.g.*, John Carmody, *Rural Electrification in the United States*, THE ANNALS OF THE AM. ACADEMY OF POLITICAL AND SOCIAL SCIENCE 82–88 (1939) [hereinafter Carmody *REA History*] (noting estimates that nienty percent of farmers were denied electricity from private providers).

[44] *See* FED. ENERGY REGULATORY COMM'N, AGENCY FINANCIAL REPORT, FISCAL YEAR 2015 2 (2015), https://www.ferc.gov/about/strat-docs/financial-reports/FY-2015.pdf.

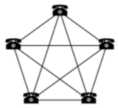
[45] *See, e.g.*, DEFENSE SCIENCE BOARD TASK FORCE ON DOD ENERGY STRATEGY, MORE FIGHT – LESS FUEL, DEP'T OF DEFENSE, OFFICE OF THE UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECH., AND LOGISTICS 3 n.6 (2008), http://www.acq.osd.mil/dsb/reports/ADA477619.pdf, [hereinafter DEFENSE SCIENCE BOARD STUDY] (finding that "[an] almost complete dependence of military installations on a fragile and vulnerable commercial power grid and other critical national infrastructure places critical military and Homeland defense missions at an unacceptably high risk of extended disruption.")

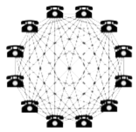
[46] Or consider that we are so removed from a world without electricity that we now occupy time watching fictional shows on our electric-powered televisions in our electrically climate-controlled homes about what the world would be like without ready access to electricity. Adventure survival shows, zombie narratives, post-apocalyptic dramas, all necessarily exist in worlds characterized by the rationing of energy. When actual blackouts have occurred—whether on the eastern seaboard in 2003, or following Hurricanes Katrina and Sandy—the resulting circumstances have been sobering.

ii. Electricity Grids do not Generate Meaningful Positive Networked Effects

While (nearly) universal access to electricity is necessary for modern civilization to function, our electricity grids remain balkanized.[47] The core modern cause for this balkanization is that the centralized grids architecture does not generate meaningful positive networked effects at scale,[48] the grids would otherwise be expected to be seamlessly interconnected.[49] Networked effects are, generally, the impact a single user of a good or service has on the value of that product to other people, such that the value (not the cost) of the network is related to the number of users.[50]

Additional users of electricity via a network do not make electricity itself more valuable. Instead, incremental users impact the relative cost of obtaining electricity through a network (either increasing or decreasing per capita costs depending on, for example, system design, available technology, location, external circumstances, and capacity). Compare electricity against the standard formalization of networked effects in communications networks where a single telephone has no value alone but great value if it can be used to connect to many other users via a network, as illustrated below:[51]





Such positive networked effects are inapplicable for the electricity grids. A modern family or business that obtains electricity from

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[47] The three grids, or interconnections, shown on the map in Part I.A. illustrate only the most obvious source of division. The grids, and their component parts, function locally or regionally for regulatory reasons, e.g., historic local monopoly control by utilities, and technical, e.g., transmission line energy losses average 6% and building redundancy is exorbitantly expensive. *See, e.g.*, OAK RIDGE NAT'L LAB., U.S. DEP'T OF ENERGY, OPPORTUNITIES FOR ENERGY EFFICIENCY IMPROVEMENTS IN THE U.S. ELECTRICITY TRANSMISSION AND DISTRIBUTION SYSTEM 1–3 (2015).

[48] For an introduction to network effects, *see, e.g.*, Michael L. Katz & Carl Shapiro, *Systems Competition and Network Effects,* 8.2 J. ECON. PERSP. 93–115 (1994), http://citeseer.ist.psu.edu/viewdoc/download;jsessionid=573D0874F04F0789803A0D37829CA87B?doi= 10.1.1.295.6783&rep=rep1&type=pdf.

[49] This is a rough logical converse. Technical challenges remain, particularly in line energy losses over significant distances. Nonetheless, it is reasonable to conclude that such challenges would be solved if the electricity grids produced significant positive networked effects, just as enormous technical challenges in communications networks have been overcome.

[50] According to Metcalfe's Law, named after its formulator Robert Melancton "Bob" Metcalfe, the value of a telecommunications network is proportional to the square of the number of connected users of the system (n2). Alternately, the community value of a network grows as the square of the number of its users increases. In both instances, the primary value questions are how many users does the network provide access to and interaction with.

[51] Nathan Wood, *Metcalfe's Law*, WIKIPEDIA (May 31, 2011), https://en.wikipedia.org/wiki/Metcalfe%27s_law#/media/File:Metcalfe-Network-Effect.svg.

generation sources hundreds of miles away does not enjoy a fundamentally different good than that of their predecessors from the 1880s with a reliable coal-fired generator in a downstairs basement sufficient to meet their electricity needs.[52] The electricity generated, delivered, and consumed in each case is identical as electricity is ultimately only useful to deliver energy for work.[53] This is not to say that electricity delivery systems do not have externalities, just that such externalities do not constitute meaningful positive networked effects.[54]

Consider the seemingly difficult question of centralized wind energy, which is oftentimes located in geographies far removed from population centers because that is where it is windy.[55] Since centralized wind energy must be shipped to population centers to be widely consumed, it might be incorrectly concluded that the intervening network of transmission lines generates meaningful positive networked effects, e.g., some groups may assign value to consumer access to renewable wind energy and argue that such a value is not accurately reflected in its price (therefore constituting an externality). A similar argumentative approach can be applied to any fuel source. Take coal for example: coal plants are not welcome near population centers due to the resulting adverse human health impacts and, thus, coal-fired power must be shipped via a network of transmission lines to population centers to be widely consumed. Some groups may assign value to the use of coal in that it tends to create jobs in areas that are currently economically depressed, or some other social value not accurately reflected in its price (therefore constituting an externality).

The error in each case is conflating desirable externalities associated with an energy generation type with externalities that constitute networked effects. A social determination might be made that the

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[52] To note that coal has human health effects and severe delivery deficiencies, while accurate, misses the present point, and concerns a generation type and its associated negative externalities. The example, as it pertains to network questions of connectivity and location, functions equally well by substituting a modern distributed generation source for the coal-fired generator in the example.

[53] If decentralized systems have or can achieve grid parity, then Q.E.D. costs/economies of scale cannot constitute meaningful positive networked effects for electricity delivery. Arguments for reliability must also account for the inherent (in)security of networked grids, a problem on which this paper is focused.

[54] Comparative costs are discussed in Part II. Here, the point is simply that, apart from cost, the consumption of electricity by one person does not impact the value of the consumption of electricity by another person. Contrast with communications networks, where the value of the network is proportional to the square of the number of connected users to the system.

[55] The author has previously written in support of investment in transmission facilities to realize enormous wind energy potential. *See* Ryan Thomas Trahan, *Social and Regulatory Control of Wind Energy—An Empirical Survey of Texas and Kansas*, 4 TEX. J. OIL, GAS & ENERGY L. 89–110 (2008). Today, the author would prefer to see continued and increased investment in wind in one of several decentralized configurations that utilize existing infrastructure and new technologies. Wind energy's reliance on fixed-locations distinguishes it somewhat from common fossil fuel types, for which power plant placement is nominally more flexible.

externalities resulting from wind energy are preferable to the externalities resulting from coal energy, or vice versa. In either case, it does not follow that dependency on a vast transmission infrastructure for delivering energy is a feature rather than a bug.

The bug of centralized electricity delivery (whatever the source fuel) is that it is costly and generates meaningful *negative* security networked effects. Negative security networked effects occur when additional users of the same electricity infrastructure have the effect of making the system less secure (less valuable) for other users. The risks of broad scale cyber-hacks and physical attacks are greatly increased in centralized electricity networks.[56]

A similar problem exists for the communications industry, which recognizes negative networked effects as a leading problem and top spending priority for its technology professionals.[57] Security spending costs are forecasted to grow rapidly for electricity providers as well.[58] Unlike communication networks, however, the level of spending by the electricity industry is ultimately elective: there are no meaningful positive networked effects produced by the electricity grids that require investment in a *centralized* infrastructure. The upshot is that electricity is useful for its ability to transfer energy for work. Whether it is relatively more valuable to deliver electricity via a network, while incurring the negative security networked effects of connected networks[59] is an economic (see discussion Part II) and social question (explored in Part III) that, to date, has been ignored.

iii. The Grids are (and have always been) Reliant on Broad Social Investment

Utility companies were provided the de facto power to tax consumers of electricity in their government-granted monopoly area because the industry could not achieve universal access and acceptable reliability

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[56] For example, if a grids asset is lost or compromised (whether the asset stops functioning due to physical or cyber-attack) that loss impacts consumers due to service interruptions, and it impacts the utility as generation must be balanced with load in tight tolerances. Otherwise electricity can "sit" on the grids' lines building up heat that damages other components of the grids. Other problems are similarly technical and pervasive, for example, certain base load generation sources (coal) cannot be quickly switched off/on without causing damage.

[57] A top spending priority, it should be noted, that does not launch new products or directly enable new efficiencies. *See* COMPUTERWORLD, 2016 FORECAST SURVEY, http://cdn2.hubspot.net/hubfs/1624046/Computerworld_2016_Executive_Summary_final.pdf?t=1463759713389.

[58] *See* BiPC CyberSecurity, *supra* note 3, at 13 (conservatively estimating $7 billion in network security spending by electric utilities by 2020).

[59] *See, e.g.,* C. Baylon, R. Brunt & D. Livingstone, *Cyber Security at Civil Nuclear Facilities*, CHATHAM HOUSE REPORT 23 (2015), https://www.chathamhouse.org/sites/files/chathamhouse/field/field_document/20151005CyberSecurityNuclearBaylonBruntLivingstone.pdf [hereinafter CHATHAM HOUSE SECURITY STUDY].

through solely private action, for one reason or another.[60] Vast social investment has been necessary to provide near-universal access as the grids do not generate meaningful positive networked effects.[61] Such monopoly grants and social investment followed a public determination that electricity is an essential good[62] and that centralized grids were the only feasible technical and economic approach to supplying that good, again with private industry lobbying hard to arrive at that conclusion in a manner that would deliver steady profits.

A reasonable requirement then for social investment in any alternative electricity generation and delivery system would consist of the satisfaction of one of the following:

- independently (and economically) meet requirements of universal access and security in a manner that is equal to or better than the existing system; or,
- demonstrate an ability to improve the fulfillment of such requirements when coupled with the existing centralized electricity architecture.[63]

II. WHY ARE ECONOMIC ALTERNATIVES AVAILABLE NOW?

Even accounting for externalities, centralized generation and therefore the centralized grids, has been the only economic approach to electricity delivery throughout the history of the U.S.[64] The primary reason—rather than human health effects, environmental impacts, or fuel availability—is that steam turbines are more efficient operating at a larger scale, and

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[60] At least not with what the industry considered to be sufficient profitability. The simple point is that the production of all centralized-generation fuel sources is subsidized, whether fossil, nuclear, or renewable. Subsidies are a tax on one group in favor of another. Alternate explanations for the existence of subsidies cannot escape the practical reality that such policies reflect social investment, even if refracted through the prism of special interest.

[61] If meaningful positive networked effects were present in the electrical grids, then private electricity industry investment would look much like the communications sector, whether because of private action, regulatory fiat, or a combination of both. *See, e.g.*, Hughes History, *supra* note 18, at 17 (noting that early on the major reverse salients of the grids quickly evolved into simple funding challenges). Formally, a reverse salient is a borrowed military term describing the backward bulge in an advancing line of a military front. Here, the analogy to a military front is the technical provision of an essential good (electricity) as opposed to dedication to an approach to providing that essential good. A regulatory analog to Hughes' observation is explored in Part III.

[62] *See* discussion Part I.B.i.

[63] These discussions have occurred in other contexts, notably following Hurricane Sandy and the work to "harden" select grid assets of Con Edison of New York in a manner useful to better respond to future super-storm events. *See* CON EDISON CASE 13-E-0030, ORDER APPROVING ELECTRIC, GAS AND STEAM RATE PLANS IN ACCORD WITH JOINT PROPOSAL 71 (Feb. 21, 2014).

[64] *See* discussion Part I.A., Part II.A. That an industrialized lifestyle is necessary or required may be considered a super-majority view from the perspective that very few individuals have elected (or would elect) to adopt a non-industrialized lifestyle, with the relatively few outliers supporting the general conclusion.

coal, nuclear, and combined cycle gas plants rely on steam turbines.[65] As recently as 2010, technologies not dependent on steam turbines were not anticipated to become cost-competitive for many years.[66] Much has changed in the interim, foremost that cost parity for distributed generation has been achieved in many markets over the last 18–24 months.[67] The debate over decentralized energy has therefore shifted from a question of whether decentralized energy systems should be

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[65] This is true for both energy and economic efficiency. The energy efficiency of a steam turbine is subject to a theoretical maximum Carnot efficiency—i.e., the efficiency of turning heat into work limited by, simplifying, the difference between the high and low temperatures of the medium (typically water vapor) experienced during the cycle—and follows the Rankine cycle of boiling water vapor to high temperatures, lowering pressure through turbines, and condensing back into liquid on the backend. Larger facilities are much better able to consistently produce such high heats in the tight temperature bands required of water vapor, and capture and control its outcomes, including the backend condensation.

[66] For just one example, the International Energy Agency ("IEA"), a group sometimes criticized as a cheerleader for decentralized energy, estimated in 2010 that one source of decentralized generation would not become even broadly cost competitive until the 2020s. *See* IEA, TECHNOLOGY ROADMAP – SOLAR PHOTOVOLTAIC ENERGY (2010), https://www.iea.org/publications/freepublications/publication/pv_roadmap.pdf. Less than four years later that forecast was discarded, and it is again due for revision. *See* IEA, TECHNOLOGY ROADMAP – SOLAR PHOTOVOLTAIC ENERGY (2014), https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf ("Much has happened since our 2010 IEA technology roadmap for PV … [B]y 2020 [PV] will probably reach twice the level previously expected . . . cost of PV modules has been divided by five in the last six years; the cost of full PV systems has been divided by almost three . . . [levelized] cost of electricity of [decentralized] solar PV systems is approaching or falling below the variable portion of retail electricity prices . . . across residential and commercial segments.").

[67] As discussed, *supra*, distributed generation is not a synonym for a decentralized energy system. Cost data points, characteristics, and trends for certain distributed generation and centralized electricity delivery systems are the subject of Part II. The current debate regarding the deployment of decentralized systems would not exist, particularly for businesses like Las Vegas casinos and technology company server farms, if distributed generation did not provide significant cost savings as compared to centralized options; however, and again, it is not an equivalent comparison. The author is not aware of any existing studies that incorporate the cost of transmission and distribution facilities into the projected cost of electricity on a per-project basis. Instead, existing studies assume the existence or necessity of a monolithic centralized infrastructure, a concept that arguably does not even well-describe the systems infrastructure that presently exists. That assumption results in a failure to attempt to more fully understand the actual cost of electricity in the context of available delivery alternatives, e.g., incentives for various generation sources viewed from a perspective of available options, the security and maintenance costs of the centralized grids architecture, or the impact of sunk technological investment in the context of changing population and technology characteristics. Common reference points (none of which address the described methodological deficiencies): Corey Honeyman, *Executive Summary: U.S. Residential Solar Economic Outlook 2016–2020: Grid Parity, Rate Design and Net Metering Risk*, GTM Research (2016) (concluding current cost parity of residential solar in many states); *compare* UNIV. OF TEX. AT AUSTIN, THE FULL COST OF ELECTRICITY, NEW U.S. POWER COSTS: BY COUNTY, WITH ENVIRONMENTAL EXTERNALITIES (Dec. 2016), http://energy.utexas.edu/files/2016/09/UTAustin_FCe_LCOE_2016-A.pdf (concluding that gas is the most economical generation source in all but a few counties, or primarily gas and wind when accounting for environmental externalities); *compare* DEUTSCHE BANK MARKETS RESEARCH, CROSSING THE CHASM (2015) https://www.db.com/cr/en/docs/ solar_report_full_length.pdf [hereinafter DEUTSCHE BANK STUDY]; *compare infra* note 84; *compare* LAZARD, LAZARD'S LEVELIZED COST OF ENERGY ANALYSIS – VERSION 10.0 (Dec. 2016), https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf.

implemented to a debate over which consumers should be permitted to deploy decentralized energy systems and what impact that transition might have on the existing grids system.[68] These battles represent a paradigm shift and raise the question of what changed in the blip of seven years.

A. Centralized Electricity Delivery Will Continue to Become Significantly More Expensive

From 1882 to the early 1980s, the average retail cost of electricity fell precipitously, with sequential declines occurring most every year, excepting for an extended spike in the 1920s, as technological improvements in power plant design and construction and declining source fuel expense resulted in significant cost efficiencies.[69] This mitigated pressure on the retail price of electricity. Since then, the utility industry itself has found that the opposite has been true:

Time Period	Percentage Increase in Price of Retail kWh
1985 to 2004 (19 years)	27 percent[70]
2006 to 2014 (8 years)	30 percent[71]

Price increases for electricity must continue to accelerate as the utility industry seeks to replace and upgrade (and build out) the existing centralized grids architecture: $1.5 to $2.0 trillion in additional new investment has been estimated by the utility industry to be necessary

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[68] See the discussion in Part III.B.iii regarding tax incentives and tax disincentives for distributed energy sources.

[69] *See, e.g.*, G. Morgan, J. Apt & L. Lave, *The U.S. Electric Power Sector and Climate Change Mitigation*, PEW CENTER ON GLOBAL CLIMATE CHANGE (2004), http://www.c2es.org/docUploads/Electricity_Final.pdf; *compare Greatest Century*, *supra* note 24, at 20.

[70] Percentage increases have been stripped of price increases due to inflation. *See Rising Electricity Costs, A Challenge for Consumers, Regulators, and Utilities*, EDISON ELEC. INST. 2 (2006),http://www.eei.org/whatwedo/publicpolicyadvocacy/stateregulation/documents/rising_electricity_costs.pdf.

[71] There is some variability in estimates for retail electricity prices provided by different commentators for this period, although most all estimates rely on data sets from the U.S. Energy Information Administration. *See, e.g.*, Robert Bryce, *Energy Policies and Electricity Prices, Cautionary Tales from the E.U.*, MANHATTAN INST. (2016), https://www.manhattan-institute.org/sites/default/files/R-RB-0316.pdf. Mr. Bryce argues that centralized grid-connected renewables have not been cost-effective in the European experience, concluding that renewable mandates make for poor policy. This is a common and wrong-footed analytical framework, focusing on partisan environmental issues rather than the inherent security of the system in the first instance. A similarly unproductive discussion surrounds the net metering "allocation of profits" debate. *See* discussion Part III.

during the period from 2010 to 2030.[72] Of that total amount, $880 billion is allocated for new transmission and distribution assets, while generation is estimated to require only $700 billion in new investment.[73] Again, transmission and distribution assets are estimated to require ~$180 billion more investment dollars than assets that generate electricity in the first instance. While the cost of centralized generation may decrease with technological advances,[74] the total cost of centralized electricity delivery will increase as transmission and distribution costs continue to comprise a larger percentage of total spending.

Regrettably, the utility industry's investment study did not account for the cost of a security event occurring during the twenty years for which the estimates run.[75] If the actual social cost of a material security event is tens or hundreds of billions of dollars,[76] then the industry's staggering investment estimates could be too low by an order of magnitude.[77] The industry's cost estimates are immense nonetheless, and it is worthwhile to take a slight technical detour to understand what more than a trillion dollars of social investment purchases. Here, large power transformers ("Large Power Transformers"), an essential and aptly named component of the centralized infrastructure, provide a useful microcosm.

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[72] *See Transforming America's Power System, The Investment Challenge 2010–2030*, BRATTLE GROUP FOR THE EDISON FOUNDATION ix–xi, 13, 40 (2008), http://www.edisonfoundation.net/iei/publications/Documents/Transforming_Americas_Power_Industry.pdf [hereinafter EDISON FOUNDATION INVESTMENT CHALLENGE].

[73] *Id.* at vi.

[74] The source of such cost improvements is largely a matter of conjecture. The point is simply that technological advances in plant efficiencies or fuel sourcing (as happened with domestic shale gas exploration) are likely from a historical perspective.

[75] Such estimates would necessarily be speculative but could be isolated from the other study conclusions and grounded in, as one example, the associated costs of the Electric Disturbance Events data referenced *supra* note 9. The omission is conceptually problematic because the study is used to justify investment that does not account for the costs of a security disruption in the system proposed to be constructed, or acknowledge inherent security weakness.

[76] The August 14, 2003 Electricity Blackout in parts of the Northeast U.S. and Southeast Canada is estimated to have resulted in economic costs of between $4 to $10 billion. That blackout, reportedly caused by a tree branch falling on a transmission line, was regional in nature, lasted only four days in the worst hit areas, and most places saw power restored within a day or so. *See* U.S. – CANADA POWER SYSTEM OUTAGE TASK FORCE, FINAL REPORT ON THE AUGUST 14, 2003 BLACKOUT IN THE UNITED STATES AND CANADA: CAUSES AND RECOMMENDATIONS, https://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/BlackoutFinal-Web.pdf.
Consider if a grids attack were strategically coordinated, what would a two or three-week blackout of Silicon Valley cost? Consider too the long-term damage to the grids, *infra* discussion note 81. The utility investment study further failed to address the security-related information technology costs associated with continuing to build the grids network pursuant to the current schema, *see* discussion Part III.

[77] A large enough difference that social upheaval might reasonably result. *See* discussion *supra* note 46.

Large Power Transformers[78]

- Big, 100 to 400 ton machines used in the bulk power systems to change/transform voltages
- Only around 2,100 such units are used in the U.S. grids, opposed to tens of thousands of smaller transformers
- Custom-built by special order (~85% are now built outside the U.S.)
- Average time to procurement from ordering = 5 to 16 months
- Each unit costs between $1.0 to $7.5 million, dependent on market factors and type
- Transportation and installation expenses typically add an additional 25% to 30% to the final price

The theoretical cost of replacing all the existing Large Power Transformers in the U.S. electrical grids (~$50 billion or so by simple math) is a line item compared against the overall investment in the transmission and distribution infrastructure. Except, as with all components of the interdependent centralized grids, the associated cost of an unexpected failure is orders of magnitude higher if it impacts reliability. If a single unit is damaged, the rest of the system is required to compensate, potentially damaging other assets (including other transformers), and coordinated security risks are generally not single-point-of-attack problems.[79] Of equal importance, Large Power Transformers cannot be purchased in quantity even if many were to fail at the same time.[80]

Certain utilities recently received regulatory approval to stockpile mostly foreign-made equipment at ratepayer expense.[81] Although a

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[78] *See, e.g.,* U.S. Dep't of Energy, Infrastructure Security and Energy Restoration Office of Elec. Delivery and Energy Reliability, Large Power Transformers and the U.S. Electric Grid v, vi, 7, 9, 10 (2014), https://www.energy.gov/sites/prod/files/2014/04/f15/LPTStudyUpdate-040914.pdf [hereinafter Large Power Transformers Study] (updating a 2012 study by the same name); *compare* John Kappenman, *Geomagnetic Storms and Their Impacts on the U.S. Power Grid, Meta-R-319*, Metatech Corp. 1–14 (Jan. 2010), http://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-319.pdf; *see also* P.W. Parfomak, Cong. Research Serv., R43604, Physical Security of the U.S. Power Grid: High-Voltage Transformer Substation (2014), https://www.fas.org/sgp/crs/homesec/R43604.pdf.

[79] Centralized grids planning is relatively better able to manage single point disruptions and planning. Once coordinated attacks are introduced, the negative networked effects of the grids overwhelm mitigation measures.

[80] *See* Large Power Transformers Study, *supra* note 78, at 8–10, 19.

[81] FERC and utilities are well-aware of these vulnerabilities. See the following FERC declaratory orders: Grid Assurance LLC, 152 FERC ¶ 61,116 (2015); Grid Assurance LLC, 154 FERC ¶ 61,244 (2016). Grid Assurances LLC is a consortium of utilities that have proposed to purchase redundant equipment, including Large Power Transformers, to be stockpiled in the event of an outage. The FERC orders provide utilities the ability to rate base stockpiling costs. The need to replace several such units at the same time is not improbable because the life

stockpiling approach is understandable, it is expensive and trades one problem for another. Large Power Transformers are custom-built by specialized work forces operating through complex supply chain and procurement processes. This is the only way such machines are built and delivered. Pre-ordering units through a supply chain merely changes short-term demand characteristics and does not increase the potential throughput of the supply chain. In fact, a stockpiling approach may diminish production capacity as manufacturers boom and then bust, thereby reducing the ability of the supply chain to ramp up production in response to a security event. It also raises a more fundamental question: how many backups, and at what cost, are necessary or efficient when a single bullet can destroy an entire Large Power Transformer?[82]

Large Power Transformers are useful for understanding that the complexity inherent in the centralized electrical grids is primarily a function of the interdependency of its components, coupled with an absolute requirement of reliability. Overlaid on those competing characteristics is the hurdle of managing vital supply chains, often for foreign-made, specialized components that need to be immediately available and must work seamlessly in the hodgepodge that is the U.S. grids architecture.

Even if specific technical problems with Large Power Transformers and other similar centralized grids assets are mitigated, the utility industry forecasts that more than half of all interim-term future electricity investment dollars must be earmarked for transmission and distribution assets.[83] Such assets, whether intentionally redundant or not, are fundamentally extraneous to the primary job of generating electricity. Thus, there is no clear path for reducing the long-term price of centrally delivered electricity even if the costs of centralized generation continue to decline.[84]

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expectancies of the existing equipment are clustered rather than staggered, a circumstance problematic in and of itself. As of 2014, the average existing life of Large Power Transformers on the U.S. grids was 38 to 40 years, with 70 percent being 25 years or older. *See* LARGE POWER TRANSFORMERS STUDY, *supra* note 78, at vi. The useable life of Large Transformers is remarkable, sixty years is a reasonably conservative estimate, albeit highly subject to the stability of the operating environment. *See, e.g.*, Radu Godina 1, Eduardo M. G. Rodrigues 1, João C. O. Matias 1 & João P. S. Catalão, *Effect of Loads and Other Key Factors on Oil-Transformer Ageing: Sustainability Benefits and Challenges,* ENERGIES 12147, 12163 (2015), http://www.mdpi.com/1996-1073/8/10/12147 (providing, in part, a summary of studies for oil-transformer ageing).

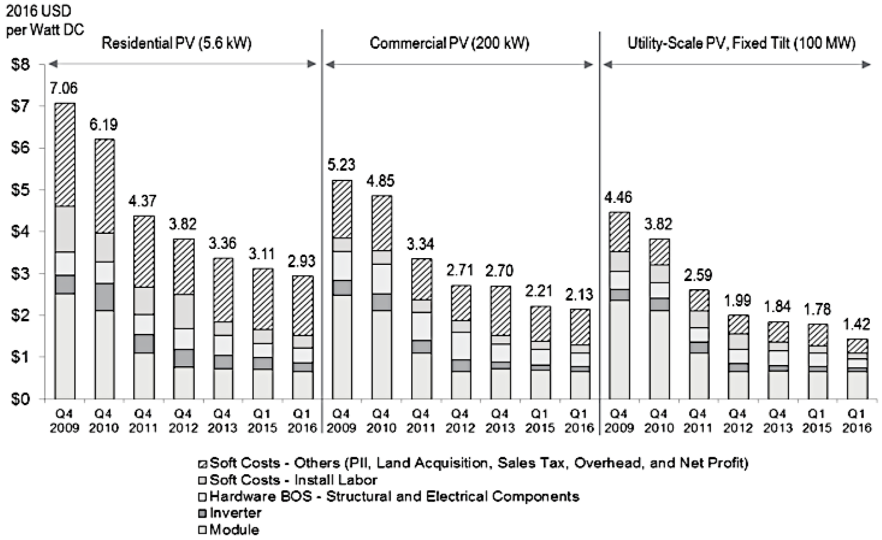
[82] There are also concerns with storing such machines in their country of origin (China, Mexico, etc.) as is sometimes the current practice. The reengineering of an existing global market supply chain is surely possible, although the wasted expense and complexity are boggling to consider.

[83] *See* EDISON FOUNDATION INVESTMENT CHALLENGE, *supra* note 72, at xi, 24.

[84] *Accord* DEUTSCHE BANK STUDY, *supra* note 67, at 1.

B. The Cost of Distributed Generation Continues to Decrease

NATIONAL RENEWABLE ENERGY LABORATORY, U.S. SOLAR COST BENCHMARK, Q1 2016



Distributed generation is ultimately required for any alternate grids architecture that does not rely solely on centralized power plants and long transmission lines. Cost parity can be achieved either as distributed generation becomes less expensive, or as centralized electricity generation, transmission, or distribution become more expensive (as described above). Most common fuel forms can be used to generate electricity in a distributed manner; in practice, the most typical applications are solar fuel utilized by photovoltaic ("PV") modules or wind turbines, and fossil fuels used in gas turbines or diesel engines. Over the past several years, certain efficiency gains have been made in small engine technologies, and component fuels costs have declined in certain instances, e.g., natural gas.[85] While important to providing heterogeneous sources of distributed generation, such incremental improvements are not comparable with the jarring 60 percent decrease in the installed cost of PV modules over the last seven years (see graph above).[86]

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[85] Natural gas, as a fuel commodity, is subject to market price fluctuations so price trends can be easily manipulated by selecting the interval of comparison. Nonetheless, since 2010, it is widely acknowledged that natural gas prices have experienced fundamental production price decreases, in some cases by a third or more. *See, e.g.,* ENERGY INFO. ADMIN., NATURAL GAS PRICES DATA SETS, https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm [last visited Jan. 2017](charting natural gas prices over this period).

[86] NAT'L RENEWABLE ENERGY LAB., U.S. SOLAR PHOTOVOLTAIC SYSTEM COST BENCHMARK, Q1 2016 33 (2016), http://www.nrel.gov/docs/fy16osti/66532.pdf [hereinafter

The reasons for the massive price decreases are several but fundamentally it is that PV modules do not rely on turbine technology[87] and are therefore more sensitive to efficiency gains from factors other than increased scale.[88] This characteristic results in PV modules displaying consistent costs across installation types, from Residential/Commercial (i.e., distributed generation) to Utility-Scale (i.e., centralized generation),[89] which means that little to no energy or economic efficiency is lost for PV modules deployed in distributed arrays. Instead, the cost differences between distributed generation and centralized generation shown in the inset chart largely originate from two sources: (i) primarily, utility-scale cost figures do not account for any allocated expense of the transmission and distribution infrastructure necessary to make such generation useful; as discussed in subpart A, above, such components constitute the majority of costs for centralized electricity delivery and cost studies simply assume such assets into existence;[90] and, (ii) secondarily, soft costs (i.e., land acquisition, sales, tax, overhead, net profit), associated with residential and commercial PV installations are materially higher than Utility-Scale PV.[91]

C. Decentralized Systems and Future Analysis

In this Part II, relative cost parity between centralized electricity delivery systems and distributed generation has been described. Further,

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NREL REPORTING Q1 2016]; *compare U.S. Solar Market Insight, Q4 2016*, GTM RESEARCH AND SOLAR ENERGY INDUS. ASSOC. 14 (2016), http://www.seia.org/research-resources/solar-market-insight-report-2016-q4 (concluding that overall PV system pricing fell by an additional 6.9% from Q2 to Q3 in 2016 and that utility-scale PV saw average pricing of $\$1.09/W_{dc}$ for fixed tilt and $\$1.21/W_{dc}$ for single-axis tracking installations, respectively). Those costs estimates are significantly lower than the NREL Reporting Q1 2016.

[87] For a clearly written introduction to the basic functions of solar cells, see JENNY NELSON, THE PHYSICS OF SOLAR CELLS (2003).

[88] Economies of scale in manufacturing is a corresponding outcome. PV modules do require the use of an inverter, which is sometimes forwarded as a rough analog to a turbine, although the comparison is not technically sound. Regardless, as is clearly shown on the inset chart, inverter costs are not a heavily weighted cost component for the installed system and, unlike steam turbine technology, do not primarily dictate the economic and energy efficiency of the installed module.

[89] Somewhat confusingly, utility-scale is sometimes used to refer to the size of the installation, a reference that bears no relationship to whether an asset is distributed or centrally delivered. In certain instances, where a single private consumer installs PV modules that are used to power a privately-owned asset with huge energy needs (e.g., a data center or casino) a utility-scale installation may actually constitute a distributed asset.

[90] The utility-scale costs reflect only the price of generating electricity, not the cost of delivering it so that it can be consumed.

[91] In part due to economies of scale, although bans or equivalent burdensome permitting and regulatory costs are the biggest line item. Labor and invertor costs are relatively minor impacts that favor Utility-Scale installations. In sum, PV module installations experience limited energy efficiency loss in distributed deployments; whereas, a crude measure of economic efficiency loss (or gain) could be estimated for a specific Utility-Scale PV project ("USP") as against a substituted distributed PV project (SDP) as follows: ((USP Soft Costs, Others and Labor) – (SDP Soft Costs, Others and Labor)) – USP cost allocation from necessary transmission and distribution infrastructure.

a sketch of the factors that will require centralized approaches to become significantly more expensive over time has been set forth. Such cost increases are independent of the awing expense resulting from a broad security event. Distributed generation, meanwhile, is set to become even less expensive in the short and medium-term as generation technology continues to improve and costs are reduced by economies of scale. As suggested in Part I.B.iii., above, a test for determining whether decentralized systems—as opposed to distributed generation—are deserving of broad social investment is whether such systems can independently (and economically) meet requirements of universal access and security in a manner that is equal to or better than the existing centralized system or demonstrate an ability to improve the fulfillment of such requirements when coupled with the existing centralized electricity architecture.

The remaining questions are then (a) what energy storage and/or load sharing capabilities are required for the operation of a decentralized system; and (b) should such technologies be integrated with the existing grids and, if so, how? The latter question is discussed in Part III. The former query is necessary because the source fuels for distributed generation are either (x) intermittent in availability (i.e., the sun and, therefore, wind); or, (y) dependent on centralized fossil fuels delivery, in which case the security risks of distributed generation would be, in part, recursive.[92] Here, batteries for energy storage, community-level generation sharing, and microgrids for islanding,[93] are diverse solutions for the independent operation or integration of decentralized electricity delivery.

A challenge in briefly summarizing such assistive technologies is that they are inherently flexible in deployment and application, and diverse applications here lead to significant cost variability. For example, such technologies could produce independent generation and consumption points. Or, in one particular combination, micrognds and community-level generation could work in a manner analogous to Edison's Pearl Street Station briefly described in Part I, essentially providing small-scale centralized generation and centralized distribution of electricity, but not transmission. This latter system fronts the same conceptual technical problem of centralized electricity delivery (i.e., negative networked effects) except those negative impacts are mitigated by the ability of such systems to be self-contained (islanded), thus reducing the risk and

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[92] The recursive fuels risk is of course present in most centralized systems as well. The structure and complexity of the U.S. pipeline infrastructure is not directly analogous to the electricity grids although, for present purposes, is near enough to warrant the conclusion that certain security risks would be recursive.

[93] Meaning that such micro-grids can be disconnected from the centralized grids architecture and continue to function independently.

impacts of national and regional security events on local operations.[94] Batteries used to store and deploy energy on demand are similarly flexible in deployment and application and are likewise difficult to characterize as centralized or decentralized technologies. Battery storage costs have also fallen at a remarkable pace over the past several years, nearly half since 2014, and are conservatively expected to drop by an additional 40 percent over the next five years.[95] Regardless of the trend line of future costs, battery deployments in centralized and decentralized battery projects are already booming at present prices.[96]

III. THE ELECTRICAL GRIDS SECURITY REGULATORY PARADOX & OPPORTUNITIES FOR REDESIGN

For most folks, the structure and systems of electricity delivery are not front-of-mind. Until the moment when a reliability event (e.g., after Hurricanes Katrina or Sandy) disrupts the modern patterns of life for families, companies, and governmental entities, the underlying infrastructure and design of the electricity architecture is rationally ignored.[97] Afterward, affected communities operate as best as they can, and the rest of the country, which continues to have access to immediately available electricity, mobilizes to help. Such reliability events have tended to be traumatic for those impacted. It is troubling to extrapolate what could occur if the U.S. experienced a broader scale system outage from a coordinated security event, one that lasted even a few weeks.

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[94] The risks are limited because the scale of the network is limited. The idea being that a small city (or, currently and literally, an island) could maintain an independent microgrid that would have the features of centralized electricity without the vast transmission interconnection so that a cyber-attack on a distant part of the centralized electricity architecture would not reach the microgrid system, assuming air gaps or similar.

[95] *See* LAZARD, KEY FINDINGS – LEVELIZED COST OF STORAGE ANALYSIS 2.0 2 (2016), https://www.lazard.com/ media/438041/lazard-lcos-20-executive-summary.pdf; *see also* LAZARD, LEVELIZED COST OF STORAGE ANALYSIS – VERSION 2.0 11–17 (Dec. 2016), https://www.lazard.com/media/438042/lazard-levelized-cost-of-storage-v20.pdf.

[96] *Id.*; *see also,* Gavin Bade, *Inside Construction of the World's Largest Lithium Ion Battery Storage Facility,* UTILITY DRIVE (Dec. 6, 2016), http://www.utilitydive.com/news/inside-construction-of-the-worlds-largest-lithium-ion-battery-storage-faci/431765/; David Hart & Alfred Sarkissian, *Deployment of Grid-Scale Batteries in the United States*, OFFICE OF ENERGY POLICY AND SYSTEMS ANALYSIS, U.S. DEP'T OF ENERGY (June 2016), http://davidhart.gmu.edu/wp-content/uploads/2016/11/Grid-Scale-Batteries-GMU-case-study-final-9-19-16.pdf. For an example of the flexible deployment of batteries in a different context, *see* Donald Chung, Emma Elgqvist & Shriram Santhanagopalan, *Automotive Lithium-ion Cell Manufacturing: Regional Cost Structures and Supply Chain Considerations*, CLEAN ENERGY MFG. ANALYSIS CTR. (2016), http://www.nrel.gov/docs/fy16osti/66086.pdf.

[97] A parallel might be drawn to the U.S. national defense, which, in its present form, does not require most people to spend days worrying about existential military threats to our country. It is no coincidence that both electricity and national defense are essential goods and that each is reliant on the other.

A. The Security Regulatory Paradox

Although much of the following exposition may be familiar or well-anticipated, it is worthwhile to take a brief detour to review a specific, well-known physical security event as a reminder that physical risks, not just cyber-attacks like the Ukrainian Grid Hack,[98] are real, as opposed to theoretical.

In 2013, Pacific Gas & Electric's (PG&E) Metcalf Substation in South San Jose was physically vandalized by a gunman(men) who fired over 100 rounds from an assault rifle at a substation.[99] The shots materially damaged seventeen transformers[100] causing approximately $15 million in damage, and it took PG&E nearly four weeks to return the substation to full operation.[101] The attack was not coordinated with attacks on other electricity infrastructure, and it did not result in a blackout of Silicon Valley as PG&E was ultimately able[102] to reroute electricity from other power stations, such that the only impacts were considerable expense, pressure on the local grid assets for a few weeks, and, perhaps, limited electricity rationing to the Valley for a period of the repair time.[103] The Federal Bureau of Investigation was officially unimpressed with the attack. "We don't think this was a sophisticated attack," said John Lightfoot, at the time the regional manager of FBI counterterrorism based in the Bay Area. "It doesn't take a very high degree of training or access to technology to carry out this attack."[104] Certain security and industry analysts strongly disagree with the FBI's conclusions and have argued that only a professionally executed and sophisticated attack could have resulted in the substation not exploding.[105] Following that line of reasoning, certain commentators have opined that the attack looked

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[98] *See* UKRAINIAN GRID CYBER-ATTACK, *supra* note 15.

[99] *See* David R. Baker, *FBI: Attack on PG&E South Bay substation wasn't terrorism*, S.F. CHRON, Sept. 11, 2014, http://www.sfgate.com/business/article/FBI-Attack-on-PG-amp-E-substation-in-13-wasn-t-5746785.php [hereinafter *Not Terrorism*] (reporting on comments made by Mr. Lightfoot at the Power Grid Resilience Summit held in San Francisco in 2014); *contra* CNA STUDY, *supra* note 3, at 7; CSPC STUDY, *supra* note 3, at 27–28.

[100] The damaged transformers were not Large Power Transformers.

[101] *See* CNA STUDY, *supra* note 3, at 7.

[102] Without providing specific detail, a coordinated attack of similar style could have resulted in more severe consequences.

[103] *See* CSPC STUDY, *supra* note 3, at 8. PG&E has noted that no customers lost power during the repair period. PG&E reviewed an earlier draft of the above summary of the Metcalf attack and had no comment.

[104] *See Not Terrorism*, *supra* note 99, at 1. Mr. Lightfoot went on to say that the gunman was not much of a marksman: "This guy was standing sixty yards away from a target the size of a house, and we didn't find as many bullet holes as we found rounds, which means that at least some of the rounds completely missed the target." *Id.* Others have pointed out that the assailants hit only the cooling fans at the very bottom of the transformers, indicating shooting ability and equipment knowledge.

[105] *See, e.g.,* CNA STUDY, *supra* note 3, at 7; *see also* CSPC STUDY, *supra* note 3, at 27–28.

much like system probing as a dress rehearsal for a future attack.[106] To date, the assailant(s) have not been arrested and the investigation remains open.[107] Mr. Lightfoot left the FBI in 2016 after twenty years to join PG&E in a compliance and ethics management role; he recently noted that despite speculation by others the FBI was (and remains) the federal lead agency on the investigation and, as such, is the only entity with the totality of information regarding the attack.[108]

The manner of the attack, and its relative success, led to subsequent calls from the utility industry, especially including certain regulators, for significant increases in public investment for grid hardening measures. It might reasonably have led to a rethink of the structure of the centralized grids architecture itself.[109] To wit, greater expertise, coordination, or tactical objectives on the part of the assailant(s) could have led to a weeks-long blackout of Silicon Valley; separately, the costs of implementing the proposed hardening measures to defend against similar attacks were and are large enough to alter the value proposition of centralized electricity delivery.[110] Why then was the primary response to the Metcalf incident an acceleration of lobbying for public funding for centralized grid hardening measures that, while making similar[111] future

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[106] *See, e.g.,* Shane Harris, *'Military-Style' Raid on California Power Station Spooks U.S.*, FOREIGN POLICY (Dec. 27, 2013), http://foreignpolicy.com/2013/12/27/military-style-raid-on-california-power-station-spooks-u-s/ (reporting comments from Mark Johnson, a former vice president for transmission operations at PG&E: "These were not amateurs taking potshots . . . my personal view is that this was a dress rehearsal for future attacks."). Mr. Johnson now serves on the Board of Directors at Midcontinent Independent System Operator, Inc. In this vein of interpretation, others have pointed out the example of the 1993 World Trade Center bombing, occurring eight years prior to the September 11 attacks.

[107] As of April 2017.

[108] Interview with John Lightfoot (Apr. 18, 2017).

[109] Because a centralized system is interdependent, a common suggestion from the utility industry has been to provide redundant physical assets (including large transformers, *see* Large Power Transformers discussion *supra* Part II.A.) and increase load sharing (through additional transmission assets and interconnection). Either choice is fantastically expensive (*see* discussion Part II.A.), wasteful versus alternatives, and introduces other problems and risks. One technical constraint to grid hardening is that the grids infrastructure is designed to disperse huge amounts of generated heat to open air. Without that natural cooling function, the grids would not operate efficiently, or at all.

[110] Repairs took nearly four weeks to complete and if one other unnamed asset were attacked, then a significant part of the Western Interconnection could have gone down. *See generally,* Rebecca Smith, *U.S. Risks National Blackout from Small-Scale Attack*, WALL ST. J., March 12, 2014 (Ms. Smith has written often on these and other security threats; here reporting comments of Jon Wellinghoff, former Chairman of FERC, that a coordinated attack on nine substations in the U.S. could take down the entire U.S. electrical system). Utilities have since built, for example, eighteen foot concrete walls (open from the top for heat ventilation like chimneys), improved security fencing, security patrols, motion detectors, and other security measures. These technologies all have deficiencies and are, together, inadequate to secure the vast U.S. electricity infrastructure. One ancillary technical problem is that critical electricity infrastructure generates huge amounts of heat which requires dispersion into the surrounding air, i.e., certain facilities can technically be enclosed but, again, the cost of doing so is fantastical.

[111] Responsive security protection measures are, by definition, rear-facing, whereas systemic security reviews focus on fundamental security design characteristics.

attacks relatively more difficult to carry out, have the effect of reinforcing existing systemic security risks?[112]

One reason might be that distributed energy sources were not economical in 2013.[113] Another piecemeal reason is that NERC,[114] investor-owned utilities, and most[115] state regulatory regimes are, by mandate, history, and/or an institutional will to survive, largely captive to existing technology and industry interests.[116] The true security regulatory paradox, however, is far more fundamental: the electricity industry nearly as a whole[117] is built on a historical dedication to a grids system that is owned, controlled, and operated from afar. That dedication constitutes the fundamental source of modern insecurity for electricity delivery.[118]

B. Immediate Policy Opportunities for Grids Security Redesign

The U.S. national interest in electricity may be expressed as universal and secure access to electricity for military and governmental facilities, companies, individuals, and all others, delivered at something near a socially desirable price. The national interest must predominate because electricity is a good that is essential to the functioning of an industrialized nation-state.[119] From the beginning of the grids, utilities have sought to profitably deliver electricity in a manner required by the public interest, all in the framework of tradeoffs with public regulatory authorities that are characteristic of government-granted monopolies.[120] Those efforts and that framework were supported by a centralized electricity architecture that required enormous social investment to economically meet the requirements of near universal access.[121] The resulting grids architecture is a technological marvel constructed by coordinated utility monopolies whose price and competitive contours are rigidly regulated. This grids architecture has performed exceptionally well for over a hundred years, although its defining technical characteristics now present existential risk to modern life in the U.S.[122]

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[112] Since that time, electric industry professionals also have the example of the cyber-hack of the Ukrainian grid system. *See* UKRAINIAN GRID CYBER-ATTACK, *supra* note 15.

[113] *See* discussion Part II.B.

[114] *See* discussion Part I.A.

[115] The Hawaii Public Utilities Commission is one counter-example, among a handful, motivated by a remote and isolated geography and source fuel costs and residential electric rates that are the highest in the U.S.

[116] *Id.*

[117] From regulators, academics, utilities, market traders, and transmission companies, to communication control companies, and many distributed power generation companies.

[118] Due to negative networked effects, for example, security risks of cyber-attacks and coordinated physical attacks.

[119] *See* discussion Part II.A.

[120] *See* discussion Part I.A.

[121] *See* discussion Part I.A.iii.

[122] *See* discussion *supra* note 3.

Today, and more so in the future, centralized systems face material negative networked effects vis-à-vis security risks. As further discussed below, properly configured decentralized systems do not.[123] At the same time, the march of technology has continued and distributed generation sources have now achieved cost parity with centralized delivery, with significant cost reductions expected to continue in the near-term including for decentralized systems as a whole.[124] Centralized electricity, by contrast, is becoming more expensive as transmission and distribution spending continues to outpace the investment needed to generate electricity in the first instance, and as investments in its security upkeep necessarily compound.[125]

The costs and benefits of fundamental technological change to the electricity grids are typically spread unevenly without regulatory intervention.[126] And, in fact, the electrical grids are experiencing disruption as private companies seek to capture the benefits of improved distributed technology by producing their own, lower-cost, decentralized generation, and incumbent utilities work to create disincentives and barriers to those efforts while seeking to cover costs of the existing grids that must provide universal access.[127] A conceptually similar, albeit practically different, circumstance is happening with utilities and individuals in the context of net metering.[128] From a national security perspective these haphazard developments and analytical frameworks are concerning. The question of how to economically utilize distributed energy sources for more robust and secure electricity procurement requires a broader public perspective coupled with formal planning. Specifically then, how should the electricity industry redesign the existing grids systems? The balance of this paper suggests opportunities and offers guideposts to steer the grids architecture toward a structure that is inherently more secure. That discussion is grounded in four basic observations:

First, as described in Part II, the centralized grids systems do not generate meaningful positive network effects and, instead, as the grids architecture becomes more interconnected, layered with control and monitoring communication, and central data repositories, its negative security networked effects become more pernicious. Two corollaries

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[123] *See* discussion Part III.B.ii.

[124] *See* discussion Part II.B.

[125] *See* discussion Part II.A.

[126] *See* Carmody *REA History*, *supra* note 43; *see also* Hughes History, *supra* note 18.

[127] Apple and Google, for example, have in the last few years formed wholly-owned and operated generation entities that serve as de facto utilities for sensitive data server farms that consume enormous amounts of power. Such projects are generally marketed as environmentally friendly actions, not defensive or offensive security measures.

[128] *See* discussion *infra* Part III.B.iii.

follow: (A) borrowing regulatory analogs from the communications industries is both misguided and dangerous; and (B) centralized fuel delivery poses recursive security risks.

Second, any alternate approach must necessarily evolve within the historical framework from which the U.S. approaches electricity: it is an essential good built on a history of vast social investment. Electricity, in a literal sense, underlies all essential functions of modern civilization.

Third, and as always, decisions regarding grids design must be viewed in the context of economically available technologies. At least two observations are relevant here. Centralized electricity delivery has, and will continue to, become more expensive over time, even more so if proposed grid-hardening measures are implemented at scale. Conversely, the interim-term operating trajectory of distributed energy sources is one of reduced costs, albeit at a decreasing rate following price stabilization.

Fourth, the centralized grids constitute a system worth more than a trillion dollars that will not be replaced, and should not be replaced, in the near or interim future. In considering policy options, it is socially desirable to inventory locally available generation abilities in the context of population and demand features such that monolithic "grid" thinking can be replaced by tailored grids and grids solutions. Each such solution must demonstrate that it will economically improve systemic grids security against the existing base case.

The following policy proposals are offered as course corrections to a centralized electricity delivery system that inadequately performs its necessary functions.

i. Require Military Security Review for Electricity Supplied to Domestic Bases

Domestic military installations are nearly wholly reliant on the commercial grid through power purchase agreements.[129] The officials that sign those contracts are required to adhere to minimum technically acceptable requirements, essentially meaning that the lowest-cost good that can be demonstrated to meet mission requirements must be selected unless a justification to the contrary is provided (and accepted).[130] While such standards are a conceptual barrier to sourcing electricity more securely, the practical reality is that any set of standards would be largely aspirational due to the monopolistic nature of power provision, i.e., each domestic operating base often has only one transmission company and generation company supplying power. Although military installations

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[129] *See* DEFENSE SCIENCE BOARD STUDY, *supra* note 45, at 5.

[130] Interviews with defense counsel that negotiate such contracts (Jan. 2017).

nearly uniformly have back-up generator options, those fuel sources are vulnerable to recursive fuel supply risks and are not intended to maintain facility power during a disruption lasting longer than recent experience. A prolonged disruption to the local grid infrastructure could therefore impact military readiness, potentially at the exact time it would be necessary to marshal resources. Such risks are untenable and are surfaced here to highlight the need for further dedicated study.[131]

ii. Promulgate Funded, Federal, Independence Standards

The magnitude of disruption for any security event affecting the grids is largely a function of the degree of the interdependence of its components.[132] The resulting damage is properly measured in its impacts on end-users, rather than outcomes for utilities and other industry companies and professionals.[133] One technical solution to respond to the outcomes of negative networked effects in the centralized grids is to promulgate security standards ("Independence Standards"), for the substantial deployment of air-gapped or islanded distributed energy sources to serve as a separate security layer for electricity delivery. An "air-gap" is a security feature used in, for example, nuclear facilities where sensitive computer systems and operating equipment are not networked with outside devices.[134] An "island" is a security feature whereby a micro-grid can function separately from the centralized grids. The lack of connectivity from the centralized grids isolates such assets, making direct disruption, including from afar, physically impossible, and indirect disruption practically difficult.[135] It also renders the centralized grids a less attractive target because the tactical advantage gained from a large-scale disruption would be mitigated: a community with a sufficient amount of air-gapped distributed energy sources is positioned to continue the basic hallmarks of civilization even if the centralized grids system were offline for an extended period. Crucially, such an approach

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[131] *See e.g.,* Jeffrey Marquesee, Craig Schultz, and Dorothy Robyn, *Power Begins at Home: Assured Energy for U.S. Military Bases*, NOBLIS, PEW CHARITABLE TRUSTS (Jan. 12, 2017); DEFENSE SCIENCE BOARD STUDY, *supra* note 45, at 6.

[132] *See*, *infra* note 158 (a failure in one part of the network can cascade through the grids system because, for one example, the need to continuously balance load within narrow bands); *see also* discussion *supra* note 76 (referencing the several billion-dollar blackout in 2003 caused by a tree branch damaging a transmission line causing problems that cascaded throughout the Eastern Interconnection).

[133] *See* BiPC CyberSecurity, *supra* note 3, at 13 (noting the purpose of the grids system is to provide electricity to consumers, not to maintain the system itself).

[134] *See, e.g.*, CHATHAM HOUSE SECURITY STUDY, *supra* note 59, at 1.

[135] Even the creative ways in which such systems have been compromised by human error are highly-involved approaches which would be challenging to implement at scale against hundreds of thousands of air-gapped distributed generation systems. Essentially, negative networked effects are removed from the system.

provides a long-term path for the transition of the existing grids architecture while providing interim protection against security risks.

FERC, rather than NERC, is the appropriate lead agency for promulgating Independence Standards. FERC's mission[136] is essentially to protect consumers (military, businesses, individuals), while NERC's mission is explicitly to protect the integrity of the centralized grids systems (utility interests) through standard setting for the bulk power system.[137] Despite being an obvious choice to act as lead agency, FERC would need substantial inter-agency (and state regulatory) consultation, and legislative guidance and funding to execute such a program effectively.[138] Inter-agency consultation would reasonably build on the numerous existing formal and informal programs and information sharing mechanisms between federal agencies, other public entities, and private interests, including utilities. Here, a formal proscribed consultation role for non-FERC agencies would provide an opportunity to rely and expand on existing institutional skill sets and agency powers, e.g., the Federal Bureau of Investigation (for information sharing, benchmarking system design, and general risk assessment), the Department of Homeland Security (for developing appropriate cyber-security standards), the Federal Emergency Management Agency (for community assessment and disaster planning), the National Renewable Energy Laboratory (for expertise on distributed grids design including micro-grids, and air-gapped and islanded technologies), and the Department of Energy more generally (for equipment standards and broad technical assistance).[139]

A reasonable starting point for planning to implement Independence Standards is to create a needs-based classification system for

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[136] A special agency might be considered but, unlike the REA, promulgation of such standards requires institutional expertise that already exists and extends beyond effectively executing a specified loan program. FERC would need legislative direction, including to overcome its institutional leaning toward centralized solutions. For FERC's stated mission, *see* discussion *supra* note 40 (noting FERC's mission is to assist consumers in obtaining reliable, efficient and sustainable energy services at a reasonable cost through appropriate regulatory and market means).

[137] NERC does collaboratively set mandatory standards for the bulk power system but its mission is focused on its utility sponsors. *See* discussion *supra* note 41 (noting NERC's mission is, specifically, to assure the reliability and security of the bulk power system in North America). Setting reliability standards within any existing system can be determinate of the design and implementation of solutions in the system itself. So too with the electricity delivery system, which is a primary reason that the investor-owned utilities success in imbuing NERC with quasi-federal regulatory powers was a coup for their interests.

[138] A programmatic goal of air-gapped distributed energy sources to isolate components would have the effect of displacing significant load on the grids, thereby impacting many different stakeholders. The vital role of states and municipalities is discussed in the following and final subpart.

[139] A legislative expression of intent is likely necessary for FERC to take such action, particularly as such actions pertain to residential markets.

consumers,[140] together with an inventory of community generation assets and minimum technical standards for deployed distributed energy sources. Regulatory examples for an inventory of community assets may be patterned on diverse existing sources such as emergency response plans. Similarly, existing regulatory standards for internet security protocols and ASTM patterned equipment rules could be repurposed to help ensure electricity system isolation and distributed generation equipment fidelity.[141] Independence Standards would be developed from a premise that locally abundant heterogeneous generation sources, whatever the source, have inherent security value, while fuel sources like coal that require long, involved, and vulnerable[142] supply lines are best consumed only in the immediate vicinity of mining areas where more secure source fuels are not economically available.[143] An inventory of existing local generation capabilities would assist in determining the distributed generation sources most appropriate for the relevant community.

The following provides an initial sketch of security problems and policy suggestions related to the deployment of air-gapped or islanded distributed energy sources:

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[140] Consumer classifications might reasonably start from one of three categories (excepting military assets which are predominant and addressed separately): (i) facilities that serve the role of first responders in their respective communities, e.g., hospitals, schools, police and fire stations ("Social Reliance Facilities"); (ii) businesses, and businesses whose activities invoke national security interests ("Businesses" and "Businesses+"); and individuals and residential assets ("Individuals"). The classification of consumers should be sought from a community perspective to reflect the interdependence of different classes of consumers, such as Social Reliance Facilities and Individuals. Social Reliance Facilities, as an example, serve end-users and, thus, are potentially less important if more Individuals have access to air-gapped assets because there would be fewer individuals to care for in the first instance. A test for the appropriate amount of air-gapped assets for Individuals might be a simple percentage test (say 25%) necessary to maintain general social cohesion, while Social Reliance Facilities would reasonably need to be reviewed on a case-by-case or asset class basis.

[141] The simple idea being that the fundamental integrity of the deployed decentralized systems should meet minimum technical standards. As with ASTM, manufacturing and installations companies should work collaboratively on such standards.

[142] Train derailments, bridge outages, and inclement weather are just three circumstances that can severely interrupt coal supplies for extended periods. *See, e.g.*, U.S. DEP'T OF ENERGY, DELIVERIES OF COAL FROM THE POWDER RIVER BASIN: EVENTS AND TRENDS 2005–2007, INFRASTRUCTURE (Oct. 2007), https://www.oe.netl.doe.gov/docs/Final-Coal-Study_101507.pdf (describing supply problems experienced by Midwest utilities in 2005 when a train derailment interrupted deliveries from the Powder River Basin in Wyoming).

[143] The upshot from a pure security perspective, ignoring public health impacts which of course cross state lines, is that certain parts of Wyoming might elect to employ local coal power generation due to plentiful and proximate supplies in the Powder River Basin. Or, perhaps not, based on Wyoming's abundant wind capabilities. States like Minnesota, which have nominal in-state mining, should not incur the security risks of using coal as a source fuel.

Security Problem	Policy Suggestion
Cost of deploying air-gapped or islanded distributed generation and storage assets	Necessary investment capital should be obtained through (i) a decrease in investment in centralized generation, transmission, and distribution infrastructure; and (ii) federal security block grants[144] to states to defray the costs of deploying distributed generation and storage assets. Federal security block grants would be premised on the national interest in secure electricity delivery.
Regulatory and electricity industry commitment to centralized delivery system	Independence Standards must require state and/or local policy decisions to demonstrate how new electricity infrastructure investment will lead to decreased systemic risk in electricity delivery against available alternatives. In the short-term, the goal of such measures is to cause security externalities to be incorporated in the market price of electricity. Once market prices reflect security externalities, deployment of air-gapped or islanded distributed energy sources or microgrids should be generally governed by market forces of supply and demand for Business and Individual consumers. Social Reliance Facilities, because of their often-public nature, may require a mixture of market and non-market solutions to achieve a faster transition.
Recursive risks of centralized fuel supply lines	Generation resources should be matched with locally available economic source fuels, regardless of type, excepting perhaps coal. The implementation of the security objectives for

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[144] References to "block grants" in this paper are intended to approximate a definition set forth in a Congressional Research Service survey publication, i.e., a form of grant-in-aid, at a specified amount, that the federal government would provide to state and local governments to assist in addressing the broad purpose of meeting the national interest in secure electricity generation and delivery. *See* Robert Jay Dilger and Eugene Boyd, CONG. RESEARCH SERV., R40486, BLOCK GRANTS: PERSPECTIVES AND CONTROVERSIES (July 15, 2014), https://fas.org/sgp/crs/misc/R40486.pdf. Local generation and delivery of electricity directly implicate the U.S. national security; however, an efficient approach to securely delivering that electricity will likely depend on state implementation in the context of local considerations, e.g., naturally available fuel types, unique demand characteristics, geographies, and so forth. Thus, on the continuum between project categorical grants and revenue sharing, blocks grants, as used herein, are intended to occupy a middle ground hewing somewhat closer to project categorical grants. Further distinctions are indicated in the policy prescriptions, while a fuller exploration is beyond the scope of this paper.

	"economic and locally available source fuels" may reasonably be determined at state and municipal levels for Individual and Business communities, while rules and standards for Social Reliance Facilities likely require more ongoing federal involvement.
Untenable risk of remote control and monitoring devices	Independence Standards for air-gapped or islanded distributed energy sources must equally reflect the need for careful regulation of networked devices, such as those from Nest Labs and internet-of-things devices. Likewise, remote monitoring systems not designed to function as part of a micro-grid should be strictly evaluated. Such technologies are of suspect value when scaled and directly undermine the benefits for implementing an air-gapped or islanded distributed system.
Recursive risk of SmartGrid technologies	Similar to the above, smart grid technologies should be less prevalent and/or more local. While the delivery of electricity does not inherently include meaningful positive networked effects, communication capabilities at scale necessarily result in significant negative networked effects vis-à-vis security risks.
Risk of distributed generation assets being insufficiently "hard"	Establish requirements and/or reward industry effort to develop and adhere to minimum accepted resiliency equipment standards against, for example, electromagnetic pulse events and other high-profile risks.

iii. Reorient State Regulatory Policy Toward Implementing Independence Standards

Under the above framework, states together with their constituent municipalities would be tasked with the implementation of Independence Standards in line with traditional state regulatory powers and established principles of federalism.[145] States and municipalities would meet federal security goalposts through local decisions on energy production, social

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[145] Recognizing states' traditional role in regulating real property, intrastate water, and mineral resources, in addition to the established power to regulate local retail electricity markets.

cost allocation, and system design. Pairing Independence Standards with local implementation would provide a security touchstone for determining which groups, technologies, and approaches are best locally-suited to meet secure electricity delivery goals. All such determinations would occur in the context of an existing grids architecture that will require sustained upkeep. The investment required to redesign the electricity delivery system should include a combination of at least two approaches: (i) savings resulting from decreased new utility investment in centralized generation, transmission, and distribution infrastructure; and (ii) federal security block grants[146] to states to mitigate the costs of deploying distributed generation and storage assets and ensure the resulting system changes reflect the national interest in electricity security.

Local implementation is appropriate as state or local decision-makers are best situated to make the necessary decisions on allocating social costs incurred in the transition from the existing technological system. Nonetheless, recent state experience in allocating profits for electricity generation through the net metering[147] framework, whether constructed as a tax or incentive, should be approached skeptically. Net metering frameworks are largely focused on allocating profits rather than determining optimal system design, considerations which are largely misplaced in the redesign of the electricity delivery infrastructure. An historical analogy would be if the U.S. pursued rural electrification by focusing, in the first instance, on how to protect the profits of the companies providing electricity, rather than ensuring that rural farmers obtained the benefits of electricity for their farms.[148]

The dangers and deficiencies of the net metering debate framework are well illustrated by experiences in Arizona and Nevada. Both states have been at the forefront of the net metering debates and are states where the primary naturally available source fuel is solar, rather than wind, coal, or gas. A microcosm of the Arizona experience is represented by a case from 2015, in which a local utility[149] servicing nearly 1 million consumers in the Phoenix area sought to implement a $50 per month

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[146] See discussion, *supra* note 144.

[147] Net metering is, simplifying, a diverse set of regulatory programs by which distributed generation, most frequently from renewable sources such as PV modules, is connected to the local distribution network of the centralized grids and the owner of such generation is either compensated or taxed, or both, for that outcome. This is an area of great tumult and strong feelings by interests on all sides.

[148] The rural electrification debate did include those elements and interests, of course, but legislative intent and careful programming made the program's overall goal clear for all participants, and the national interest in obtaining the food produced by more productive farmers was ultimately achieved. *See generally* Carmody *REA History*, *supra* note 43.

[149] The Salt River Project is an umbrella organization that includes the Salt River Project Agriculture Improvement and Power District ("Salt River Power"), an agency of the state of Arizona. *See* SALT RIVER PROJECT, www.srpnet.com [last visited Apr. 2017].

surcharge on owners of rooftop solar systems (purportedly to recover grid system costs, and in an even sum).[150] The average utility bill in Arizona in 2015 was approximately $124.[151] At least one rooftop solar company determined its business interests were threatened and it sued the utility; that litigation was ongoing as of early 2017.[152] A year after implementing the surcharge, in September of 2016, the same utility announced that it had entered a 25-year power purchase agreement with Apple, Inc., the phone manufacturer, to purchase (not sell) 50MW of utility-scale solar power constructed by Apple.[153] Both of these decisions by the local utility appear rational when evaluated through the prism of its narrow business interests, and the fuel source in both cases is the same (i.e., it is not a solar versus coal dynamic). From a national security perspective such decisions, the announced justifications, and the litigation, are, however, entirely untethered from vital considerations of security and system design.[154] Nevada, in certain respects, represents an opposite approach, having followed a more thoughtful and considered, and slightly less litigious path.[155] In 2014, the Nevada Public Utilities commissioners perceived a need to evaluate the state's net metering program and employed a well-known economics consultancy to produce a report on the benefits and disadvantages of its net metering policies.[156] The state followed up on that useful report with a cost and benefit calculator intended as a guide to setting policy decisions regarding net metering. In May of 2016, environmentalists together with rooftop solar interests collaborated on a white paper that commented on the report

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[150] *See Public Pricing Process*, SALT RIVER PROJECT, http://www.srpnet.com/prices/priceprocess/default.aspx [last visited Apr. 2017].

[151] *See* U.S. ENERGY INFO. ADMIN., 2015 AVERAGE MONTHLY RESIDENTIAL BILLS BY STATE, http://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf.

[152] Solarcity Corp. v. Salt River Project Agric. Improvement & Power Dist., No.15-17302 (9th. Cir. 2017) (challenging Salt River's proposed $50 per month surcharge on owners of rooftop solar systems).

[153] *SRP Launches Major New Renewable Energy Project with Apple*, SALT RIVER PROJECT (Sept. 21, 2016), http://www.srpnet.com/newsroom/releases/092116.aspx (stating under the terms of the 25-year power purchase agreement, Salt River Power will buy 50MW of generation from the plant). Interestingly in the context of these difficulties, SRP holds a 42.9% ownership interest in the largest coal plant in the West, the Navajo Generating Station, originally constructed in 1969-1976. SRP announced earlier this year that the plant is scheduled for closure in 2019, *see* Ryan Randazzo, *Utilities vote to close Navajo coal plant at end of the 2019*, ARIZONA REPUBLIC, http://www.azcentral.com/story/money/business/energy/2017/02/13/utilities-vote-close-navajo-generating-station-coal-plant-2019/97866668/ [last visited Feb. 28, 2017].

[154] NERC's mandatory security standards do not encourage the mitigation of systemic security risks resulting from negative networked effects, indeed such a consideration is outside the ambit of NERC's mission and experience.

[155] This is not to imply that the process has been friendly, only more considered than the events in Arizona.

[156] That report, by Energy+Environmental Economics (E3), was updated in August of 2016. *See* E3, NEVADA NET ENERGY METERING IMPACTS, http://pucweb1.state.nv.us/PDF/AxImages/DOCKETS_2015_THRU_PRESENT/2016-8/14179.pdf.

and calculator with an eye toward adjustments that would better reflect the technical, social, and economic conclusions that such groups believed and favored.[157] The Public Utilities commissioners commissioned a follow up study that was released in August of 2016, and discussions were ongoing as of early 2017. Despite Nevada's more considered approach, no participant in the Nevada discussions addressed fundamental security considerations either.

The relevancy, and universality, of the Arizona and Nevada experiences is that the net metering debate cannot be expected to produce a framework in which fundamental security and design considerations are even surfaced. The participants in such debates are acting out of narrow interest and understandably no participant is representing the national interest. That dynamic, while it may serve its purpose, results in heightened security risks if the national interest is not otherwise represented in actions that impact the technological path of grids development. Consider, for example, the impacts of a 2011 service disruption resulting from a routine maintenance problem on a single 500kv line in Arizona.[158] That line, operated by Arizona's largest utility, cascaded into a blackout of most of Arizona, Southern California (including the entire City of San Diego), and part of Baja, Mexico.[159] Although that event did not impact electricity services in Nevada, any number of scaled security events would impact Nevada and every other state on the Western Interconnect.[160] Shared vulnerability is the rule not the exception as all U.S. utilities (and most distributed power companies) are reliant on a centralized electricity delivery architecture. Shared reliance and vulnerability must be explicitly addressed in state/local deliberations and the current net metering framework does not offer an opportunity for the national security perspective to be represented.

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[157] SOLARCITY AND NATURAL RESOURCES DEFENSE COUNCIL, DISTRIBUTED ENERGY RESOURCES IN NEVADA, http://www.solarcity.com/sites/default/files/SolarCity-Distributed_Energy_Resources_in_Nevada.pdf.

[158] Botched maintenance on a single 500kv APS' transmission line was the precipitating cause of a blackout in 2011 that left 2.7 million consumption end-points (individuals, factories, business towers) without electricity in Arizona, Southern California, and Baja, Mexico. FED. ENERGY REGULATORY COMM'N AND N. AM. ELEC. RELIABILITY CORP., ARIZONA-SOUTHERN CALIFORNIA OUTAGES ON SEPTEMBER 8, 2011 (Apr. 2012), http://www.nerc.com/pa/rrm/ea/September%202011%20Southwest%20Blackout%20Event%20Document%20L/AZOutage_Report_01MAY12.pdf.

[159] APS was not the sole cause of the outage, in fact FERC fined various entities including a $12 million fine of The Imperial Irrigation District for its role in the failures. APS was fined $3.25 million. *Id.*

[160] As demonstrated by the 2003 Blackout; *see also* Smith, *supra* note 110 (J. Wellinghoff's comment that taking nine substations offline could take down the grids system, in total).

IV. CONCLUSION

The U.S. national interest in electricity delivery is uncomplicated: universal and secure access to electricity for all consumers (i.e., military and governmental facilities, companies, individuals, and all others), delivered at something near a socially desirable price. Centralized electricity delivery carries with it demonstrated vulnerabilities that cannot be extricated from its fundamental design. Decentralized electricity delivery systems, properly designed and deployed, are inherently more secure. Meanwhile, the costs of centralized electricity delivery are increasing while the costs of decentralized electricity systems are falling rapidly.

Security risks are serious and important considerations at both the federal and state/local levels. States and municipalities, however, must balance attention to security issues with impacts to ratepayers and local civic institutions and employers. The federal and state interests thus overlap but oftentimes diverge and that divergence presents security and economic risk to all constituencies. Such risks are imminently addressable.

FERC, together with other relevant federal agencies, can provide a national framework for addressing security risks by developing and enforcing Independence Standards. Simply setting standards is insufficient if not coupled with federal support to mitigate the social and economic costs that will necessarily be incurred to make the U.S. electricity delivery system more secure. Federal block grants to states, grounded in the U.S. national interest in secure and available electricity for all consumers, are necessary to defray economic costs in the transition away from centralized delivery. Block grants are an appropriate mechanism for delivering federal support, while retaining flexibility for state and local decision-makers to account for local social costs. State and/or local leadership is likely best positioned to determine the most effective and socially efficient means for achieving the requirements of the Independence Standards, all within their respective political, technical, demographic, source fuel availability, and geographic circumstances. Net metering, as presently constructed, is a fundamentally inapposite framework for making such state-level determinations. Whatever mechanisms states and local decision-makers employ to achieve the transition of the grids architecture, such grids redevelopment plans must demonstrate, in intent and execution, an ability to achieve the goals of the Independence Standards in reciprocation for federal energy security block grants.