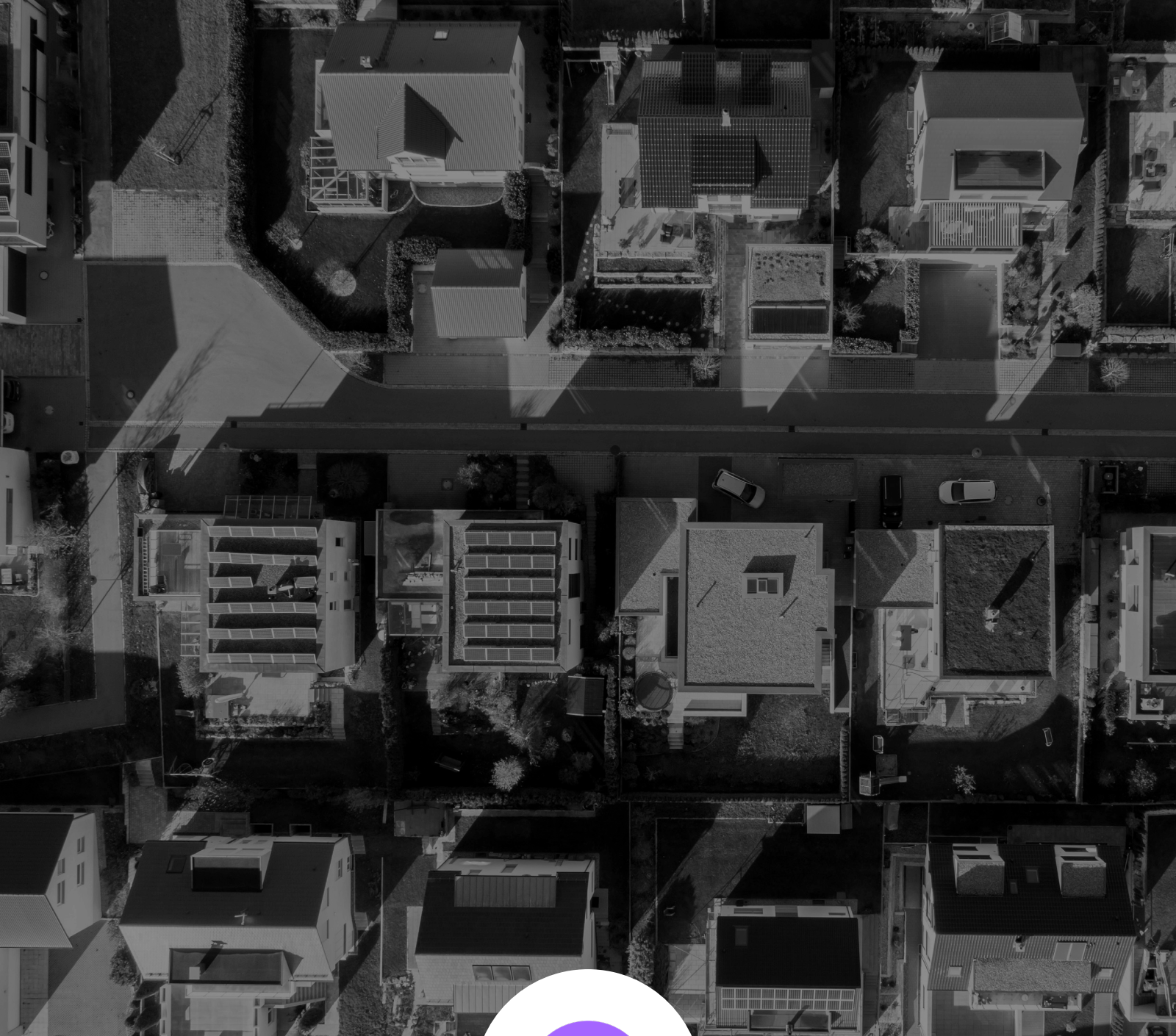

energy web

EW-DOS: The Energy Web Decentralized Operating System

The Open-Source Technology Stack for Accelerating the Energy Transition

PART 1: VISION & PURPOSE

June 2020

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This paper explains Energy Web's refined vision for leveraging blockchain and decentralized technologies to accelerate the energy transition, based on the past three years of hands-on experience building solutions with our global community of members. It is intended for a general audience. For a more-detailed technical description of EW-DOS, please see this paper's companion piece.

Key Takeaways

- By 2030 customer investment in renewable energy, distributed energy resources (DERs), and electric mobility will exceed utility investment in generation, transmission, and distribution. Renewables and DERs will represent two-thirds of global installed electric generating capacity.

- At Energy Web (EW), we believe that **open, public, digital** infrastructure will be as integral as *physical* infrastructure for the secure, reliable operation of a highly decarbonized and distributed electricity grid. Just as grid operators have built and operated the grid's physical infrastructure over the past century, our vision is for grid operators to invest in, build, and operate digital systems that securely integrate millions and eventually billions of customer-owned DERs into core operation and planning functions.

- Based on business and technical requirements from the global energy community, the **Energy Web Decentralized Operating System (EW-DOS)** is a public, open-source stack of technologies (including the Energy Web Chain) for connecting customers, assets, and existing energy-sector IT and OT systems with energy markets and programs. EW-DOS can be applied in any regulatory context or market framework.

- We intend for EW-DOS to become a de-facto global standard for digital infrastructure in the energy sector. When EW-DOS is fully deployed, anyone—utilities, startups, individual customers—will be able to write an application on their laptop and instantly deploy it at enterprise scale without needing any of their own infrastructure. The decentralized network of EW-DOS nodes will provide all the infrastructure needs (such as messaging, storage, and consensus).

- EW-DOS comprises three layers:

  1. **Trust,** which provides consensus and immutability via the public Energy Web Chain;

  2. **Utility,** the "middleware" layer of the EW-DOS stack, which simplifies the experience of creating and using decentralized solutions; and

  3. **Toolkit,** which offers open-source templates to speed the development of applications for renewable energy markets, e-mobility programs, and DER market participation.

- EW-DOS features a universal, hardware-agnostic protocol for connecting customers, physical assets, and existing grid infrastructure with a rapidly growing number of digital applications. Within a defined territory, EW-DOS provides local stakeholders with a shared state of the attributes of operational capabilities of grid resources and participants. EW-DOS leverages self-sovereign digital identity, decentralized identifiers, a series of decentralized registries, messaging services, and integrations with legacy information technology (IT) systems to facilitate transactions between billions of assets, customers, grid operators, service providers, and retailers.

- To achieve our mission, EW is developing and deploying EW-DOS with market participants globally. Since the initial launch of EW-DOS in December 2019, we have worked on more than a dozen implementations around the world, including integrating small-scale customers into wholesale balancing markets with Austrian Power Grid AG, launching next-generation renewables marketplaces in Southeast Asia with PTT and in the U.S. with PJM EIS, supporting virtual power plants in Germany with sonnen, and building an open e-mobility platform with Share&Charge. Other members from the EW community, like The Energy Origin (TEO) by Engie in France and SP Group REC in Singapore, are leveraging EW-DOS for commercial applications as well.

Preface

Energy Blockchain and Energy Web

Since our founding in early 2017, we have delivered on our initial vision. The energy sector's first public blockchain—the Energy Web Chain (EW Chain)—is live and EW has released a series of open-source software development toolkits (SDKs) that enable market participants to more-easily launch new digital solutions that support the global transition towards low-carbon energy systems. This was accomplished with EW's 100+ member organizations, the world's largest energy blockchain ecosystem. They represent 12% of global electricity consumption and 280 million customers.

The energy blockchain space is maturing quickly. The EW Chain, one of the only public blockchains among any industry worldwide whose validator nodes are run by known corporations, is now powered by a community of more than 25 validators in 17 countries. In the 12 months following its launch, the EW Chain has processed over a million transactions supporting first-of-their-kind applications for renewable energy procurement, virtual power plants, DER integration, and advanced e-mobility solutions.

We are proud of the technology groundwork we have laid, the ecosystem of market participants we have fostered, and the initial solutions being deployed that leverage the EW Chain and our SDKs. But our mission ***to accelerate the global transition to a low-carbon future using decentralized digital technologies*** is far from complete.

Over the past three years we've worked with our member organizations to research and test more than 100 use cases for blockchain in the energy transition, developed dozens of proof-of-concepts, and launched several commercial applications. Along the way, we have learned important lessons about what it takes to bring decentralized digital solutions to commercial scale in the energy sector:

- **Blockchain technology is uniquely capable for establishing multi-party consensus, anchoring trust, and providing proofs.** It should be used accordingly, and not as a database or messaging platform.
- Energy market participants gain little by simply "adding blockchain" when attempting to solve a problem. **Taking advantage of blockchain's full potential requires reimagining business and market processes—including the roles and responsibilities of different actors—and simultaneously embracing novel technical architectures.**
- **Blockchain is not a replacement for legacy information technology (IT) systems.** We like to define legacy systems as systems that actually still work today. In order to create impact fast, blockchain should integrate with existing systems and augment existing IT capabilities.

- **Existing blockchain technology is fully capable of supporting enterprise-grade applications** with respect to scale, cost, and data privacy—as long as solutions are designed thoughtfully.

- **Blockchain will play a key role in the energy transition, but blockchain alone is not enough.** To truly create impact, a full stack of decentralized technologies—with dedicated solutions for low-latency messaging, data storage, legacy IT integration, and more—is needed.

With these lessons in mind, we have narrowed our focus to what we believe to be one of the single most valuable use cases of blockchain technology in the energy sector: **creating a universal, hardware-agnostic protocol for connecting customers, physical assets, and existing grid infrastructure with a rapidly growing number of digital applications.** We achieve this through assigning self-sovereign, decentralized digital identities to energy assets.

With more and more technical proof points each passing day, there is now widespread recognition among the EW community that the combination of an open blockchain architecture and self-sovereign, decentralized digital identifiers (DIDs) has the potential to transform the 21st-century grid architecture and reduce global carbon emissions by 10 gigatons over the next decade.

Therefore, to realize the full potential of decentralized technologies for the energy sector, in December 2019 we launched a new technology stack called the **Energy Web Decentralized Operating System (EW-DOS)**. EW-DOS is a stack of software and standards, including the Energy Web Chain, that will enable market participants to digitally integrate and orchestrate the billions of low-carbon energy assets, buildings, and customers that will comprise the 21st-century grid. We hope for EW-DOS to become a de-facto industry standard: a secure, shared operating system used by all and owned by none.

The Situation

Customers are on track to invest more in the grid than utilities by 2030. But today's power grids and electricity markets are not designed for a customer-centric future.

Utility-scale wind and solar are now the cheapest sources of electricity in most regions of the globe.[1] Renewable generation will comprise an estimated 50–80% of overall capacity in the coming decades, largely replacing aging thermal generation assets (see Figure 1, page 7). This alone represents the most dramatic shift in the electricity sector since the advent of alternating current.

But perhaps more significantly, for the first time in over a century, individuals, companies, and communities can switch to local, independently-produced power at prices competitive with grid supply by investing in a mix of renewables and DERs (e.g., distributed solar PV, energy storage, electric mobility, smart meters, energy management systems, and "smart" appliances such as thermostats).

Customers are making the switch quickly and at scale: in the next 10 years, electricity end-users will spend a cumulative $830B on DERs and $7T on electric vehicles. By 2030, roughly a third of global installed capacity will reside "behind the meter." Along with this massive investment shift to the grid edge is a coming tsunami of device interconnections: **an estimated 3.5 billion internet-connected DERs are expected to integrate with existing electric grids by 2030.**

[1] Customer investment and DER deployment data based on EW analysis of Bloomberg New Energy Finance's *New Energy Outlook*, S&P Global Intelligence, and Rocky Mountain Institute internal data.

Taken together, these assets have the potential to form the basis of decarbonized, flexible, resilient energy systems the world-over. But there's a fundamental problem: everything about today's grid architecture—from the rules governing asset qualification, to the way prices are set, to the systems used to monitor and manage the grid—assumes that supply is controllable, demand is fixed, and grid investment is a centralized function driven by grid operators.

Those axioms are no longer valid. Supply from renewables is variable, demand is increasingly flexible, and customer investment in energy is projected to eclipse grid operator investment over the next decade. This investment is taking place in a naturally decentralized way: some customers want backup power, others want to lower their energy bill or carbon footprint, and others simply want to control smart appliances remotely.

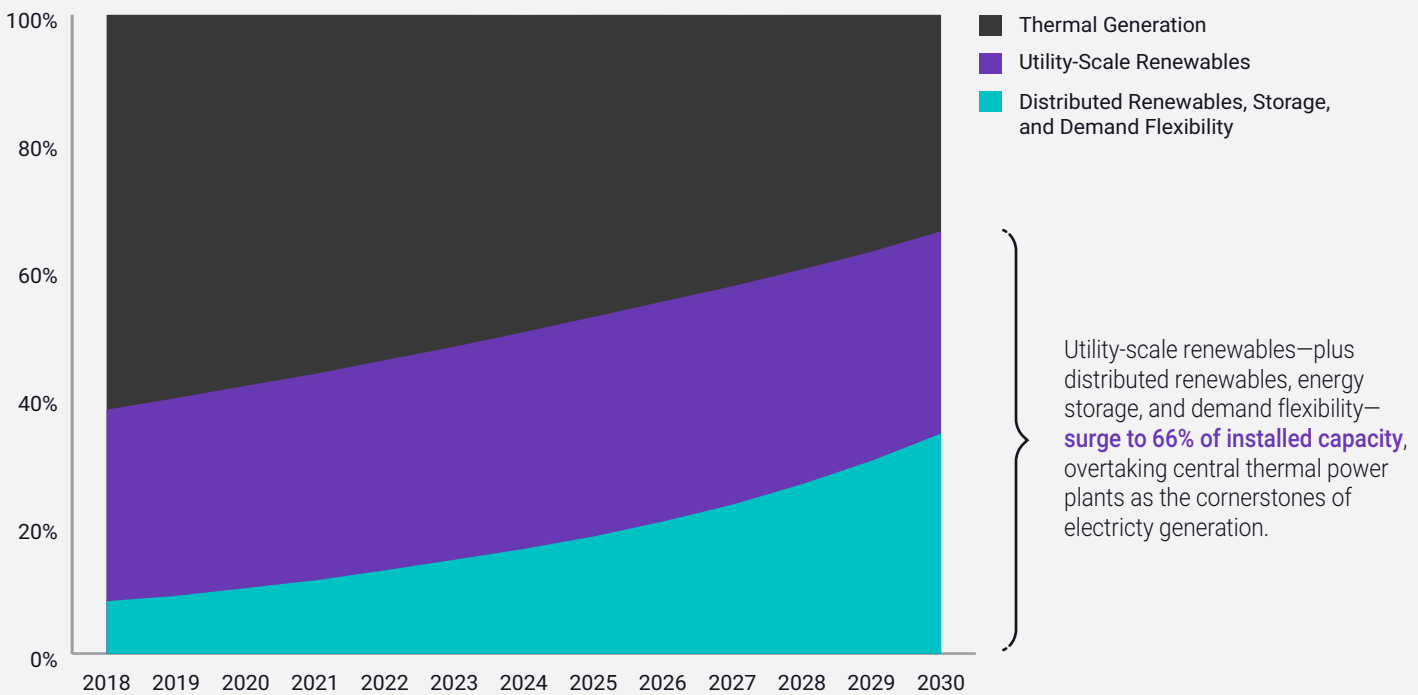
In this environment, **asset and customer information is fragmented across multiple siloed systems and is often invisible to grid operators.**[2] Consequently, many assets remain largely isolated from core system planning and operation functions, and DERs in particular are chronically underutilized and frequently fail to capture their full potential value.

We aim to overcome these issues with EW-DOS.

[2] We use the term "grid operators" as a catch-all for entities responsible for administering markets and/or processes that maintain overall balance between supply and demand on the grid. Terminology varies depending on geography and regulatory regime, but this list includes transmission system operators, distribution system operators, market operators, independent system operators, and regional transmission operators.

Fig. 1

Global Installed Capacity by Resource Type

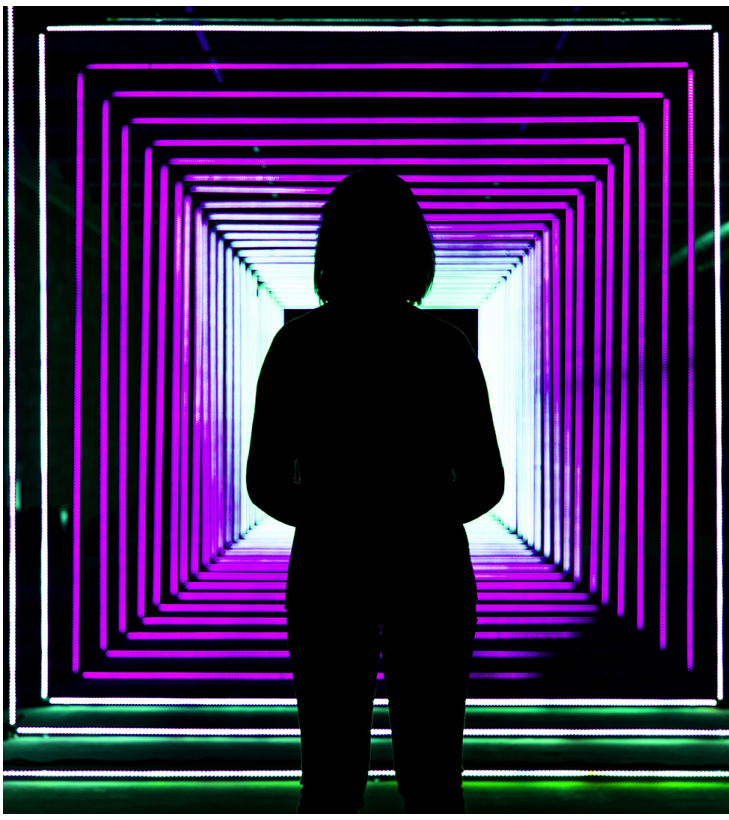


The Opportunity

Decentralized technologies can enhance energy-sector traceability and unlock the full potential of customer-owned resources.

Bigger databases, more-efficient algorithms, or faster computers will not solve the aforementioned barriers to DER integration. The problem is today's grid architecture.

Centralized architectures, no matter how performant, ultimately place the onus on a single party to maintain infrastructure, administer user roles and permissions, update data based on events over time, and establish a secure way of coordinating data across multiple discrete technical and organizational boundaries on a permissioned basis. In such architectures, data is duplicated across systems, which increases the risk of inconsistencies. This in turn leads to low trust and high cost.



Instead, we believe market participants ranging from regulators to grid operators to customers need to fundamentally re-evaluate their respective roles and responsibilities. We believe in democratizing the way renewables and DERs are integrated into grids, such that:

- Regulators set high-level rules of engagement;
- Grid operators provide infrastructure for transactions (in such a way that appropriately enforces the established rules), as well as visibility into process outcomes; and

- Individual customers, retailers, DER installers, and other smaller actors are empowered to perform many of the administrative functions that currently reside within grid operator functions.

That's why we designed EW-DOS as a narrow-waist protocol, purpose-built to connect the billions of customers, assets, and myriad physical technologies that comprise the 21st-century grid with any market or program one can imagine.

EW-DOS is not a product, or a market design, or a standalone application. It is a stack of open-source technologies and standards to meet global requirements for establishing identity, enforcing rules, and facilitating transactions. **We intend for EW-DOS to become a de-factor global standard for digital infrastructure in the energy sector.**

With EW-DOS, we can support widespread value creation via the two most-promising use cases we have uncovered to date:

- **Enhancing traceability in the energy sector,** giving market participants the ability to purchase a variety of digitalized, attribute-based green commodities ranging from International Renewable Energy Certificates (I-RECs) to certified green electric vehicle charges or low-carbon fuels (e.g., biogas).
- **Unlocking deep demand-side flexibility,** enabling grid operators to tap into the vast technical potential of customer-owned distributed energy resources and electric vehicles in a trustworthy, low-cost, scalable way.

How It Works

EW-DOS completely inverts today's system of top-down, unilateral management of energy-sector data acquisition and management.

Instead of any given person or device maintaining separate digital accounts for every product and service they use (i.e., duplicated identities among market participants) there's one universal and persistent identity controlled by the identity owner and accessible to all other market participants on a permissioned basis. When conditions change (e.g., a customer switching from one electricity retailer to another), there is no need to start the registration process from scratch. The identity owner simply updates the verifiable credentials, directs new relevant actors to the modified identity, and uses their identity to sign messages, perform transactions, and interact with market platforms.

Travel passports are the best analogy for describing how EW-DOS works (see Figure 2, page 10). At a very high level, passports summarize who you are, where you've been, and where you're allowed to go or not go now and in the future based on a variety of factors. Passports are a global standard for verifying identity and credentials; individuals are granted specific permissions based on attributes like nationality and the rules of different jurisdictions; the passport itself contains both intrinsic data about you (e.g., name, birth date, nationality) as well as dynamic data like visas and travel history, which evolve and update over time.

EW-DOS is a tool for similarly establishing digital "passports" for every customer, asset, service provider, and authority in a given electricity system. But instead of a central entity being in charge of verifying credentials and issuing the passport itself, any individual can create a passport and establish verified credentials over time through interactions with peers or various authorities.

Here's how digital identities fit into the EW-DOS architecture, step by step (see Figure 3, page 12):

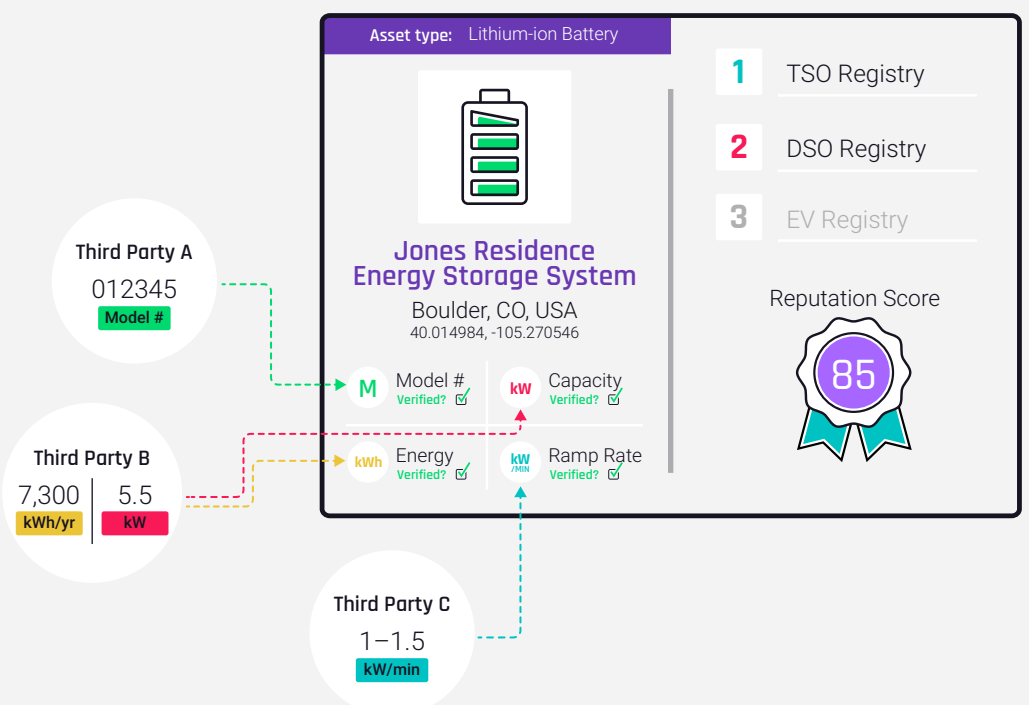
- **Digitalize:** Any customer, market participant, or device that wants to participate in a given electricity market first establishes a self-sovereign digital identity to coordinate with other systems and participants. Every digital identity is anchored on the EW Chain and fully owned and controlled by its creator forever.
- **Authenticate:** Once identities are created, local grid operators and market participants need a system to authenticate them and know, for example, whether a given solar PV system in Asia or an electric vehicle in California is what it says it is and has the attributes it claims to have (e.g., power capacity, ownership). To do so, identity owners make claims to peers or relevant authorities such as grid operators and installers.

Every claim is authenticated (or not) through bilateral transactions, in which the "claimer" (i.e., identity owner) provides a "verifier" (e.g., a DER installer) with agreed-upon documentation or data to prove a given credential.

For a simple example, envision a homeowner claiming to a DER installer that they own a 5 kW solar PV system during the commissioning process. The installer can confirm details about the system as well as the homeowner in-person to verify the claims. As claims are verified, the underlying digital identity becomes richer and more trusted. Identity owners can also use claims to delegate other entities to perform transactions or claims on their behalf. Claim messaging and data storage can be done "off-chain" or "on-chain" depending on the application. The Energy Web Chain is primarily used for providing proofs about each identity, enabling market actors to

Fig. 2

Decentralized identifiers—enriched by multi-party attestation of verifiable claims—form the backbone of EW-DOS digital identities.



achieve consensus about a given identity or claim without needing to share or expose underlying data.

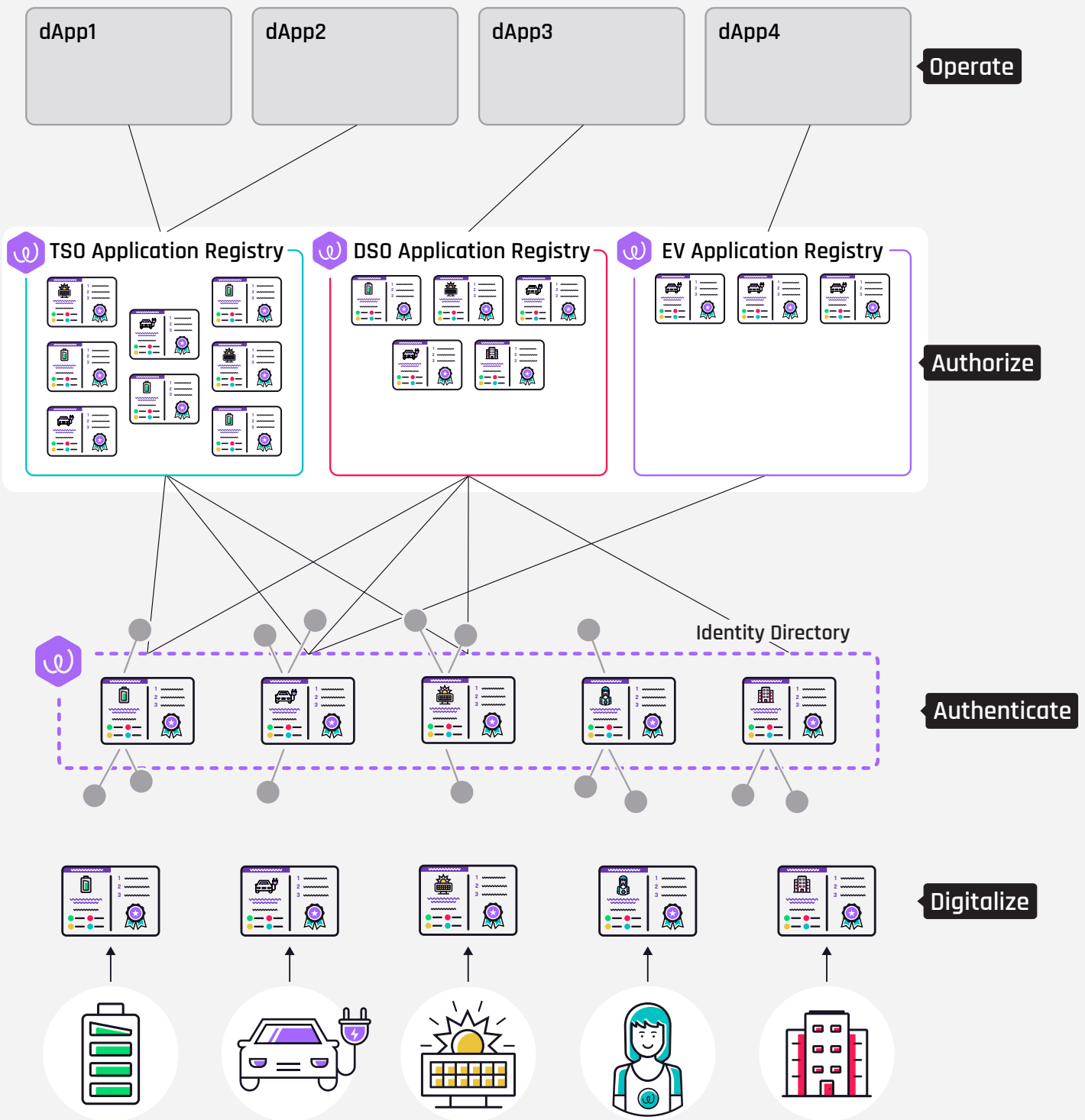
- **Authorize:** Once authenticated, identities must then be authorized to participate in electricity markets or services for which they are qualified. To do so, grid operators, regulators, and/or retailers create registries that query the pool of on-chain digital identities and integrate all identities that meet defined eligibility criteria into the relevant platforms or systems. These registries enforce market rules or business logic based on the verified claims of digital identities, thus providing the foundational identity and relational data that other business processes and systems rely on—from market bidding, to dispatch, to settlement.

- **Operate:** With identities allowed into their respective registries, the corresponding customers and resources can participate in markets. For a traceability example, authorized wind plants may be added to an International Renewable Energy Certificate registry and begin producing digitally unique I-RECs that authorized corporate buyers can purchase directly. For a flexibility example, authorized behind-the-meter batteries are added to a local transmission system operator registry and begin participating in the wholesale market for frequency regulation. Actual market operations are accomplished using a mix of decentralized architectures and existing information and operational technology systems, depending on the requirements of the specific application. Over time, operational and contractual data can be fed back to digital identities as verifiable claims to further augment the performance or "reputation" rating of each identity.

In this architecture, blockchain-based digital identities become the common reference point for all participants and systems within a given market. Just as real-world passports form the basis for establishing identity and permissions (e.g., the ability to travel or work) in any region, they are the basis for registering and monitoring the actions of assets and customers in electricity markets.

Fig. 3

'EW-DOS Passports' based on decentralized identitifiers (DIDs) reside in an Identity Directory that interfaces with various application registries.



A Closer Look

The Energy Web Decentralized Operating System (EW-DOS)

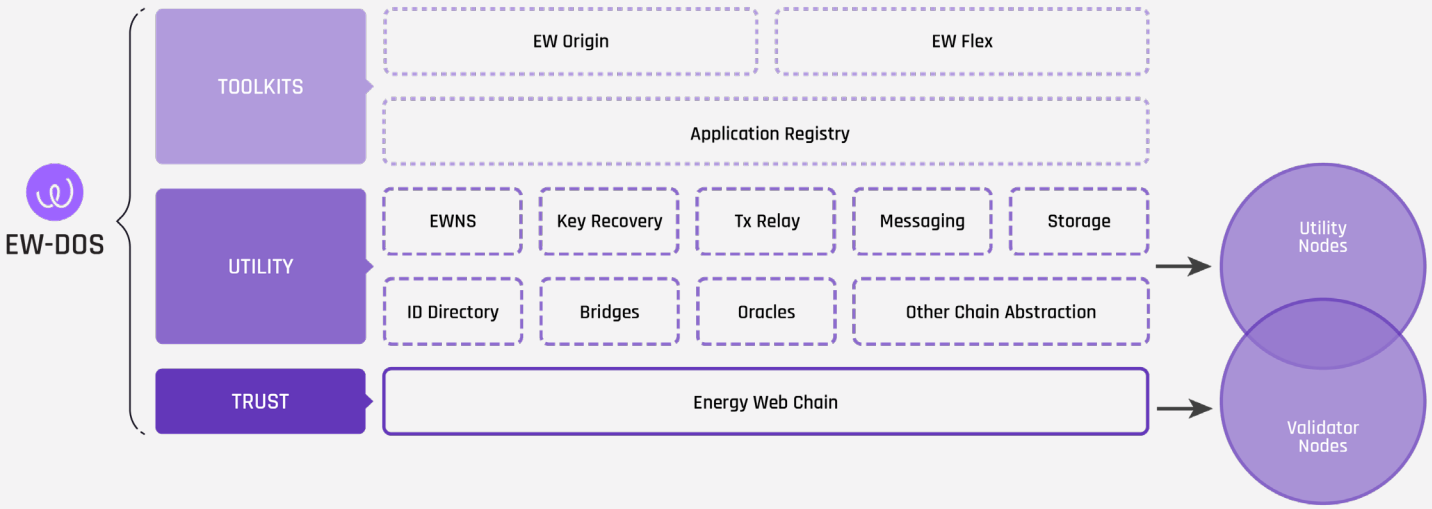
EW-DOS comprises three layers (see Figure 4, page 14):

- **Trust,** which anchors self-sovereign decentralized digital identities (DIDs) and provides a way to timestamp immutable data-sets and the associated state transitions in smart contracts via the public Energy Web Chain;
- **Utility,** the "middleware" layer of the EW-DOS stack, which simplifies the experience of creating and using decentralized applications with dedicated solutions for high-volume messaging, user-experience tools, and back-end application services; and
- **Toolkit,** with open-source templates for constructing applications that facilitate renewable energy markets, e-mobility programs, and DER market participation.

In this section, we describe at a high-level each component of EW-DOS.

Fig. 4

EW-DOS is our vision for a stack of open-source software and standards enabling market participants to digitally orchestrate low-carbon electricity systems.



TRUST LAYER: multi-party consensus and shared state on the EW Chain.

- **EW Chain:** A public, proof-of-authority (PoA) blockchain operated by validator nodes from the EW member ecosystem that features a native token (EWT) and hosts decentralized digital identities, executes smart contracts, and provides proofs for verifying the state of data and events.

UTILITY LAYER: "Middleware" components that give developers tools to easily build user-facing applications that gain the advantages of decentralized digital infrastructure yet deliver familiar UX to customers. The EW-DOS Utility Layer services are provided by Utility nodes, a separate set of nodes hosted by members of the Energy Web community. These services are priced and paid in EWT.

- **Energy Web Name Service (EWNS):** Enables users to map human-readable names (e.g., name.ewc) to their DID address and create a sub-name for other resources, like an email address or smart contract (e.g., resource.name.ewc.). This is a deployment of the Ethereum Name Service on the Energy Web Chain.
- **Key Recovery:** A multi-signature wallet that governs ownership over a DID, solves the "password reset" problem, and prevents adversaries from unilaterally gaining control over a DID (itself a smart contract governed by a key pair) in the event that the identity owner loses access to their original key pair.
- **Transaction Relay:** A service enabling end-users to interact with the EW Chain without needing to hold or manage tokens. Delegated proxy nodes pay for transaction fees in EWT on behalf of users and applications.
- **Messaging:** A decentralized messaging service for high-volume, low-latency (e.g., machine-to-machine) communications that can be integrated with on-chain transactions and signatures.
- **Storage:** EW is developing decentralized storage solutions for content addressed data (those which must not be editable) and key-value data (which contains things that need to have a predictable key or an arbitrary key), but in many cases existing storage solutions (e.g., either private cloud or

on-premise database) will be used for commercial applications and the messaging and other chain abstraction components will serve as a connective tissue to on-chain components.

- **Identity Directory:** Decentralized identifiers (DIDs) are a new type of identifier for verifiable, persistent, resolvable, and secure digital identities that are directly owned and controlled by end users. DIDs enable the controller of a DID to prove it has control over itself and to be implemented independently of any centralized registry, identity provider, or certificate authority. The Identity Directory is a smart contract that contains the universal list of DIDs and associated claims on the EW Chain.

- **Bridges:** Purpose-built smart contracts that enable the transfer of tokens, and eventually any arbitrary data or transaction, between different blockchains (e.g., EW Chain to public Ethereum). The first two production bridges are designed to transfer tokens between the EW Chain and the main Ethereum network; one enables users to transfer native EWT from the EW Chain to an ERC-20 representation on Ethereum and the other enables users to transfer DAI stablecoins from the Ethereum network to a bridged DAI on the EW Chain.

- **Oracles:** For use cases where it's beneficial to leverage multiple input sources (e.g., monitoring of local voltage for multi-party reconciliation, reporting of distributed solar for renewable portfolio standards accounting), we are building on top of emerging open-source protocols, particularly the Chainlink protocol, for establishing a network of independent nodes to provide event data to on-chain contracts.

- **Other Chain Abstraction:** In addition to EWNS and the Transaction Relay, we are continuing to develop application programming interfaces (APIs) that make it easier for applications and users to interact with the EW Chain.

TOOLKIT LAYER: free, open-source templates that simplify and speed up the process of developing enterprise applications.

- **Application Registry:** Application registries act as an "authorization layer" for DIDs, and this reference architecture provides a standardized way to create bespoke registries with administrative features specific to a particular geography, market, or application.

- **EW Origin:** A series of customizable open-source software modules designed to support provenance and traceability use cases, including digital renewable energy marketplaces and demand-side management.

- **EW Flex:** An open-source software architecture for coordinating DER data and operations across organizational and technological boundaries, allowing millions of DERs to participate in wholesale electricity markets and demand-side management programs.

- **Other Toolkits:** We are continuing to develop additional toolkits as we gather additional requirements from our global network of members. In-development toolkits include functionality that enables digital identities to settle payment; automatically conduct evaluation, measurement, and verification (EM&V); post value in escrow; and engage in complex transactions (e.g., financial contracts).

The Roadmap

EW's Plan to Drive Impact at Scale

EW's theory-of-change is simple. To achieve our mission in a timeframe relevant to mitigating the worst impacts of climate change, we work directly with some of the world's largest energy companies—including utilities, grid operators, and others—to develop and deploy solutions for integrating low-carbon DERs based on EW-DOS.

We believe we can transform the energy sector, enabling new market designs of all shapes and sizes (in both developed and emerging economies) by implementing EW-DOS in collaboration with major market participants. EW has already begun to develop and deploy discrete pieces of EW-DOS with several market participants:

In Austria, EW is helping Austrian Power Grid AG (APG) integrate grid-edge customers to participate in wholesale balancing markets.

In Thailand, EW is co-developing a renewables marketplace platform with PTT.

In the United States, EW is working with PJM-EIS to develop a next-generation renewable energy certificate (REC) tracking system.

In Germany, Sonnen is using EW-DOS to enhance grid flexibility and reduce renewable curtailment through its virtual power plant.

Globally, EW is collaborating with Vodafone to develop a secure, SIM-based architecture for connecting billions of IoT devices to EW-DOS.

These are just a few examples from a growing list, but they highlight three important points:

- **EW-DOS enables private solutions that can leverage public, decentralized networks.** If a utility wants a solution where they are the only party capable of confirming and rejecting DID claims (meaning they can restrict who does / does not participate in the local market), EW-DOS supports that. If that same utility wants all operational matters to be conducted in-house using legacy IT systems, no problem. EW-DOS does not prescribe a particular approach to privacy and is flexible enough to work in any context.

- **EW-DOS is market- and regulation-agnostic.** It creates value in vertically-integrated utility territories as much as fully deregulated competitive markets. It works just as well in well-established markets in Western Europe as it does in developing economies in Africa.

- **EW-DOS is not a "use case" or an "application"; it is public infrastructure that supports companies that want to build solutions.** Like other infrastructure platforms such as telecommunications, the Internet, and blockchains like the EW Chain, the applicability of EW-DOS is limited only by the imagination. It enables myriad use cases and applications, especially those that leverage the swell of customer DER investment to envision a low-carbon, decentralized electricity grid.

Contributors

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About Energy Web

Energy Web is a global, member-driven nonprofit accelerating a low-carbon, customer-centric electricity system by unleashing the potential of blockchain and decentralized technologies. EW focuses on technology integration and development, co-creating standards and architectures, speeding adoption, and building community.

In mid-2019, EW launched the Energy Web Chain, the world's first enterprise-grade, open-source blockchain platform tailored to the sector's regulatory, operational, and market needs. EW also fostered the world's largest energy blockchain ecosystem, comprising utilities, grid operators, renewable energy developers, corporate energy buyers, and others.

Energy Web has become the industry's leading energy blockchain partner and most-respected voice of authority on energy blockchain.

For more, please visit https://energyweb.org.

Learn More

For a more-detailed technical description of EW's current technology and roadmap, see this paper's companion piece, ***EW-DOS: PART 2: Technology Detail***.

To explore EW's existing technology stack, visit our Github and Wiki.

To learn how to work with EW, contact us at info@energyweb.org.

To learn more about EW's mission, visit energyweb.org.