Local Power Networks

Building Electricity Generation and Delivery

optimized for

Accessibility, Affordability, Security and Resilience

A Policy and System-Design Blueprint

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Overview

This document presents a conceptual “blueprint” for solar-based Local Power Network mini-grids optimized for accessibility, affordability, security and resilience, and for rapid decarbonization.

The goal of this Local Power Network (LPN) blueprint is to advance an energy generation and delivery system that fully recognizes electricity as a basic human need while accelerating the development of a carbon-free electricity system.

At this time, two principal pathways to electricity decarbonization are being implemented in the United States. One follows a conventional, centralized approach primarily relying on utility-scale solar and wind generation delivered over expanded transmission grids. The other is an emerging “distributed energy resources” (DER) model, relying primarily on distributed devices and infrastructure to enable load control and obtain “grid services.” In both approaches the control is top-down, the drivers are primarily financial and the operation is optimized for profit production.

Alternatives to these two pathways have been proposed, including DER-based systems that use a “bottom-up” and layered building block approach. The LPN model draws from these emerging concepts but interweaves crucially distinctive threads. The novelties of the LPN structure are:

1) a non-price mechanism within each mini-grid to incentivize and maximize self-sufficiency;
2) an integrated generation plus storage resource pool – called a reservoir – to enable the network to operate independently, with power only incidentally drawn from or exported to the transmission grid; and
3) local, not-for-profit ownership, coupled with local operational control.

This draft blueprint provides a countermodel to mainstream transition pathways, which are premised on the idea that profit optimization must be the driving mechanism for electric energy supply. It is also intended as a countermodel to mainstream plans that are designed so that household and other small end-user electricity consumption and generation are managed to benefit the bulk power system. The LPN model optimizes, instead, for the benefit of users themselves. Absent a coherent alternative model, the electricity transition now underway seems likely to set in place systems that will be far less than optimal for the smaller players, whether these are individual households, small businesses, or local or remote communities.

1. Purpose and Background

At this stage in human technological and social development, and in view of the effects of climate change, electricity has arguably become a fundamental human need. On national, regional, state and local levels, the design of the electricity supply system should recognize this reality. In addition, electricity production is a prime contributor to climate change. And, crucially, the electricity supply system can be disrupted by climate-related impacts.

Two principal pathways to electricity system transition are being rolled out now in the United States. One takes a conventional top-down approach, primarily relying on utility-scale generation sources delivering power over expanded transmission grids. The other is an emerging "distributed energy resources" (DER) approach in which devices are widely distributed but control remains top-down and the operating system is grid-services centric. In neither case is system design optimized for affordable, universal electricity access or for maximal decarbonization.

This document presents a conceptual blueprint for an electricity generation and delivery system designed to address electricity as a basic human need and to decarbonize generation and supply -- a system of Local Power Networks (LPNs) optimized for accessibility, affordability, security and resilience, and for decarbonization.

LPNs are an alternative, bottom-up approach, relying predominantly on local distributed solar power generated at or near the point of use. LPNs are mini-grids, locally-owned and operated, comprised of generation and storage at both the individual building level and at the network level. LPNs offer an untapped pathway that could be implemented at large scale within the energy transition now underway. The LPN design draws on a tapestry of emerging "bottom-up" concepts that offer alternatives to the two predominant pathways being devised in the U.S., but the LPN model weaves in crucially distinctive threads.

System Design: Key Characteristics

- **Generation and storage are sited close to load, creating efficiencies both economically and in terms of reduced energy loss from remote generation sources that rely on long-distance transmission.**
- **The system incentivizes self-generation and storage and energy self-sufficiency.**
- **LPNs support energy efficiency, including self-determined load-shifting at the individual building or local network level.**
- **Electricity power-pooling at the local level (detailed in sections below) is enabled and operated using a non-price mechanism.**
- **Per-kWh costs to participants are reduced four ways: 1) hardware cost savings (e.g., bulk purchasing of solar and battery storage equipment); 2) elimination of investor profit-taking at the LPN level; 3) absence of transmission charges; and 4) non-monetary power pooling.**

- **Inverters and other controllers are programmed for control by the LPN operator and network participants.**
- **LPNs reduce the number of grid interconnections and move the concept of "virtual power plant" from the individual household level to the LPN level, simplifying bulk power system operations while undergirding local control.**
- **The LPN model recognizes electricity as a basic human need. It reflects a view of electricity as a public good[1] not in a moral sense nor (necessarily) through public provision, but reflects the reality that public action – policy and financial supports – are required to ensure that electricity is universally accessible and affordable and its supply is secure and maximally decarbonized.**

It is clear from a large body of technical literature and industry studies that locally controlled, operated and owned solar and storage networks are *technologically* feasible. The principal issues revolve around institutional structures and finance. These are discussed below.

Why this pathway is needed

A transition is underway in how electricity is generated, distributed and accessed in the United States. The transition is being driven primarily by climate change and its present and projected impacts. Laws and commercial pressures to decarbonize electricity generation and delivery are driving technological change, which has been advanced by government policies and supported by government finance.

The energy transition will require a significant amount of new investment. Industry and government leaders recognize this and some acknowledge it.[2] Decarbonization can increase the cost of electricity production in the near-term. In coming years, public utility regulators will be inundated with requests from utilities for rate increases, most of which will likely be approved. Ratepayers' bills will go up. Already, electricity is unaffordable for many -- 20 million U.S. households are behind on their electricity bills, and utilities have shut off residential electricity to millions.[3] Energy poverty is significant: 27% of U.S. households experience energy insecurity, sometimes foregoing food and medical care to pay for energy.[4]

Increased electricity consumption by industrial users will exacerbate these problems. After decades in which demand was essentially flat, utilities now project skyrocketing demand[5], driven largely by data centers, especially for A.I.[6] Other contributors to demand growth projections include crypto-mining and other industrial and commercial uses, as well as residential uses because of increasing electrification. This demand surge will hit a grid already at or near capacity[7], with much of the cost for

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[1] See discussions of public goods at Sekera, J. "Re-thinking the Definition of 'Public Goods'", *Real World Economics Review*, July 9, 2014; and in Sekera, J. (2016), *The Public Economy in Crisis; A Call for a New Public Economics*.
[2] For example, see discussions of cost concerns in: *Pathways to Commercial Liftoff: Virtual Power Plants*, U.S. Dept. of Energy Sept 2023; "Real Reliability; The Value of Virtual Power", prepared by Brattle Group for Google; Hledik & Peters, May 2023; and *Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035*, National Renewable Energy Laboratory, Denholm et al. 2022.
[3] Utilities shut off power an estimated 4.2 million times in the first 10 months of 2022 - "Powerless in the United States" Center for Biological Diversity, 2023.
[4] Energy Information Agency data reported in Congressional Research Service Jan 31, 2023 https://crsreports.congress.gov/product/pdf/R/R47417
[5] "The Era of Flat Power Demand is Over", Grid Strategies, Joh D. Wilson & Zach Zimmerman, Dec. 2023.
[6] The *Washington Post* in 2024 produced a series of eleven articles, under the rubric, Power Grab, on the surging demand caused by data centers, particularly A.I. data centers.
[7] "The Era of Flat Power Demand is Over", Grid Strategies, Joh D. Wilson & Zach Zimmerman, Dec. 2023.

grid upgrades borne by residential ratepayers unless alternatives are found.[8] Such cost shifting – from private corporations to households – goes largely unacknowledged.

Meanwhile, climate change impacts are taking a mounting toll on system reliability. Communities and local governments are increasingly anxious about the growing frequency and duration of local power outages[9] in the wake of disasters caused by severe weather, flooding and fires. While operators and owners of the electric power system[10] look to expand and enhance transmission grids, thereby enhancing private profits under the present regulatory framework, improvements to the transmission system will not solve the problem of faltering local system resilience.

Another issue of concern for electric system operators and owners is "grid defection".[11] As the costs of rooftop solar PV and battery storage continue to decline, increasing numbers of customers will opt for self-generation where it is financially feasible. Over the last decade, investor-owned utilities (IOUs) and their financial beneficiaries have expressed concern about a utility and grid "death spiral" as customers opted to self-supply at less cost.[12]

Attempting to deal with these dilemmas, system stakeholders and planners are undertaking to configure an electric power system that can respond to increasing demand, maintain or increase profitability (in the case of IOUs) and decarbonize. In an attempt to meet its decarbonization targets, the federal government is supplying technical expertise and financial subsidies to greatly expand the bulk power system (both utility-scale generation and power transmission) in order to incorporate increased production from utility-scale, remote wind and solar projects. Utilities and bulk system actors are struggling to find ways to further expand generation capacity and transmission infrastructure to meet surging demand from new and planned A.I. data centers. In the process, they are delaying the closure of coal- and gas-fired power plants, as well as building new gas-fired plants,[13] undercutting the nation's ability to meet decarbonization targets.

However, utility-scale wind and solar supply is stumbling. Wind generation is running into significant opposition, with plans for wind farms offshore and on land increasingly being scuttled. Likewise, plans for new utility-scale solar generation are meeting strong and widespread local opposition. And on top of it all is the "bottleneck" in which more than 2,000 gigawatts (GW) of potential generating capacity, amongst thousands of solar and wind utility-scale proposed projects, is held up awaiting studies and approvals by grid managers. In short, centralized utility scale expansion is faltering.

Simultaneous with the strategy of expanding utility-scale generation and transmission, and in recognition of the obstacles being encountered, the federal government and its industry research-lab contractors along with large energy consulting firms, large technology corporations (and, increasingly, utilities), are designing and rolling out a "distributed energy resources" (DER) strategy – a configuration that enables a new business model, with new income streams for industry actors, and obtaining "grid services" from customers. Households and other small customers are expected to become energy arbitrageurs, monitoring and responding to price signals from their smart devices.

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[8] "Amid explosive demand, America is running out of power", Evan Halper, Washington Post, March 7, 2024.

[9] The frequency and duration of power outages in the U.S. are increasing, with outages from severe weather doubling in the past two decades.

[10] The Electric Power System (EPS) includes generation, transmission & distribution.

[11] Grid defection has been a concern of utilities for decades. And a new research paper suggests it is economically sensible in some solar-rich U.S. locations (Sadat, S. A. & J. M. Pearce; Nov. 2024, "The threat of economic grid defection in the U.S. with solar photovoltaic, battery and generator hybrid systems"; *Science Direct*). Also see RMI reports; 2014 and 2022: "The Economics of Grid Defection: When and Where Distributed Solar Generation Plus Storage Competes with Traditional Utility Service" 2014; Dyson, M & R. Gold, April 17, 2022; "Grid defection and net energy metering".

[12] E.g., e.g., see "The Economics of Grid Defection", RMI 2014.

[13] 220 new gas fired power plants are in stages of development across the U.S.

These plans entail the rollout and sale of new electronics. Much of this planning has been advanced and financed by the federal government, which enlisted technology companies, utilities and grid operators to develop a "unified" approach.[14] Yet, although the technology may be distributed, the DER models being planned retain a hierarchical, top-down control structure.

Technological and investment choices that public and private leaders are making now will determine how, when and the extent to which people will have access to electricity in the future. Arguably, the two present pathways – conventional grid expansion and top-down DER -- are failing to address in whole or in part the fundamental needs of our households, communities and nation: electricity supply that is affordable to and accessible by all, secure and reliable, within a decarbonized electricity supply system.

System design should recognize the reality that solar energy is an abundant, non-depletable energy source, unlike legacy sources of energy used for electricity generation - principally fossil fuels[15] – which are limited in supply and ultimately depletable. Access to abundant and "free" solar energy has been gated, and therefore limited, by the market-organized electricity supply system prevalent in the U.S. Likewise, the designs of new supply models being planned are optimized for private profit potential. This includes both utility-scale solar and wind as well as the mercantile DER/"grid services" model now being configured by energy and technology industries, policymakers and consultants.

The physical properties of solar and wind as primary energy sources can revolutionize electricity access. With solar and wind, once the infrastructure to utilize it is in place, the cost of generation approaches zero because the "fuel" does not have to be purchased. In contrast, with fossil fuels, even when the electricity generation and delivery infrastructure is in place, there is perpetually a cost to obtain, transport and utilize the fuel. These properties mean that whereas a market system might be suitable for fossil-fueled electricity supply, the dynamics of a market system can be unsuitable and even counter-productive when the energy source is free and abundant. For example, in U.S. regions where solar is a significant share of supply, there are frequent instances of "excess generation" when solar production is at its peak and solar power is "curtailed". With no market value, production of electricity is impeded or the product is in effect discarded. In part, curtailment is due to an inadequate grid that is unable to handle, export or store the power, but the fundamental problem is pricing dynamics. At times of "oversupply" the energy produced has zero value, and sometimes even negative value in the market system that now controls electricity supply for most people in the U.S. The marginal cost of electricity produced from wind and solar is near-zero,[16] and in competitive markets, prices will tend toward marginal production costs[17]. As Pollard and Buckley[18] point out, "Renewables are deflationary…" While the deflationary impact of renewables would be a positive for customers, it is a negative for a market-organized electricity supply system, undercutting the profit expectations of electricity producers and bulk system traders. The economics of renewables means that they are often at odds with the profit-reliant model of electricity generation and delivery predominant in the U.S. In sum, the use of a market mechanism to supply solar energy can lead to inefficiencies, waste, higher costs and inaccessibility to a vital human need -- a problem that has been largely unacknowledged by most U.S. policymakers.

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[14] The "UNIFI Consortium" was funded by the U.S. Dept. of Energy in 2021 and housed under the National Renewable Energy Lab. Members include electric utilities, grid operators, universities and technology companies.

[15] This paper does not discuss nuclear energy as it represents only about 19% of U.S. electricity generation. and because, in terms of energy sector interests, the fossil fuel industry has been the primary obstacle to the model presented in this Blueprint.

[16] Pollard, Matt and Tim Buckley (2024) "Queensland's Energy Transformation: From Coal Colossus to Renewable Energy Superpower;" *Climate and Energy Finance*.

[17] Economists letter to U.S. Sen. Christopher van Hollen Oct. 26, 2021 on the "Polluters Pay Climate Fund Act" legislation introduced in Aug. 2021.

[18] Pollard, Matt and Tim Buckley (2024) "Queensland's Energy Transformation: From Coal Colossus to Renewable Energy Superpower;" *Climate and Energy Finance*.

Numerous researchers have identified the ways in which the current U.S. electricity supply system, with its dependence on market dynamics, has been counter-productive for ratepayers. John Farrell, Co-Director of the Institute for Local Self Reliance, in his 2024 report “Upcharge: Hidden Costs of Electric Utility Monopoly Power”, aims to educate activists and policymakers about the problems, costs, and conflicts-of-interest in the profit-driven, monopolistic IOU model of electricity supply. Tyson Slocum in 2007 and McKay & Mercadal in 2023[19] revealed the failures of “deregulation” to reduce prices as had been predicted. Instead, it resulted in higher wholesale prices and an increase in retail rates to end users. Energy system expert and engineer Bill Powers, in a 2020 report for the city of San Diego,[20] showed how replacing the incumbent IOU with a not-for-profit utility could enable the city to move to a decarbonized electric system and lower rates for customers largely by moving to local solar generation and storage. Welton (2021)[21] discusses how the “United States’ functionally privatized mode of electricity governance”, and control of the grid by fossil fuel corporations, produces results that favor “private interests at the expense of societal goals.”

Evidence suggests that the least-wasteful and likely least-cost[22] model for a decarbonized electricity system that can enable universal access and affordability will be one in which generation and storage are sited close to load and under local control. In other words, a “bottom-up system” (as Lorenzo Kristov has put it [23]). The foundational layer is solar PV -- on rooftops, parking lots, and other sites in the built environment – which, in the LPN model, is integrated with local storage at both the building level and community level. Local control is necessary so that these systems can be *optimized for user benefit* -- affordability, accessibility and security.

Small-scale, locally-generated solar power could meet much of the nation’s electricity demand now and in future. One study[24] conservatively estimates that rooftop solar alone has the technical potential to generate electricity equivalent to about 45% of all national electricity sales at the 2022 level of U.S. demand. The Center for Biological Diversity in a 2023 report,[25] estimated that the generation potential of solar PV on rooftops is 37% of the amount of electricity sold in 2022, and that adding parking lots puts the generation capacity at *greater than* the total 2022 level. A 2021 international study[26] estimated the rooftop solar potential in the U.S. at 4,247 terawatt-hours per year (TWh-yr), which is greater than U.S. total electricity demand of ~4,000 TWh-yr.

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[19] Slocum, Tyson (2007) “The Failure of Electricity Deregulation: History, Status, and Needed Reform” https://www.ftc.gov/sites/default/files/documents/public_events/Energy%20Markets%20in%20the%2021st%20Century:%20Competition%20Policy%20in%20Perspective/slocum_dereg.pdf . And see MacKay, Alexander & Ignacia Mercadal (2023) “Do Markets Reduce Prices? Evidence from the U.S. Electricity Sector”; Working Paper 21-095, Harvard Business School. https://www.hbs.edu/ris/Publication%20Files/21-095_5398d456-f1de-432d-9a0b-cc7a58b51145.pdf

[20] Powers, Bill; “Roadmap to 100 Percent Local Solar Build-Out by 2030 in the City of San Deigo” (2020) https://tinyurl.com/2p5txywx

[21] Welton, Shelley (2021) “Rethinking Grid Governance for the Climate Change Era” , University of Pennsylvania Carey Law School Legal Scholarship Repository.

[22] E.g., Pollard, Matt and Tim Buckley (2024) “Queensland’s Energy Transformation: From Coal Colossus to Renewable Energy Superpower;” *Climate and Energy Finance*.; Role of Distributed Generation in Decarbonizing California by 2045 Vibrant Clean Energy (2021).

[23] Kristov, Lorenzo, “Power System Evolution From the Bottom Up”, Oct. 2018; Kristov, Lorenzo, “Building the 21st Century Electricity System” 2021; Kristov, Lorenzo, “A new value proposition for electric distribution networks” in *The Future of Decentralized Electricity Distribution Networks*, F. Sioshansi Ed. 2023.

[24] Neumann, Johanna & Tony Dutzik (2024) *Rooftop Solar on the Rise*; Environment America and Frontier Group.

[25] Center for Biological diversity (2023) “Pursuing a Just and Renewable Energy System; A Positive & Progressive Permitting Vision to Unlock Resilient Renewable Energy and Empower Impacted Communities”

[26] Joshi, Siddarth et al., (2021) “High resolution global spatiotemporal assessment of rooftop solar photovoltaics potential for renewable electricity generation”; *Nature Communications*; doi.org/10.1038/s41467-021-25720-2. This study assumes rooftop availability on the high side (100% availability) but assumes panel efficiency on the low side, at 10%, whereas panels are now at ~20% efficiency.

Sites with solar and battery storage do not necessarily need to be grid connected. It is technologically possible for networks of residential and commercial rooftop solar systems to operate off-grid, as mini-grids already do in other places in the world. But mini-grids can be grid connected, enabling two-way power transfer with the bulk power system on an "as needed" basis. Another name for these grid-connected mini-grids is Local Power Networks (LPNs).

LPNs in the U.S. would not entirely displace utility-scale generation and transmission of renewable energy. Regionally, and nationally, prioritizing the LPN concept means that local generation sources would eventually supply the major share of electricity for residential demand. The bulk power system would supplement LPN generation and storage, and would be much smaller in geographic footprint -- and require less generation and transmission capacity -- than is currently being envisioned and planned by bulk power system stakeholders and most policymakers.

The energy transition is an opportunity to simultaneously address climate change as well as to design a secure and reliable electricity supply system with access and affordability for all, thus meeting the fundamental human need for access to electricity. This requires the development of a new economic / technological model that will incentivize, support, and reward local generation and storage of solar energy, as well as local energy exchange and reservoir-building. This is the model described in the sections below on "System Design".

Developing this model now is timely, as microgrid and smart grid technology companies, working with utilities, bulk power system operators and government leaders, are actively forming and developing their working structure and priorities. Concurrently the fossil fuel industry is implanting false climate solutions in our energy systems. These false solutions, such as carbon capture and storage[27] and other inadequate or counter-productive methods, are being advanced along with efforts to undermine or preclude local solar self-generation and storage. A campaign, launched jointly by private utility companies in concert with the fossil fuel industry in the 2010s, continues today to effectively arrest and reverse the development of rooftop solar – putting out false information such as the now widely believed idea that rooftop solar net metering harms all other utility customers, and especially low-income ones. While the claim that rooftop solar financially harms other customers has been repeatedly debunked and disproven,[28] the campaigns have been effective in moving state regulators to increase the cost and decrease the benefits of small-scale renewable electricity generation. **A different model is needed,** one that optimizes for end-user affordability and accessibility and for local system security and resilience.

This document presents that different model: a draft blueprint for Local Power Networks.

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[27] Sekera, June and Andreas Lichtenberger (2020) Assessing Carbon Capture: Public Policy, Science and Societal Need; A review of the literature on industrial carbon removal", *Biophysical Economics and Sustainability.*

[28] See, for example: *How Rooftop Solar Customers Benefit Other Ratepayers Financially to the Tune of $2.3 Billion*, M. Cubed, November 2024; Crystal, Howard, Roger Lin, Jean Su (2023) "Rooftop Solar Justice; Why net metering is good for people and the planet and why monopoly utilities want to kill it", Center for Biological Diversity March 2023; "Debunking the 'Cost-Shift' Debate"; Calif Solar + Storage Assn., June 7, 2021; and Eisner, Gabe, "Edison Electric Institute Campaign Against Distributed Solar" Energy and Policy Institute, March 7, 2015.

Long-term and short-term objectives

This Blueprint has both long-term and short-term objectives:

- Long term - Articulate the concept and system design for a program of national scope. Legislation and regulatory reform will be required to achieve the long-term vision.
- Short term – Use the LPN principles and system architecture articulated here to implement LPNs at pilot sites in the near-term.

The following sections articulate: a) the driving needs the U.S. electricity supply system must address; b) the system design principles, which are based upon those needs; and c) the institutional, technological and financial design features and related public policy, which flow from the needs and system design principles.

2. The Needs

To address global warming and its increasingly catastrophic impacts, an electricity generation and delivery system must be designed to meet both biophysical and societal needs.

Biophysical need

➢ Decarbonization: A rapid transition to non-carbon fuel sources for electricity generation is essential for reducing carbon dioxide (CO2) emissions (and other gases, such as methane,[29] that increase net warming) and for meeting national and local reduction targets intended to minimize global heating and its catastrophic impacts. 31% of CO2 emissions in the U.S. come from electricity generation, so ending those emissions would be highly consequential. This biophysical[30] need *cannot* be met by the failing and often counter-productive methods being widely advanced, such as "carbon capture and storage",[31] which claim to reduce or recover emissions from fossil-fueled electricity generation. But the biophysical need *can* be met by moving to non-carbon energy sources such as solar photovoltaics (PV).[32]

Human needs

➢ Crucial problems and needs:
  - Households, communities, schools, hospitals and small businesses are experiencing increased energy insecurity -- losing utility-supplied power due to grid unreliability caused by antiquated, ill-maintained infrastructure and climate change-related disasters and disruptions.
  - Electricity is unaffordable for many in the U.S. – over 20 million U.S. households are behind on their electricity bills; arrearages may be at their highest level ever[33]. Utilities have shut off

[29] https://climate.nasa.gov/vital-signs/methane/
[30] The term 'biophysical' as used here is in line with the definition used in biophysical economics: "the study of the ways and means by which human societies procure and use energy and other biological and physical resources to produce, distribute, consume and exchange goods and services, while generating various types of waste and environmental impacts."
[31] There is a growing literature on the inadequacies and failures of "carbon capture and storage" and "direct air capture"; Sekera, J. et al Carbon dioxide removal–What's worth doing? A biophysical and public need perspective; *PLOS Climate* 14 Feb 2023.
[32] While this document concerns only solar PV, other forms of harnessing solar energy, such as solar thermal, should also be incorporated into Local Power Networks.
[33] "…we believe that these numbers represent the highest level of arrearages on record." National Energy Assistance Directors Association (2023) "Utility Arrearages Continue to Increase".

residential electricity to millions.[34] Energy poverty is significant: 27% of U.S. households experience energy insecurity, sometimes foregoing food and medical care to pay for energy.[35]

- Entire towns are being burned to the ground because of downed utility-company power lines, with the utility held liable.[36]
- Thousands of people are being dislocated from their homes as the result of violent storms and the accompanying loss of electricity.
- Thousands of people have died each year from extreme heat exposure and lack of cooling appliances, often because they cannot afford air conditioning or cannot afford to run the A/C. Many communities lack cooling centers.
- Thousands of people have been displaced or died amidst winter freezes accompanied by power outages.
- Decentralized generation has been stymied – rooftop solar derailed and local microgrid self-management blocked – by private utilities and allied interests[37] and by current regulatory arrangements.
- Electricity is a fundamental human need, but, increasingly, it is inaccessible to many, particularly among the low-income and communities of color.
- Increased consumption by industrial and commercial users is projected to further drive rate increases (and cost shifting from corporations to households), and will exacerbate the problem of reduced system reliability. Recent projections from industry and other sources show a heretofore unexpected rapid increase in the demand for electricity. "Over the past year, grid planners nearly doubled the 5-year load growth forecast".[38] Chief drivers of the unanticipated growth in electricity consumption are data centers, especially A.I. data centers – new demand that will challenge an unprepared grid,[39] with much of the costs for grid upgrades being borne by residential ratepayers.[40]

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[34] Utilities shut off power an estimated 4.2 million times in the first 10 months of 2022 - "Powerless in the United States" Center for Biological Diversity, 2023.

[35] Energy Information Agency data reported in Congressional Research Service Jan 31, 2023 https://crsreports.congress.gov/product/pdf/R/R47417

[36] Lahaina, Hawaii, HECO; Paradise, Calif., PG&E

[37] Crystal, Howard, Roger Lin, Jean Su (2023) "Rooftop Solar Justice; Why net metering is good for people and the planet and why monopoly utilities want to kill it", Center for Biological Diversity March 2023; Eisner, Gabe (Mar. 7, 2015) "Edison Electric Institute Campaign Against Distributed Solar", Energy and Policy Institute; Weissman, Gideon & Bret Fanshaw (Oct 2015) "Blocking the Sun"; Frontier Group; Blocking Rooftop Solar (June 2021) U.S. Public Interest Research Group.

[38] "The Era of Flat Power Demand is Over", Grid Strategies, Joh D. Wilson & Zach Zimmerman, Dec. 2023.

[39] "The Era of Flat Power Demand is Over", Grid Strategies, Joh D. Wilson & Zach Zimmerman, Dec. 2023.

[40] "Amid explosive demand, America is running out of power", Evan Halper, Washington Post, March 7, 2024.

3. System Design Principles

To address the above-articulated problems and meet the needs, the United States must have an electricity supply system that is optimized for decarbonization and user benefit.

Principles

➢ **Decarbonization**

The design of the electricity generation and delivery system should be optimized for:

a. Effectiveness in decarbonizing generation and delivery; and
b. Efficiency in decarbonization; e.g., generation and storage should be close to load.

➢ **User benefit**

The electricity generation and delivery system design should be optimized for user benefit, meaning:

a. Affordability – electricity is affordable to all, including low-income users;
b. Accessibility – electricity is physically and financially available;
c. Security – local system reliability and resilience.
   - Reliability – generation and distribution capacity; frequency and voltage stability; black start capability.
   - Resilience – ability to seamlessly island; local control over when to island; ability to speedily recover from power outages. Demand management (load prioritization) and the decision to connect to or disconnect from the grid is locally controlled. Resilience is a local attribute.[41]

Based on empirical evidence and a growing body of literature, it is clear that a system of localized generation and control can best optimize for user benefit. This is unlike current rooftop generation in the U.S., which, in most places, is configured to disconnect and cease electricity supply to the house in the event of a grid power outage.

Another design principle is that the system must be designed to assure that the following groups can benefit:

- renters;
- middle income and low-income homeowners;
- fixed-income populations (e.g., students and older Americans);
- workers (system construction, operation and maintenance must generate jobs with family-supporting wages; organized labor should be engaged in helping to achieve these ends).

Moreover, the system should produce *local* economic benefit; i.e., for communities and small businesses/entrepreneurs, rather than optimizing financial rewards for corporate managers and producing profits exported to distant shareholders and investors.

[41] "Resilience entails preparation for more frequent and damaging climate-related disruptions, as such it is essentially a local attribute" Lorenzo Kristov, "A new value proposition for electric distribution networks" in *The Future of Decentralized Electricity Distribution Networks*, F. Sioshansi Ed. 2023. And "resilience is a local attribute": Lorenzo Kristov, "Building the 21st Century Electricity System" 2021.

4. The Economics of Solar Energy Supply: Implications for Public Policy, Finance and System Design

Both mainstream economics and the majority of the U.S. energy supply system rely on the idea that markets are the optimal method to allocate resources, which, in neoclassical economics, are assumed to be scarce. However, unlike fossil fuels, solar energy is not a scarce resource; it is abundant[42] and non-depletable. What *is* scarce is the ability to access this energy source, access that is currently gated by a market system. Although 65% of electric utilities are publicly owned and operated, 70% of U.S. customers are serviced by for-profit corporations (IOUs). See Figure 1. Thus, the vast majority of U.S. customers get their electricity from a system that is designed to optimize for profit generation for investors, developers and operators. Market systems intrinsically optimize for profit production, not for meeting biophysical and societal needs.[43]

Figure 1. Types of Electricity Providers, U.S.

Electricity providers	#	%	# of customers	%
Publicly-owned utilities	1,996	**65%**	24,625,115	16%
Co-op's	894	29%	21,317,435	14%
IOU's (private corps.)	179	6%	106,444,853	**70%**
Federal Power agencies	10	0%	39,485	0%
total	3,079	100%	152,426,888	100%

Source: American Public Power Assn, 2023 Statistical Report

It is possible to create a system that meets both biophysical and societal needs. Networks of locallized solar generation and storage, with the bulk power system as supplementary, can ensure electricity is reliable and secure, and is accessible and affordable to all. Technology exists which allows electricity users to access, control, and maximally benefit from abundant solar energy. Such a system would also be far superior in achieving decarbonization. The bulk power system will remain for the foreseeable future as a power supply source and will continue to be organized on the market model. However, LPNs are optimized for decarbonization and user benefit, and will use a non-pricing mechanism for energy exchange and reservoir-building within each local network. This is described in the following sections.

It is important to stress that essentially all forms of electricity system transition *being crafted by mainstream designers* (industry and government) at all levels and stages of supply, including both centralized and localized generation, reflect the market paradigm of standard economics. Precepts of orthodox economic theory influence the emerging DER strategy in crucial ways. This model is shaped by the idea of people as monetizers; it casts electricity users as energy price arbitrageurs. Ordinary energy users are expected to be motivated by, and become adept at, monitoring and responding to price signals in order to capitalize on electricity market volatility by shifting times of usage or exporting power to the grid. This approach may attract financially secure customers who have the time and technology to track prices and shift usage or power export.[44] But this strategy for national electricity

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[42] "Solar energy is the most abundant energy resource on earth - 173,000 terawatts of solar energy strikes the Earth continuously. That's more than 10,000 times the world's total energy use; " NOAA.
More solar energy hits the earth in *one hour* than is needed to supply the world for *one year;* Univ of Calif., Davis.
[43] Sekera, June, "Missing from the Mainstream: The Biophysical Basis of Production and the Public Economy;" *Economics, Management, and Financial Markets* 13(3), April 5, 2018.
[44] These systems are often forbiddingly complex, as Kristov explains in "Building the 21st Century Electricity System" (2021): The program requirements are all different, typically complex, and often require extensive utility control that often undermines the value of

supply can be unrealistic for, and even disadvantage, many customers, particularly low-income homeowners and renters whose breadwinners may work multiple jobs and could scarcely afford the time and expense for the technology, or the new home appliances, to engage in electricity market trading.

To address the overarching issues, public policy is foundational. This includes federal, state and local levels. At the state level, the current regulatory framework is counter-productive to the transition needed. There is a large literature on this issue; much of it explains how the codified incentives of the current regulatory regime that supports IOUs, the monopoly model and guaranteed profits based on large infrastructure construction and ownership, all work to disincentivize and even thwart a transition to local renewable energy generation. This regulatory framework needs a complete overhaul. This blueprint does not make comprehensive recommendations for such a regulatory system overhaul. It does present specific policies and actions that could be taken, particularly at state and local levels, to remove existing barriers to the LPN model. The blueprint also provides a framework for longer-term public policy development that could usher in system reform.

5. System Design: Institutional, Technological and Financial.

This section addresses the institutional, technological and financial aspects of an LPN system. It also reflects factors identified as crucial in a "policy design" framework for mini-grids by Lawrence Berkeley National Lab (2013) – "owning, building, operating, maintaining and paying for a mini-grid system". The system design outlined here aligns with the principles stated in Section 3, above.

A. Institutional

1. System entities, legal forms

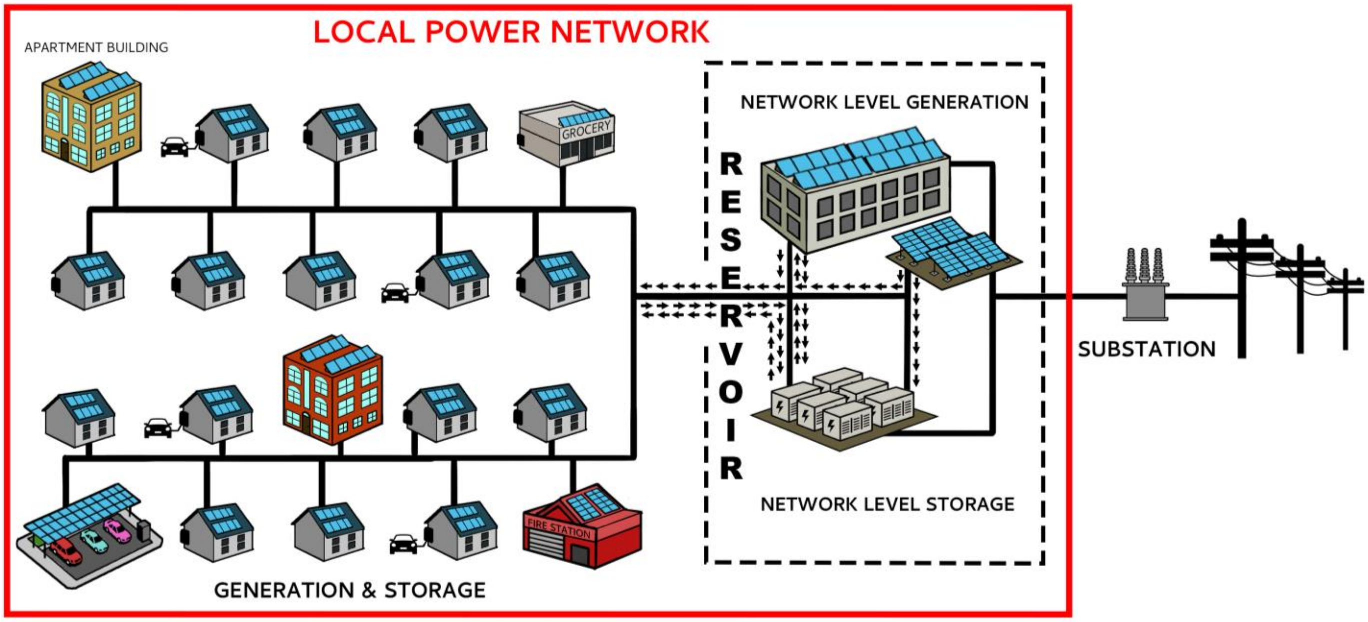
LPNs would be not-for-profit entities. Their legal forms and structures would vary from place to place; options include: municipal, co-operative, local special-purpose district, tribal non-profit entity, and other non-profit (principally 501(c)(3)) forms.

2. Siting and structure

Solar PV generation would be sited on residences, parking lots, municipal and commercial buildings, and other areas of the built environment, and potentially on disturbed land (such as capped landfills). Storage, including batteries and other means of energy storage, would also be locally sited, and would include both batteries at individual buildings (residences, public facilities, small businesses, etc.) as well as network-level batteries or other forms of energy storage (e.g., potentially pumped storage hydro). Structurally, an LPN is a mini-grid comprised of solar PV generation and storage and physically/electronically connected. It will also have grid interconnections at the border of the mini-grid, as well as metering and telemetry at key points in the network, including all participant sites. LPNs would be organized at the neighborhood level (substation or feeder line level). See Figure 2.

the battery for the customer. The terms and conditions utilities place on third-party DER providers and aggregators are also complex and often place most risk on participating households.

Figure 2. Schematic diagram of a Local Power Network



3. Autonomy and control

An LPN mini-grid would control – electronically and with institutional/legal authority – connection to and disconnection from the electric power system layer above it (see Appendix regarding the concept of layered architecture).

4. Grid interconnection

LPNs would operate in an islanded mode the majority of the time in many parts of the U.S. LPNs would also have a grid-connection to enable power transfers with the wider grid. Regarding the grid interfaces, see discussion in the Technology section below.

Regionally, and nationally, if LPNs are the standard building block, these networks would eventually supply the major share of electricity to end users (residences, municipal buildings, small business, etc.). The bulk power system would supplement the LPNs and would be much smaller in geographic footprint and require less generation and transmission capacity than is being envisioned by bulk power system stakeholders and most policymakers currently.

5. Regulation and law

(a) State level

LPNs would initially need to be created under the existing regulatory framework. Wholesale revision of the present regulatory regime is a long-term proposition. Potentially, LPNs might be feasible under some current state regulatory structures, particularly because a non-price mechanism is the basis for energy pooling (creating reservoirs of solar PV-produced energy within a defined local area, as explained below). Modest but pivotal changes in regulations could allow LPNs in IOU territories in some states. However, it is most likely that areas served by municipal or other public utilities or electric co-op utilities would be most hospitable initially. These entities do not rely on maximizing profit as a key driver in strategic decision-making.

(b) Federal level
At the federal level, the Federal Energy Regulatory Commission (FERC) could play a role in removing barriers to LPNs. However, historically FERC has regarded markets and market-making as crucial, including in FERC rules crafted in the last several years. For example, FERC Order 2222 (2020), which is often cited as a major federal policy initiative for DERs, was designed to "facilitate DER participation in the regional electricity markets." The order laid the foundation for expanding profit extraction via "aggregators".

Besides issuing orders and rules, FERC can convene discussions and open cases that can be influential, and a "force for good", as UC Berkeley professor Dan Kammen has indicated. In 2019, senators Sanders and Warren suggested reorienting FERC's mission toward fighting climate change, and changing the agency's name from FERC to FREC – the Federal Renewable Energy Commission.

(c) Local level
As noted above, it is likely that LPNs initially could most easily be introduced in areas served by municipal or other public utilities, or electric cooperatives.[45] Municipalities and counties can exercise their statutory powers to enable, create and support LPNs. Examples of favorable actions include: ordinances to enable legal structures and frameworks; laws to authorize municipal battery arrays and to appropriate funding for them; creation of bonding authority and bond issuance; bulk purchasing of solar panels to lower the cost for residential and municipal entity buyers; and much more.

6. Operation and staffing

As noted earlier, LPN ownership could be by any type of not-for-profit entity. A particularly viable option for initially piloting LPNs may be for each LPN to be owned, operated and staffed by an existing municipal utility or electric co-op. There are over 2,000 publicly-owned utilities and almost 900 electric co-ops in the U.S. (American Public Power Assn. 2022). In this option, the LPN staff would be employees of the municipal utility or the electric co-op.
Advantages of this option are:

- expertise in electricity systems already exists at the municipal utility or co-op;
- these entities have a personnel hiring and vetting capability;
- economies of scale in terms of operations, maintenance and administration could be realized if multiple LPNs were formed in the utility's service area.

7. Apartment buildings / Renters

An important policy objective of the LPN model is to enable renters to participate in localized solar plus storage. Since a single distribution line typically feeds an apartment building,[46] it will be necessary for the apartment building owner to participate in the LPN. There are two types of incentives that could interest apartment building owners in participating – inherent and added. Inherent incentives include: a) a lower cost of electricity for all common areas of the building; b) a potential competitive advantage in attracting renters who prefer clean energy as their electricity source; c) competitive advantage in attracting renters by being able to offer islanding capability during power outages. An example of an added incentive is low-cost financing for

[45] Publicly owned utilities are distinguished from electric cooperatives. The former are utilities owned and operated by municipal, county, state, federal or territorial governments or governmental special purpose districts. Electric cooperatives are private not-for-profit entities. Two reasons the distinction is significant are that governments have powers, such as enacting laws and ordinances, that cooperatives do not, and they can undertake bond financing at lower cost than private issuers. The distinction between public power utilities and electric cooperatives follows the convention of the American Public Power Association.
[46] Typically, supply is then sub-metered to individual units.

installation of solar PV and batteries in apartment buildings. This could be done via a municipal bond issuance, as described in the Finance section. This financing should be conditioned on, first, the owner installing sufficient generating capacity to serve all units in the building; and, second, allowing all rental units to automatically participate in the LPN. Also, if the municipality chooses, this financial assistance could be preferentially targeted to low-income neighborhoods.

8. LPN-potential venues, near-term

Given the urgency to implement LPNs in the near-term in order to rapidly reduce CO2 emissions in the electricity sector, and the reality that revision of the institutional and regulatory regime is a long-term proposition, LPNs should be initiated in the most hospitable environments to enable near-term proof of concept demonstrations. As noted above, those are most likely to be areas served by municipal utilities, co-ops or other forms of not-for profit electricity supply including special districts. There is undoubtedly greater opportunity for the LPN model in municipal or electric co-op utilities than with IOUs because consumer-owned utilities are not-for-profit and are not regulated by PUCs as investor-owned utilities are.[47] Their non-profit structure is, in principle, most compatible with the LPN framework.

In addition, there is an economic development incentive for municipal utilities to set up LPNs, since more of the expenditures on energy will be kept in the local economy. MOUs would spend less on market purchases of electricity. In turn, LPN participants would spend less on market-purchased electricity and, instead, their monthly bill payments would support salaries for LPN staff, again recirculating more money in the local economy.

9. Pilot LPN sites

The LPN model first needs to be implemented at pilot sites, since broad-scale, nation-wide implementation in the long-term would entail fundamental regulatory reform and federal or state financial support for local infrastructure. But pilots are feasible in local areas in the near-term. In LPN pilot sites, ideally every residence (including apartment buildings), every small business and every publicly-owned building would self-generate with a solar PV array, and most would have battery storage. Ideally, there would be a mix of residential participants including not only low-income, but all income levels, as well as commercial and municipal participants. Each LPN would have community-level generation and storage. As discussed in the Finance section, public financing would facilitate this infrastructure build-out and low-income household participation.

B. Technological

Existing and emerging technologies can support and enable LPNs.

1. LPNs are a form of mini-grids.

LPNs are a form of mini-grid (often called microgrids; these terms are often used interchangeably in the literature), but differ from most of the current microgrid and mini-grid systems in the U.S. in that LPNs:

- Are 100% powered by renewable energy (except when an LPN must import electricity from the bulk power system). In some parts of the country, wind generation may supplement solar generation. But no diesel or fuel cell generators are anticipated.

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[47] "Consumer-owned utilities, such as municipal utilities or rural cooperatives, are generally not regulated by PUCs"; pg 7 State Microgrid Policy, Programmatic, and Regulatory Framework *National Association of Regulatory Utility Commissioners (NARUC) and National Association of State Energy Officials (NASEO).*

- Operate autonomously using grid-forming inverters, electronic controllers and other electronic devices needed for autonomous control and management of electricity flows; controllers are programmed to maximize efficiency and self-reliance.
- Could be located at the substation level, or by making a feeder loop a dedicated, islandable mini-grid.

2. Interconnection and maintenance of voltage and frequency.
Integrating electricity from an inverter-based resource system (e.g., solar PV) into a grid that is powered mainly by synchronous generators has raised some technical issues, but these are being addressed and overcome via new technologies (e.g., grid-forming inverters).[48] The technical literature indicates that inverter-based resources may enable improved grid stability. Experts observing from an institutional perspective have also weighed in. See, for example Welton et al (2022)[49] who argue and show that "much of the perceived tension between clean energy and reliability is a failure of law and governance…" Delays in interconnection can no longer have a technological rationale, except in the sense that enabling technology is not being adequately deployed and infrastructure upgrades are lacking.[50] Likewise, the inverter technology (grid forming inverters) has the ability to regulate voltage and frequency at least as well as the current system, and may be capable of more rapid and efficient "black starts" than the synchronous generators that mainly power the grid currently (see publications at NREL).

3. Interfacing with the distribution and bulk power systems.
In the LPN model, control of whether and when to "island" – operate independently of the grid – would be in the hands of the local LPN owner/operator (which would act in coordination with the distribution system operator), a power that would be granted institutionally (by the overseeing utility) and is enabled through technology. Crucially, the electronic controls would need to be programmed to allow local choice rather than top-down control. In addition, "anti-islanding" features typically built into solar-only inverters would be absent, disabled or reprogrammed. Devices with transactive control technology would need to be programmable, and programmed to enable local choice and decision-making (in coordination with the distribution system operator). Each LPN would interface with the LPN in the next layer above.

This concept is patterned after the "layered architecture" approach that has been envisioned and described by Lorenzo Kristov ("Building the 21st Century Electricity System" 2021; and "Two Visions of a Transactive Electric System" 2016). Kristov's concept is illustrated in the Appendix.

Each LPN only needs to manage its interface with the layers above and below it. The top layer LPN interfaces with the bulk power system (grid). In some areas there may be only one LPN layer; other areas may have more layers. The number of layers would be based on local choice (i.e., the number and size of LPNs that are formed in a city or geographic area) as well as technological and financial considerations (opportunities or constraints).

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[48] e.g., see Kroposki, Benjamin et al (2017) "Achieving a 100% Renewable Grid: Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy" *IEEE Power and Energy Magazine Vol 15 No2. March/April 2017*; and Lin, Y, et al (2020) "Research Roadmap on Grid-Forming Inverters" National Renewable Energy Laboratory. NREL/TP-5D00-73476.

[49] Welton et al (2022) "Grid Reliability Through Clean Energy", 74 Stan. L. Rev. 969.

[50] There many sources on this point; for an early one see "Grid Integration and the Carrying Capacity of the U.S. Grid to Incorporate Variable Renewable Energy" (2015) J. Cochran, P. Denholm, B. Speer & M. Miller; National Renewable Energy Laboratory;Technical Report, NREL/TP-6A20-62607, on the point that "carrying capacity" is a function not of technology but is based on what is considered economically desirable.

4. Grid system balance.
Balancing the bulk power system grid (transmission and distribution functions) would not significantly differ from how it is done now, except that: 1) there would be less load to balance at the regional level than would otherwise occur because more generation and storage would occur at the local level, close to load; and 2) problems such as curtailment when there is "overgeneration" of solar will be reduced at the regional grid level as surplus generated electricity would go to a local LPN storage reservoir (battery, pumped storage hydro, or other). Only when the LPN storage is full would excess power be fed into the grid or curtailed.

5. Local network connections.
Within an LPN all generation sources and storage devices, as well as load sources, would be connected with each other. Options include: 1) in areas currently served by IOUs, create LPNs at the substation level (or feeder-line level) and contractually assign control of all generation and load sources in the LPN to a designated LPN operator (who is independent of the IOU); 2) in areas served by a municipal utility, special district or co-op utility, obtain contractual authorization to operate the local distribution system poles and wires as an LPN, and to rewire/reconfigure as necessary to maximize LPN operational efficiencies; 3) construct a new physical and electronic network.

6. LPN-level generation and storage reservoir

"Reservoir" is the name used in the LPN model to designate network-level generation and storage capability that serves all LPN participants. See Figure 2.

A solar PV array at the network level (e.g., substation, feeder or community level) would supply power to LPN participants as needed – including entities without self-generation capability or with limited solar insufficient to meet all of their demand. This solar PV array also supplies the LPN-level storage system.

The storage system would receive inputs from three sources: network-level solar array(s); surplus electricity sent from individual LPN participants (as described below); and out-of-network sourcing when and if needed. The storage system would in most cases be a battery array (in the expected range of 0.5 MW/2 MWh to 10 MW/40 MWh capacity), unless site-specific conditions economically favor another form of storage, such as pumped storage hydro.

The network-level solar array and storage system – the reservoir -- would be owned and maintained by the LPN (see ownership options discussed earlier).

There are two chief reasons that each LPN would have its own generation and storage reservoir. One reason is to have a source of resilience that is under local control, rather than control being in the hands of an IOU or other body exercising top-down control. With proper sizing, the network reservoir should enable LPN participating entities to meet their load needs most of the time. When they cannot, the LPN purchases power from outside the network.

The second reason is to enable participation by renters and low-income households. The LPN design is optimized to keep costs down for end-users. First, keeping generation (and storage) close to load, if efficiently implemented, would result in electricity supply at a lower cost by avoiding the expense of long-distance transmission. In addition, generation by commercial-size (LPN-owned) PV systems at the network level will contribute to cost reduction. Commercial-size solar PV systems cost less per watt than generation by small-scale (e.g., residential rooftop) systems,[51] thus keeping costs down. (For other cost savings see the energy pooling system and accounting section below.) Renters will be able to draw on electricity supply from solar PV on their apartment buildings (see earlier discussion on incentives for apartment building owners to participate) as well as from the network-level PV array.

7. Energy pooling system and accounting.

As outlined above, electric power is pooled by generation inputs to the storage reservoir from three sources: the network-level solar PV array(s); individual LPN participating entities with solar PV and onsite battery storage sending their surplus electricity to the reservoir; and, via purchases from outside the network when the first two sources are insufficient to keep the storage reservoir at target capacity.

Each LPN participating entity (residences, including single-family and multi-family apartment buildings; municipal buildings; other public buildings like schools, libraries and fire stations; shops and local small commercial buildings; parking lots; warehouses, etc.) would: a) self-generate and self-store to meet its own demand; b) export its surplus energy to the LPN reservoir; and c) draw from the LPN reservoir as needed. The amount of energy input to and drawn from the LPN reservoir -- expressed in kWh's -- would be electronically automatically tracked by a "Power Tracker". This type of system has been implemented in Australia; in a pilot project, the system tracks where energy is coming from and going to within a "hub". In this model, "If your neighbor has been importing electricity, at the same time as you have been exporting electricity from your solar power system, we say this energy has been "shared." The model also sets up energy "trading" – financial transactions between individuals.

However, in contrast, the LPN model is not based on *ascribed* sharing or on *financial* trading transactions. Rather, it operates by participants contributing to and drawing from a common reservoir. This is tracked by a *non-financial* mechanism -- a monthly accounting of how much each entity supplies to the reservoir and how much it withdraws. There is an annual financial settlement, as discussed in the Financial section.

Network- or neighborhood-level energy pooling is novel, although some forms of it are being applied in some places, (e.g., Australia [52]). Structures to pool and share solar-generated power at the local level on *a non-financial basis*, are nascent. There are proposals and ideas for electricity as a "commons".[53] However, such ideas have apparently not been implemented, nor has there been an adequate articulation of the institutional, legal, and statutory supporting structures that would be required to enable the commons idea. LPNs are not based on an informal idea of a "commons", but rather are legally-instituted and constructed entities, enabled and supported by government laws, regulations and financing, as delineated in this section.

The LPN concept in broad strokes is this: A layered electricity supply system in which the foundational layer is comprised of entities at the community level that are simultaneously electricity self-generators (producers) and users. The popular term for users who are also producers is

[51] Wood Mackenzie (2022) reports: average per-watt cost of small scale (8 kW rooftop systems) - $2.99/W; mid-size (500 Kw rooftop systems) - $1.77/W.
[52] Totally Renewable Yackandandah; Project: Yack01 Community Battery; undated; accessed 7-21-24.
[53] Giotitsas, C, Nardellim P. et al (2022) "Energy governance as a commons: Engineering alternative socio-technical configurations", *Energy Research & Social Science* 84; Farrell, John (2024) Upcharge: Hidden Costs of Electric Utility Monopoly Power, Institute for Local Self-Reliance.

"prosumers". But that term typically applies to individual households or businesses. In the LPN concept, a prosumer would also be an entire neighborhood or substation area.

In sum, three design features core to the LPN concept are: 1) keep generation (and storage) close to load (i.e., reduce reliance on long-distance transmission); 2) enable energy pooling in each LPN, and do so using a non-price mechanism; 3) enable local control. Crucially, contrary to the DER pathways being envisioned by mainstream planners now, in which data is utilized by IOUs, centralized operators[54] or DER aggregators to manage customers' activity primarily for the operators' or aggregators' self-benefit, in the LPN model, data is utilized by LPN operators to optimize the system for users' benefit.

C. Financial

Electricity supply costs and payers

In the electricity supply system that now dominates in the U.S., in which the majority of customers are serviced by IOUs, all costs are paid for by ratepayers and taxpayers. Investors do not pay. Equity investors and debt holders *increase* their wealth, as do energy traders. The profits received by investors are at a guaranteed rate of return set under the current regulatory framework [55] and paid by ratepayers. The fact that ratepayers bear the cost of the electricity system is, in itself, not remarkable or untoward: electricity supply is a service that must be paid for. But from other perspectives, the present financing system is deeply flawed in terms of both economics and physics, and it is disadvantageous for end users.

First, given that this service for most end users is supplied through a monopoly system, customers lack choice (despite "community choice aggregators"[56] in some states). Second, generation is not located close to load, since, for most users, electricity is generated centrally and transmitted over substantial distances – an arrangement that is inefficient both financially and in terms of energy loss. Further, solar energy is an abundant, non-scarce, non-depletable resource, yet access to it is gated by the market actors controlling the existing electric power system. This financial system, designed to optimize for profits to investors, developers, marketers and operators, limits and even denies access to solar energy to the individual ratepayer. To be sure, public electricity suppliers may sometimes behave like profit-driven companies and impede access to renewables or local solar, TVA being an example.[57]

Due to the capital intensiveness of creating electricity infrastructure, and in order to make electricity affordable to all, some observers argue that the state should provide electrical infrastructure.[58] Given the increasing impetus for decentralization of generation and storage, this argument would apply to the building of infrastructure for local solar networks.

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[54] Independent System Operators - ISO's, or Regional Transmission Organizations –RTOs.

[55] Under the current regulatory framework, investor-owned utilities earn profits by building and owning infrastructural assets.

[56] Community Choice Aggregators (CCAs) aggregate electricity demand and then purchase electricity to meet that demand and sell it to end users. They ae not organized to prioritize the ability of electricity users to self-generate, e.g., through roof-top solar. Thus, they do not offer "choice" in that sense. CCAs exist in 10 states in service areas covered by IOUs; they are non-profit organizations created under state and local laws. It is conceivable that their authorizing legislation could be revamped to help support local self-generation. However, instead, current planning sees CCAs as vehicles to organize and deliver "grid services. E.g., the US Energy Dept., in discussing rooftop solar and community solar, suggests that a virtual power plant (VPP) could "provide additional revenue streams for VPP owners and operators"; U.S. Dept. of Energy "Pathways to Commercial Liftoff: Virtual Power Plants" Sept 2023; pg 61.

[57] Tabor, Nick (2024) "The TVA helped electrify the South — but now its plans are sparking backlash", *Washington Post*, Sept. 9 2024.

[58] Pirani, Simon (2021) "How energy was commodified, and how it could be decommodified"; Durham University, Working Paper.

However, the DER system being devised and rolled out in the U.S. is, like the legacy electricity system, based on market mechanisms. Leading government entities, such as the U.S. Dept. of Energy and the regional labs it funds (e.g., National Renewable Energy Laboratory, NREL), assume profit-seeking as integral to system design. See for example, "Pathways to Commercial Liftoff: Virtual Power Plants" and "Innovative Grid Deployment; Pathways to Commercial Liftoff". A recent spate of reports on the electricity system transition and the DER strategy by leading energy consulting firms also use profit generation and market penetration as fulcrums for their analyses, identifying, for example "monetization pathways" for a DER strategy.[59]

Least-cost system for the future

Although the transition to a decarbonized, renewables-based electricity system will require major investment, no matter how it proceeds, evidence suggests that a system of localized and locally-controlled generation and storage could provide the least-cost, most affordable system for electricity supply and access. Studies indicate that decentralized generation and storage could cost billions of dollars less nationally than centralized generation and transmission. A 2021 study by Vibrant Clean Energy found as much as $120 billion in cumulative savings for California ratepayers from 2018 to 2050 in total system costs ('Local Solar & Storage Future' scenario compared to 'Utility-scale Only' Nussey, 2018). Referencing Lazard, the study states that "community-scale solar power can cost as little as $0.07 per kilowatt hour." In a "roadmap" to 100% local solar for San Diego, energy expert Bill Powers lays out the cost advantages and financing options for local solar power. A 2024 study (Pollard & Buckley[60]) of renewable energy in Queensland, Australia found rooftop solar "to be the lowest cost source of electricity", with a solar system retail price to customers (including incentives) of 96 cents (Australian) per watt for a 10 kW array.

It is hypothesized that LPN-supplied electricity will be less costly for end-users than electricity supplied by IOUs or other market-based system suppliers. This projection follows from the studies noted above as well as other studies of "business as usual" vs localized generation. However, we have not seen existing studies that specifically compare *costs to the household end-user* of utility-scale solar generation/transmission vs residential rooftop solar, particularly in the form of locally owned, not-for-profit solar plus storage mini-grids. A cost-to-the user analysis of LPN scenarios compared with centralized generation/transmission will be undertaken when the basic blueprint design has been finalized.

Regardless, it is evident that in order to increase access and affordability an alternative type of financing system is required. Following are salient features of such a system.

1. Financing: basic features

As underscored throughout this Blueprint, the LPN mini-grid model is designed to enable access, affordability and energy security. The financing structure is likewise designed to achieve these goals.

Public financing is required. This, in itself, is not new; the current system and currently dominant transition pathways are heavily publicly subsidized through a variety of mechanisms. While, in the long term, dramatic change in public financing is needed to usher in comprehensive system reform, in the near term, existing public financing tools can be used to support local, and locally-controlled generation and

[59] *Real Reliability: The Value of Virtual Power* by The Brattle Group, prepared for Google, 2023; Wood Mackenzie (2023) "North America virtual power plant (VPP) market"; 23 Feb.2023.
[60] Pollard, Matt and Tim Buckley (2024) "Queensland's Energy Transformation: From Coal Colossus to Renewable Energy Superpower;" *Climate and Energy Finance*.

storage.

a. Infrastructure creation

- Infrastructure construction and installation costs would be facilitated and supported by public financing (grants or debt financing or both). Public financing could support the construction of local, non-profit-owned (in some cases municipally-owned) generation and storage equipment at the substation, feeder, or community level. For entities participating in the LPN, public financing could help defray part of the cost for solar PV and/or battery purchases (e.g., through municipal bulk purchasing), and could be targeted to low-income neighborhood or households.

b. System operation

Participants in an LPN pay for the cost of system operation.

- LPN participant entities (households, businesses, public entities like schools, libraries, town halls, etc.) are billed monthly for:
  (1) Services: system operational costs (management, maintenance, and other operational costs) debt servicing, etc.;
  (2) Energy: electricity drawn from the LPN power pool, based on a volumetric kWh charge.

This billing is for cost recovery only; no markup for profit is permitted.

- The sources of electricity input to the reservoir are:
  (1) In-network electricity supply
  (2) Out-of-network electricity supply
  These are discussed in the Details section below

- **Subsidies for low-income households:** Municipalities (or co-ops) may choose to subsidize the kWh billing to low-income LPN participants, and particularly low-income renters or low-income homeowners who cannot afford to install rooftop solar and battery systems onsite.

- **Export of electricity from LPN to bulk power system**

LPN's may choose to export surplus power to the bulk power system when advantageous to the local network. Such out-of-network exports can bring in revenue to the LPN, further reducing kWh costs to LPN participants who use electricity supplied by the power pool reservoir.

This feature of LPN design is fundamentally different from the DER systems being designed now.

In the electricity systems being planned by mainstream designers (industry and government) electricity supply is premised on the neoclassical economics assumption that humans are driven by financial utility maximization. DER plans and "demand-response" programs are founded on this assumption and are based on people responding individually to price signals and selling or buying power at times that maximize one's financial advantage.

Even for people who do have the interest, financial capacity and time flexibility for shifting times of consumption or electricity export in order to eke out price advantages, the result can be perverse. Observers have noted that current options for utility-managed DER programs for load-shifting provide a "false empowerment", as these programs are housed within a stratified system designed to favor those with the most economic and political power. In the U.K., objectives are shifting from urging households to make money by selling electricity to save money by fully meeting home energy needs.[61]

Rather than a system based on customers as market actors and profit-maximizers, the LPN design addresses what evidence shows most people want – **lower bills and energy security**. At the institutional level, the LPN as an energy manager can leverage time-of-use (TOU) pricing by utilities and engage in price arbitrage on behalf of the LPN as a whole to the extent it chooses to do so.

This LPN system:

- Incentivizes maximum self-generation and storage and maximizes self-sufficiency: it creates incentives to produce as much electricity as possible and consume as little as possible. Entities that can own and maintain solar PV plus battery systems will generally not have to purchase electricity, or can greatly minimize their purchases.
- Reduces the per-kWh costs for all participants who need electricity supplied from the reservoir, because much of the electricity input to the reservoir is supplied via the non-monetary mechanism for inputting to the reservoir by participants with solar PV plus battery systems.
- Reduces or eliminates “curtailment” of solar power from home energy systems since what is now regarded as “excess” generation of no commercial value and is curtailed on the bulk power system, can instead be sent to local storage, whether at individual buildings or community-level storage systems.
- Incentivizes energy efficiency, including load shifting that is *self-determined*.

2. Financing details

a. Infrastructure creation

Transforming the electricity supply system requires up-front capital investment that must be enabled by public financing. Private capital alone, with its requirement for profit maximization, cannot produce a system that will meet the biophysical and societal driving needs discussed above.

(1) Public financing

Much of the *current* energy system is already publicly financed or subsidized. Subsidies for fossil fuels[62] need to be redirected toward local, renewable generation and storage, and new, focused, public financing is required. In terms of debt capital, public financing is almost always less costly and offers better value than private capital because public finance rates are normally lower and transactions costs are less; see the study by Hall and Nguyen, 2018.

***Long-term** public financing*

Redirect existing fossil fuel subsidies

U.S. government subsidies for fossil fuels are estimated at around $20 billion annually. There are additional billions in subsidies for “carbon capture and storage”, which is primarily used to

[61] Brown, Paul (2024)“Solar power becoming standard even in UK’s soggy summer; Previously the idea was to sell electricity back to the grid, now the object is to power all of a household’s needs”, *The Guardian*, 19 July 2024.

[62] The worldwide fossil fuel industry receives $1.3 trillion in *explicit* subsidies annually according to the International Monetary Fund 2023. The U.S. government provides an estimated $20 billion annually according to the Senate Budget Committee 2023.

subsidize fossil fuel operations – $23.7 billion as of 2022[63] plus tens of billions of dollars annually[64] in carbon capture and storage tax credits. These subsidies should be curtailed and the funding redirected to support local solar infrastructure creation. This requires federal legislation and so is a long-term objective whose achievement requires overcoming the power and legislative influence of fossil fuel interests. Though difficult to accomplish, nevertheless, it is important to target this source of funding.

Focus Federal supports for solar on building local generation and storage

Many of the existing tax credits, grants and loan programs for renewable energy (e.g., under the Inflation Reduction Act - IRA) were created to help finance the purchase and installation of solar PV systems and battery storage systems. Some incentives under IRA are for projects 5 MW or less in capacity. Additionally, grant programs were announced in 2024, e.g., "Solar for All" at $7 billion to states, tribal governments, municipalities and nonprofits across the U.S. The extent to which any of these supports will continue under the new administration is unknown, but if they do, ideally they could be tapped to support local generation and storage in an LPN framework.

Near-term *public financing*

Use existing federal supports for local solar generation and storage

To the extent that federal financing sources continue to exist under the new federal administration, they could be utilized for LPN pilot implementation.

Authorize local bonds – municipal utilities

Municipalities can use their bond-financing authority to issue revenue bonds to provide low-interest financing to support the buildout of local, locally-owned solar PV generation capacity and storage. Special bond authorizations could be enacted to enable this financing to be used to assist homeowners. It also could be targeted to middle-and low-income homeowners. The authorization could be enacted by the local government body (e.g., city council) or by voter referendum. The bonds are repaid by the beneficiaries of the infrastructure that is built. For LPN pilot sites, these could be called "Energy Freedom Bonds" or "Energy Independence Bonds" in order both to support not only solar, but also other types of renewable generation (e.g., wind or geothermal) and to appeal to a wide array of local voters.

There is precedent for this type of bond financing. In 2001 in San Francisco, voters approved two ballot initiatives authorizing the city to issue bonds for the construction of solar PV systems and other renewables and for energy conservation. One bond would finance the construction of solar PV systems on city facilities and properties; the other bond would allow provision of electricity to residential and commercial customers. The City never exercised its authority to issue the bonds, in part because of opposition from the IOU that already served residential and commercial customers in San Francisco.

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[63] Sekera et al. (2023) Carbon dioxide removal–What's worth doing? A biophysical and public need perspective; *PLOS Climate* 14 Feb 2023.

[64] Walsh J, Hart P. Will the Manchin Climate Bill Reduce Climate Pollution? Food and Water Watch.2022 Aug 10. Available from: https://www.foodandwaterwatch.org/2022/08/10/will-the-manchinclimate-bill-reduce-climate-pollution/

Eligible recipients

Eligible recipients for public financing would be electricity end-users: households for residential use; small businesses; tribal government entities; and municipal and other governmental entities of all forms. Eligibility would vary by financing type; e.g., non-taxpaying entities, such as municipal bodies, generally cannot utilize tax credits except where they are designed to be "refundable" or to be convertible to "direct pay," which enables municipalities to participate.

(2) Private financing

While public financing is essential for electricity system transformation, private capital is also needed. Public financing can catalyze private finance. Public capital expenditures "crowd in" private financing, both in general[65] and specifically in the case of renewable energy and "consumer energy resources". This blueprint does not explore the sources of private finance because *public* finance is fundamental for assuring universal, affordable access; it catalyzes private finance.

b. System operation

- **Electricity supply**

In-Network electricity supply; power pooling/reservoir creation
LPN participant entities with solar PV send to the reservoir any surplus electricity they produce in excess of their load needs. As discussed earlier, the reservoir is a network-level energy storage system. Electricity inputs to the reservoir are *not compensated financially*. Rather, LPN participating entities that input power to the reservoir will receive kWh credits that will reduce their bill for any electricity they draw from the reservoir.

All LPN participants' monthly bills would show:

- kWh's input to the reservoir
- kWh's withdrawn from the reservoir
- Balance – credit or debit – shown in kWh's

Each participant's account would be settled annually or semi-annually. Those with a kWh credit would receive a financial deduction on their bill at the end of the year or mid-year; those with a kWh debit would owe a financial amount. In both cases the financial amount is based on the average kWh rate the LPN billed all participants during that year or half-year. LPN participants who do not input to the reservoir (because they do not have generating capacity) are billed monthly for their kWh usage.

A financial benefit of this system is that the "free" inputs to the reservoir will lower the kWh cost of energy for everyone drawing from the reservoir.

LPNs would have network-level solar PV generation and potentially could have wind or geothermal generation. However, this Blueprint does not address wind or geothermal provision.

Out-of-Network electricity supply
The source of out-of-network supply is purchases of electricity from the bulk power system. (Also, LPNs could exchange power with each other on a non-financial or financial basis, but such arrangements would need to await the development of multiple LPNs in a geographic region).

[65] "The Macroeconomic Effects of Public Investment: Evidence from Advanced Economies" International Monetary Fund; WP 15/95; 2015.

As noted in the Technology section earlier, each LPN would have the technological ability and legal authority to determine when to operate in a grid-connected mode and when to operate off-grid, or island.

A “Power Tracker” system keeps an accounting of all energy inputs to and withdrawals from the power pool reservoir. The kWh cost to each LPN participation is automatically calculated by this system. Since the amount of “free” power input to the power pools and the amount purchased from the bulk power system will vary each month, the kWh price likewise will vary monthly.

- **Management, maintenance and administration of each LPN** [66]
  Expenses for system operation are billed at cost; there is no markup for profit. Expenses include:
  - System manager/s
  - Operations
  - Maintenance
  - Repair
  - Power Tracker (kWh’s and billing)
  - Customer service
    Troubleshooting
    Handling outages
    Technical assistance
    Public education
  - Administration
    Billing
    Collections
    HR

6. Conclusion

This draft blueprint for an LPN system provides a countermodel to mainstream transition pathways, being developed, which are premised on the idea that profit optimization must be the driving mechanism for electric energy supply. It is also intended as a countermodel to mainstream plans designed so that household and other small end-user electricity consumption and generation are managed to benefit the bulk power system, The LPN model optimizes, instead, for the benefit of users themselves. Absent a coherent alternative model, the electricity transition now underway seems likely to set in place systems that will be far less than optimal for the smaller players, whether individual households, small businesses, or local or remote communities.

[66] This section borrows from Hannegan (2023) in which he describes a system that decouples utility revenue from volumetric sales (kWh’s sold) and instead institutes fees for explicitly-defined services; purchased electricity is supplied with no markup for profit. Bryan Hannegan, “How an innovative co-op is planning to thrive amidst the market disruptions: The case of Holy Cross Energy” pp 364-368 in *The Future of Decentralized Electricity Distribution Networks,* F. Sioshansi Ed. 20233.

Summary

Reasons to Launch the LPN Alternative

Reasons for **public policymakers**…..*to* ***finance and support*** **LPNs**

- Expand the population who can participate in zero carbon electricity and benefit from lower costs.
- Avoid building new transmission lines.
- Moot or reduce conflicts over utility-scale solar and wind facilities and transmission lines.
- More rapid decarbonization than with centralized generation and transmission.
- Affordable electricity for low-income households.
- Renters can participate in zero carbon electricity and benefit from lower cost.
- More secure electricity for public services and communities.

Reasons for **publicly-owned utilities and co-ops**…..***to set up*** **LPNs**

in addition to the reasons above --

- Reduce reliance on volatile markets and high peak prices; less expensive source of electricity.
- Decarbonization that is more effective and more efficient (generation & storage are close to load).
- Avoid curtailing rooftop solar.
- Ability to supply power for public services during grid outages, e.g., cooling centers (summer) or warming centers (winter).

Reasons for **people, communities and small businesses**…***to be in LPNs***

- **Energy security** - no loss of power during lengthy grid outages.
- Lower cost (relative to most IOU billing)
- **Choice and control**: decisions are made locally, by user-owners, not by remote corporations.

The **frequency** and **length** of power outages are at their highest levels since reliability tracking began in 2013. Power outages from **severe weather** have **doubled** over the past two decades, rising from 50 to 100 annually, with U.S. customers on average experiencing more than eight hours of outages in 2020.
Source: AP News, April 2022

Appendix

Layered Architecture and Interface Points

Source: Lorenzo Kristov, "Power System Evolution From the Bottom Up", Oct. 2018