Blockchain Transactive Energy and the Electric Grid

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Overview

- Building the 21st century grid.
  - Review of the societal imperatives driving the grid architecture transformation.
- Introduction to transactive energy, blockchain, and tokenization.
  - Review technological underpinnings.
- Use cases for BCTE.
  - With focus on the near term, deployable today use cases.
- Organizations providing BCTE services or software.
  - Review of three organizations/projects in the North America, Europe, and Australia.
- Summary

About Me

1984 - PhD from University of Arizona in Systems Engineering and Computer Science.

Until 2020 - Worked mostly in industrial research at medium to large tech companies with research labs in Silicon Valley.

- HP, Sun Microsystems, NTT Docomo Labs, Ericsson Research, Equinix, VMWare.

1996-2006 – Member of the Internet Engineering Task Force (IETF).

- Defining Internet protocol standards for wireless networks.
- Internet Architecture Board for 1 term and chaired 3 working groups.

2016 – Began consulting part time with cleantech companies at Powerhouse incubator in Oakland, CA.

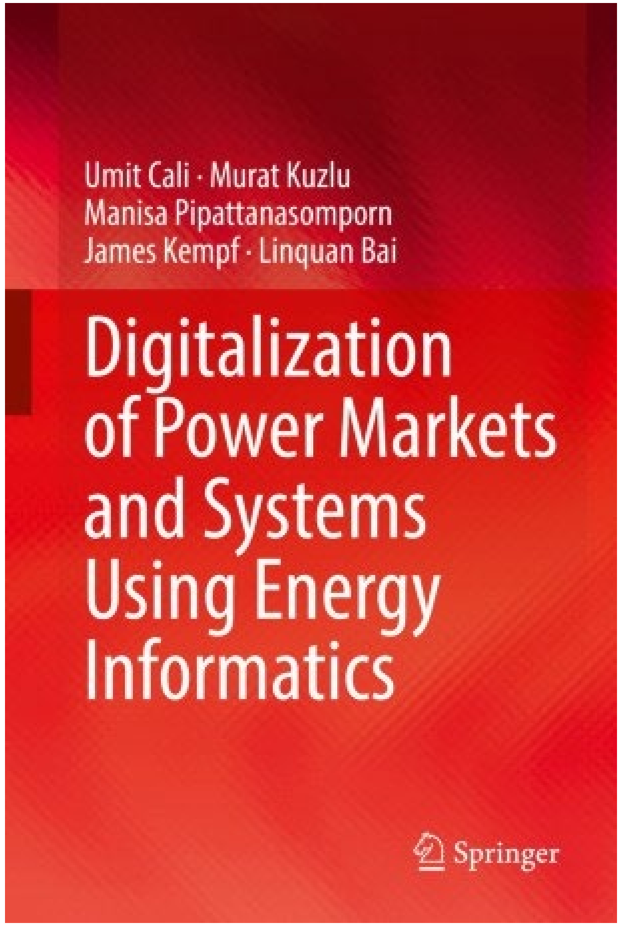
- On application of information and communication technology (ICT) to cleantech/renewable energy.

2020 – Transitioned to full time cleantech consulting.

2021 – Part of the 4 co-author team for *Digitalization of Power Markets and Systems Using Energy Informatics* (see picture).

Research interests: applying ICT to building decarbonization, distributed renewable energy, microgrids.

57+ papers, 30 patents, 4 books

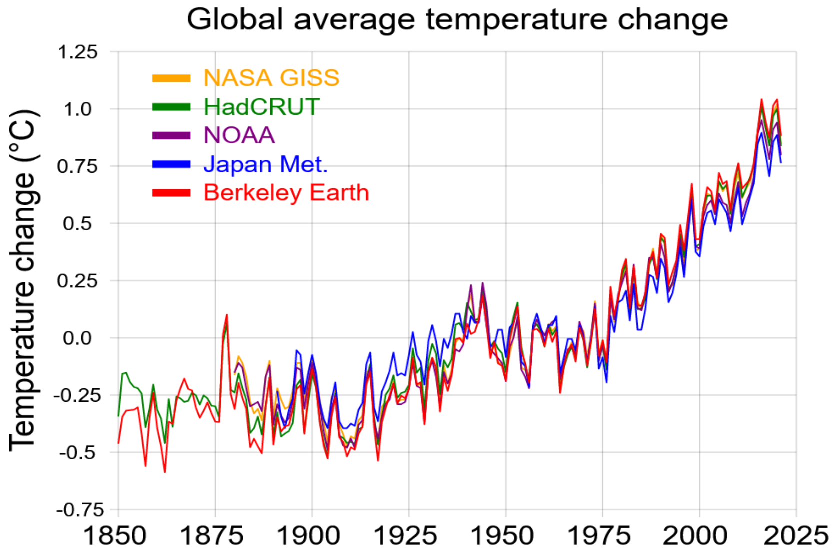


Building the 21^{st} century grid

Decarbonize, decentralize, digitalize!

Decarbonization

- Global temperature average is on track toward a 2.5 degree Celsius increase over pre-industrial levels by mid century.
  - Driven by historical carbon emissions from combustion of fossil fuels including from the generation of electricity.
- Increasing heat retention in the atmosphere is making weather changes more unpredictable and violent.
  - Longer droughts in dry places.
    - Increasing wildfires.
  - More rain and concentrated storms in wet places
    - Stronger hurricanes.
- Many states and countries have goals to decarbonize their grids by mid-century.
  - Example: California SB 100 and Executive Order B-55-18
    - Require 60% of all electricity sold on the California grid to be renewable by 2030 and 100% by 2045.
- Since we have a roadmap for decarbonizing the grid, push to electrify services that currently utilize fossil fuels.
  - Electrify Everything!
  - Transportation, space conditioning, water heating.



Source: wikipedia.org, time.com, latimes.com

Decentralization

In the 20th century grid, power flowed in one direction and load profiles were fixed.

- From a large, centralized, fossil fuel powerplants to loads in residential, commercial, and industrial buildings.
- Load profiles were well known and not controllable.

Decarbonization is driving an increase in deployment of DERs like solar generation, battery storage and electric vehicles and flexible loads like heat pumps in the distribution grid.

- California has mandated that all new single family homes be outfitted so that solar can be installed.
- Opportunities for increasing distributed renewable generation and flexible load control.

For resilience, many communities and enterprises are looking at microgrids.

- PG&E public safety shutoffs.
- NREL fractal grid architecture.

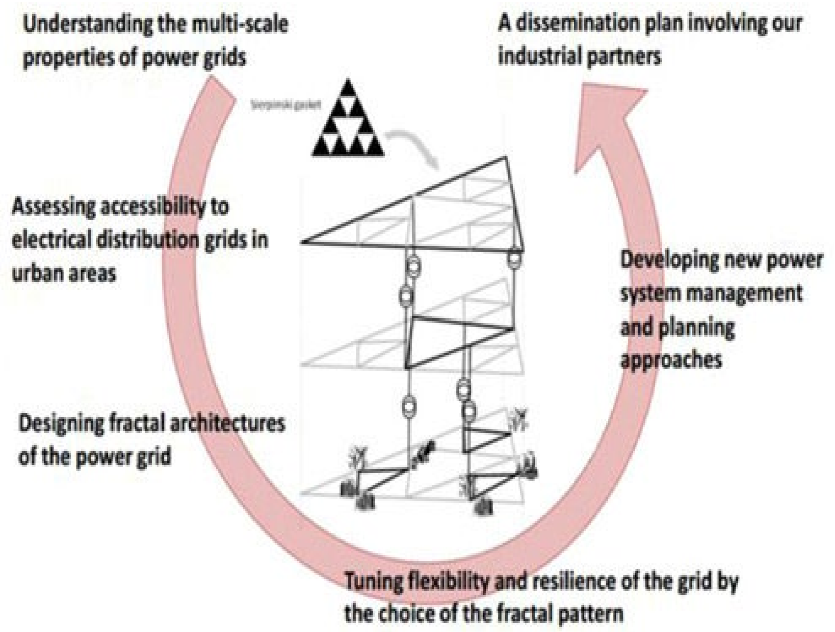
Rise of intermediaries between the utility and the customer.

- Demand response aggregators like OhmConnect.
- In California, nonprofit Community Choice Agencies (CCAs) allow consumers to buy renewable energy directly at a competitive price.

In the 21st century, the distribution grid is bidirectional and loads can be controlled.

- Distributed energy resources (DERs) like rooftop solar, on premises batteries, and V2G EV charging inject power into the grid.
- Flexible loads allow scheduling of consumption and deferral if grid conditions warrant.

Managing the supply/demand balance with hundreds of thousands of DERs and millions of flexible loads strains traditional grid management methods.



Source: researchgate.net

Digitalization

After almost no load growth for over 20 years, NREL study identifies three load growth scenerios over the 2016-2050 period due to beneficial electrification:

- Low scenario - 21% increase, 0.65% CAGR.
- Medium scenario - 45% increase, 1.2% CAGR.
- High scenario - 67% increase, 1.6% CAGR.

Distribution grid (DG) management must become more efficient to handle load growth:

- Upcoming growth in demand will require managing flexible loads.
- More DG generation such as solar PV and batteries will require co-ordination with transmission grid imports and flexible loads.

New protocols allow unparalleled communication and control.

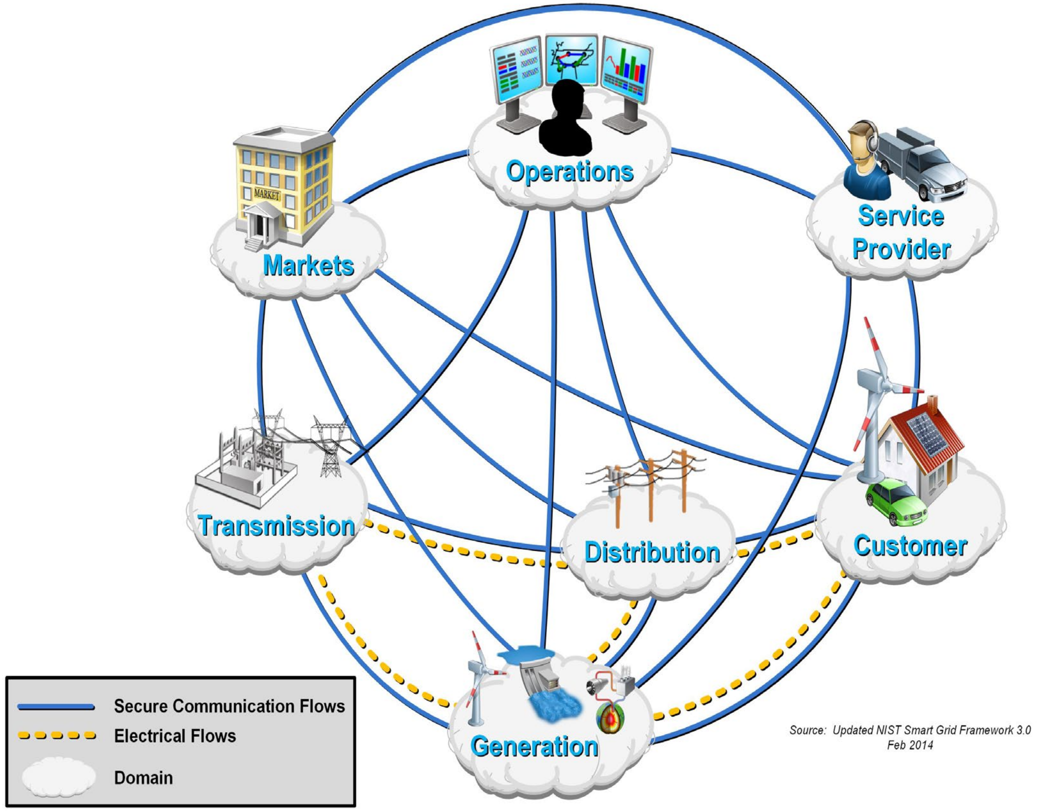
- IoT protocols like MQTT and AMQP enable communication between controllable devices and utility.
- OpenADR and IEEE 2030.5 enable monitoring and control of generation and load devices.

Low cost sensors enable more precise, fine grained measurement.

New generation of building management systems (such as DemandX) apply machine learning to building energy management.

NIST smart grid conceptual model provides a framework for utilities and others to implement the digitally enhanced grid.

Digitalization of the grid is where information and communication technology (ICT) is impacting operational technology (OT).



Introduction to Transactive Energy, Blockchain, and Tokenization

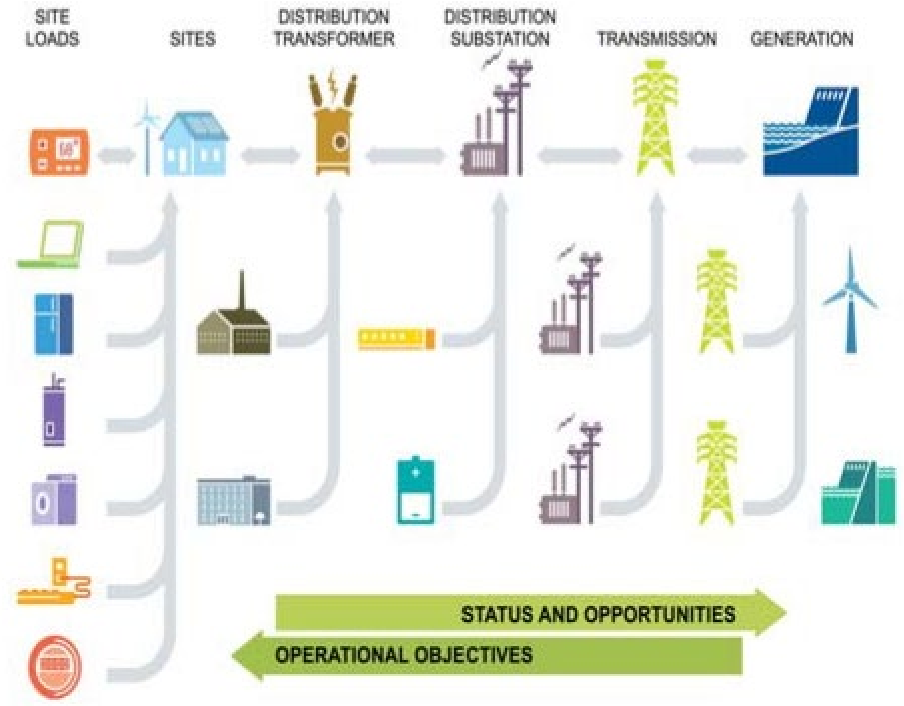
What is Transactive Energy (TE)?

GridWise Architecture Council defines transactive energy as:

> … techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market-based constructs while considering grid reliability constraints. (GWAC 2015)

TE was originally proposed in the late 2000's as a distribution grid deployment of the same principles as in the bulk power market.

- Bulk power market has had transactive features since the late 1990s/early 2000s.
- Day ahead and real time prices used to control amount of power on grid.
  - Energy price increases -> expensive fossil gas peaker plants are fired up.
  - Energy price decreases-> fossil gas peakers shut off.



Source: https://scholar.archive.org/work/tafdhjnz5na2jbrc3sb63arqzy/access/wayback/https://core.ac.uk/download/pdf/84005212.pdf

TE and Grid Transformation

In the mid-2010s, TE was viewed as a replacement for traditional optimal control techniques to manage the distribution grid.

- Optimal control techniques work for tens to hundreds of large scale generators and noncontrollable loads with fixed load profiles.
- With potentially hundreds of thousands of DERs and millions of controllable loads, solving the optimal control equations to balance supply and demand in real time becomes infeasible.

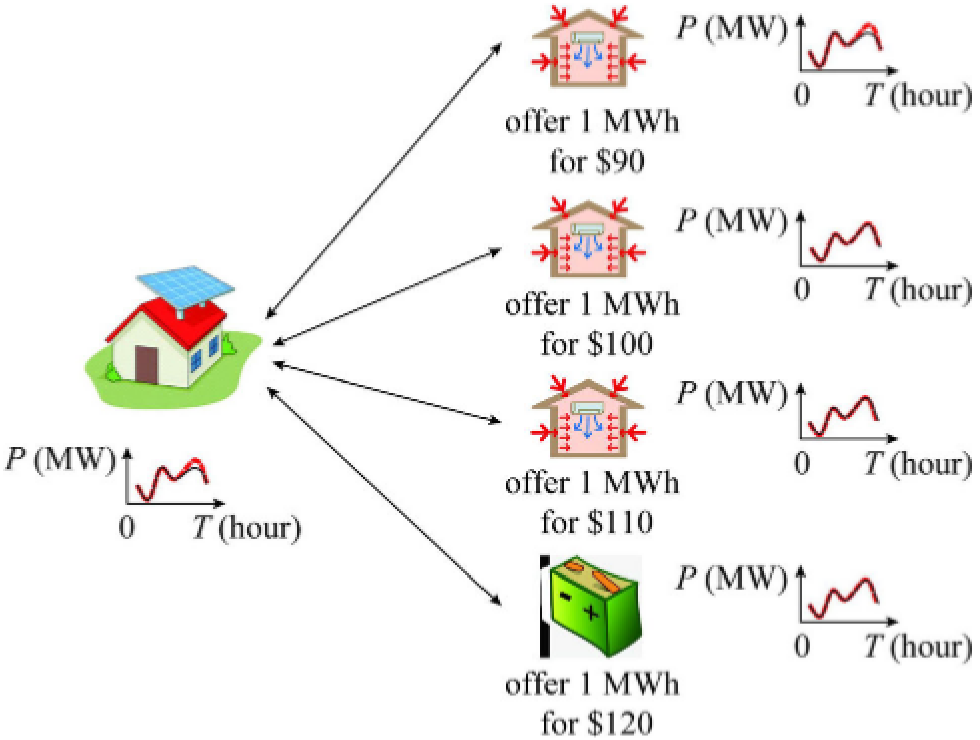
Market-based mechanisms such as TE have in the past been successful at maintaining supply/demand balance in complex markets with lots of participants.

Despite promising pilots, TE has been slow to catch on among distribution utilities and state regulators in the US.

- Regulatory authorities have been slowly moving toward time of use tariffs to encourage reduced power use during the late afternoon-early evening peak.
- But they are still covering their marginal costs with demand charges and tiered pricing, complicating customers' energy cost planning.
- Transactive tariffs would fold all the marginal costs into the transactive price and allow the customer's software agent to bid their preferences into the market.

Regulatory regimes in Europe and especially Australia have been much more favorable for TE.

- Australia today is a leader in transactive energy application.



Source: https://ieeexplore.ieee.org/iel7/8685265/8944234/08944236.pdf

What is a Blockchain?

A blockchain is a distributed ledger (database) structured as a chain of blocks.

- “Distributed” means copies of the ledger database are stored on all participating nodes.

Transactions entered into the ledger are cryptographically signed by the transaction originator’s private key and verified with the public key

- Transactions can’t be repudiated

Transactions are gathered into a block and when the block is complete it is submitted to validator nodes for distributed consensus.

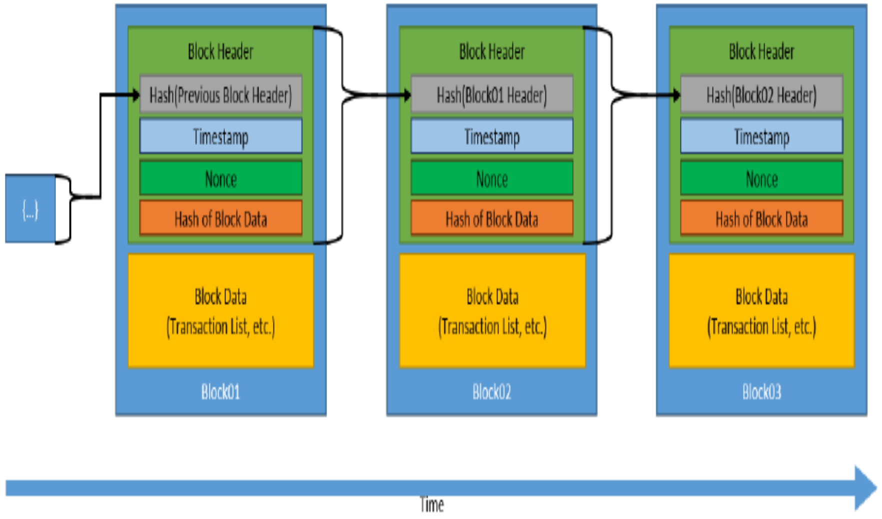
- Many types of distributed consensus algorithms.
- All have different properties.

When the block has been validated, it is linked into the chain with a cryptographic hash of the previous block in the header.

- The hash ensures that blocks cannot be moved or changed after insertion ensuring tamper resistance.

Each node maintains a copy of the ledger.

- All participants in the blockchain have access to the ledger contents ensuring full transparency.



Source: “Blockchain Technology Overview”, NISTIR 8201, D. Yaga, P. Mell, N. Roby. and K. Scarfone

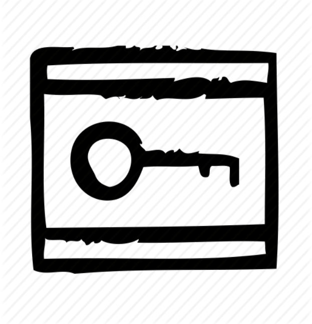
The Three Basic Technologies Underpinning Blockchain

Distributed consensus and transactions to determine agreed upon state changes.

- State changes allowed only within transactions.
  - Prevents “double spending”
- Note: energy wasting Proof of Work is only one of many possible distributed consensus algorithms!
  - Proof of Stake, Proof of Authority, Proof of History are all others used by energy blockchain applications

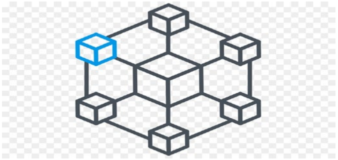
Cryptographic operations using cryptographic hashes and digital signatures based on asymmetric (public key) cryptosystems to establish trust.

- Also enables auditing and traceability.



A transparent, tamper evident, and tamper resistant distributed ledger to record state.

- Contains the state agreed upon by all nodes connected into one global data structure with copies on all blockchain participant nodes.



Source: https://www.kisspng.com

Source: https://thenounproject.com

What is Blockchain Transactive Energy (BCTE)?

Replace TE centralized database with a distributed ledger/blockchain.

- Cryptographic verification ensures that transactions and records can be trusted.

Depending on the service, blockchain nodes run at the regulator, ISO, utility, aggregators, and behind the meter DERs.

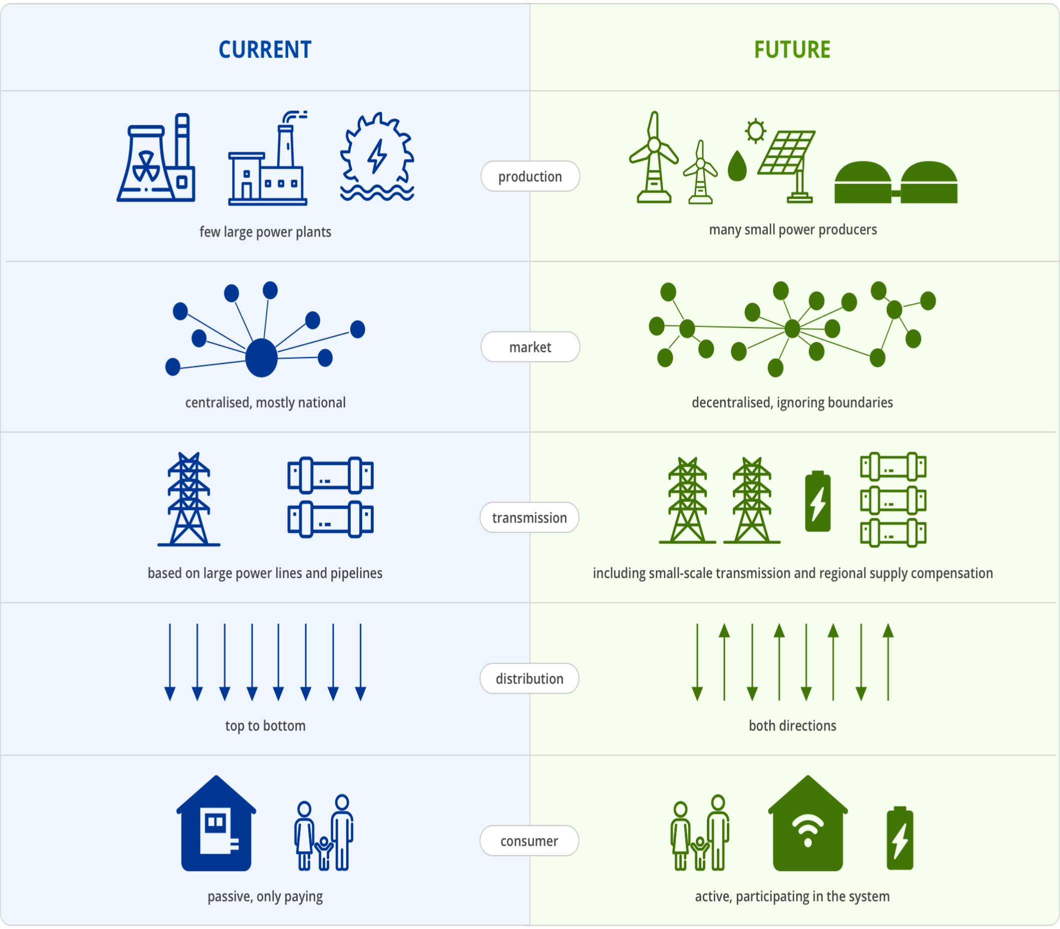
- Transparency ensures every participant can view transaction records.

Blockchain platform selected for security and access control.

- Need for identity and access management suggests a permissioned blockchain.

For real time transactions use a fast distributed consensus algorithm.

- Examples:
  - RAFT if private blockchain.
  - Proof of History if public blockchain.
- Many others!



Source: sustain-impact.com

The Business Case for Blockchain in TE

From a 2018 study by NIST

Common shared database? ✓

- Tracking real time prices and carbon content, determining the flow of energy or load reduction among parties, and charging and billing requires a shared, distributed database.

Multiple different sources of truth? ✓

- Currently every participant in the business ecosystem has their own database.

Parties involved have conflicting incentives, or do not fully trust each other? ✓

- Utilities don't trust third party aggregators or homeowners to deliver their promised load reductions when requested or that they will double count when supplying power to the wholesale and retail markets.

Lack of mutual trust is currently handled by a trusted third party? ✗

- Mostly the parties use bilateral agreements but for some operations the independent system operator (ISO) serves as a trusted third party.

Participants are governed by uniform rules? ✓

- The rules are different depending where the participant sits in the ecosystem.
- All participants at that position must obey the same rules.

Cryptography can be used for authentication, data integrity protection, and non-repudiation? ✓

An objective, immutable history or log of facts is required? ✓

- For regulatory purposes.

Decision making of the parties is transparent, rather than confidential? ✓

- To ensure grid stability.

Transaction frequency does not exceed 20,000 transactions per second? ?

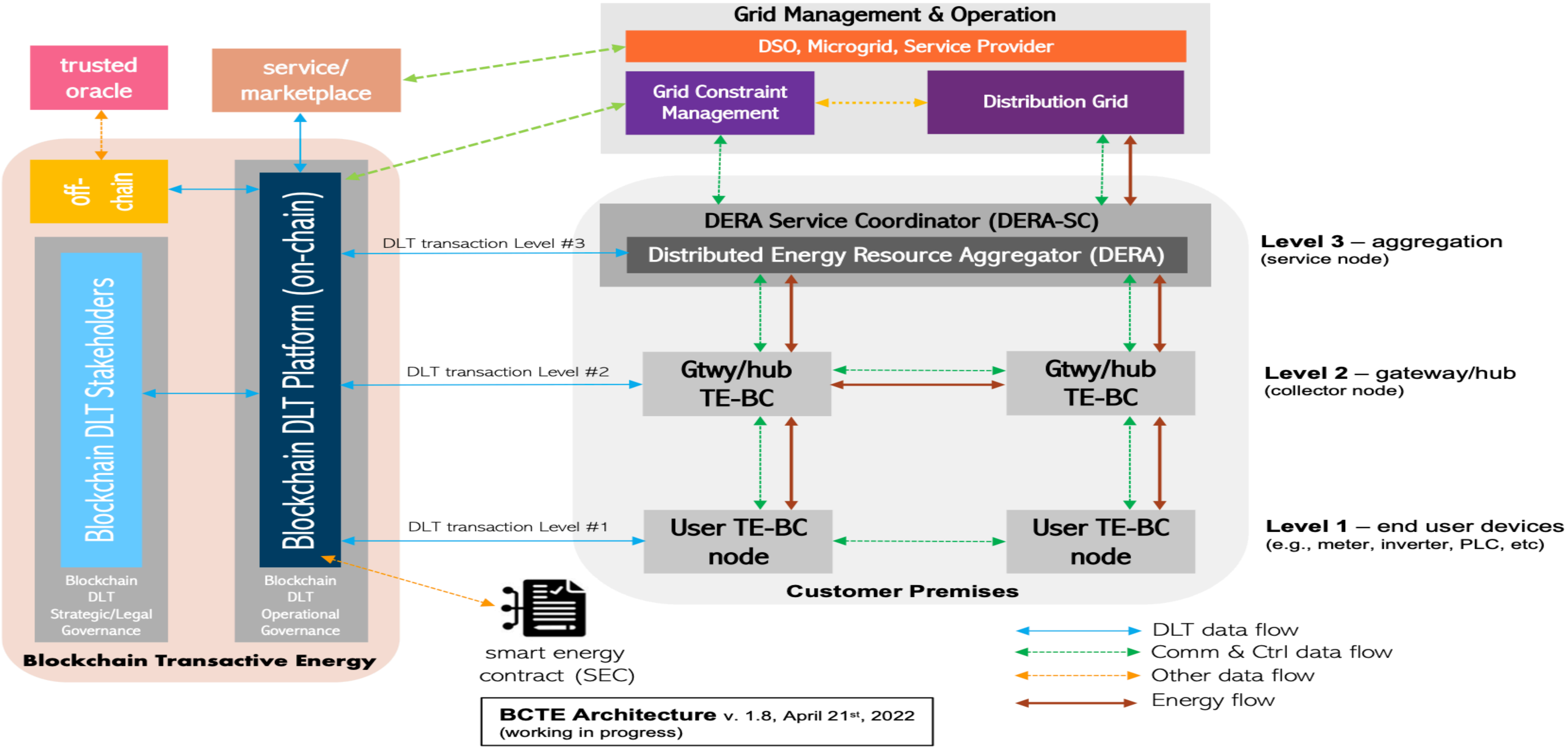
- As long as measurement and recording frequency greater than 0.05 msec.

See NISTIR 8202 for more

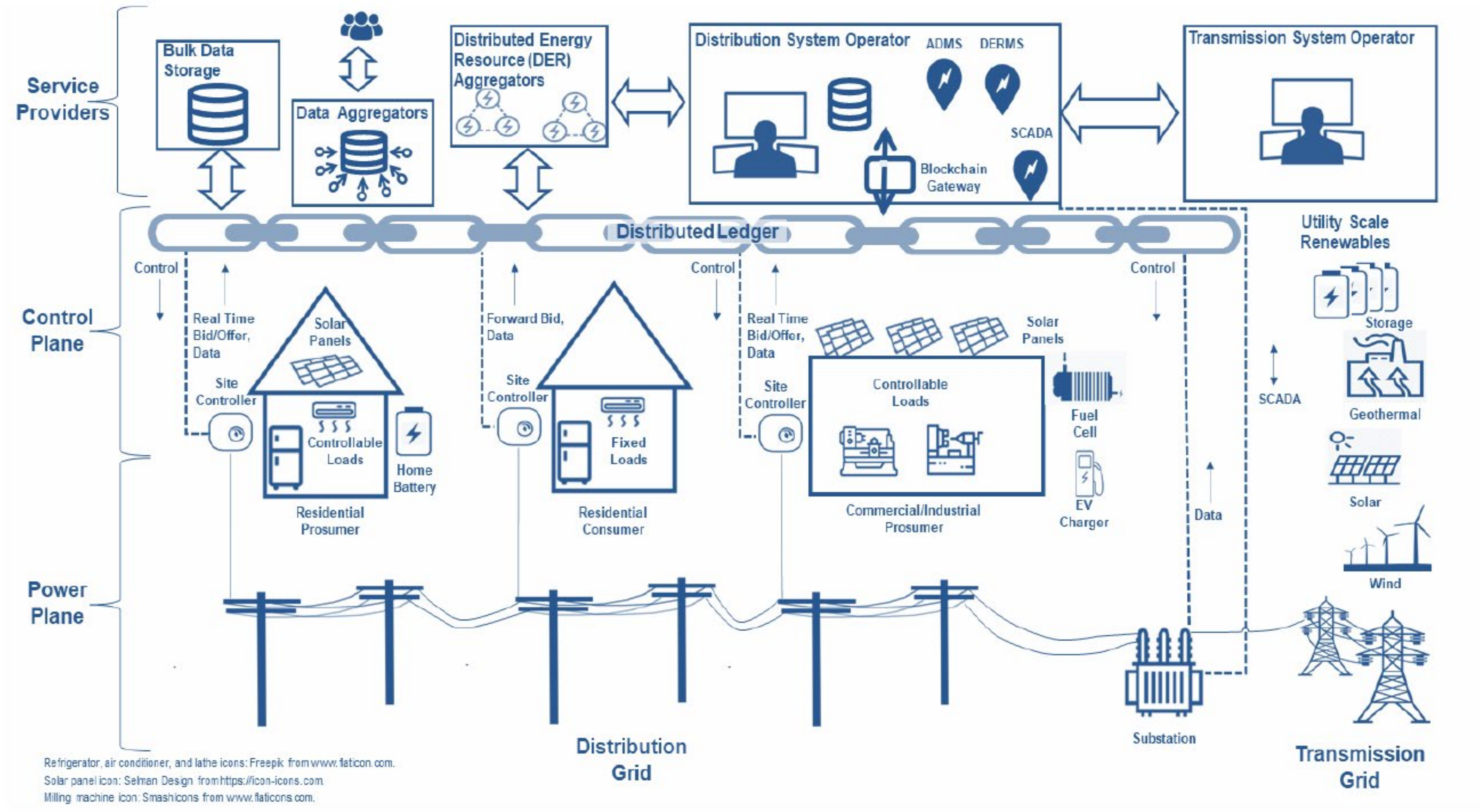
Icon Source: https://iconscout.com/icon/blockchain-5

Conclusion: BCTE is a good match with Energy Use Cases!

BCTE Functional Architecture



BCTE Deployment Architecture



Source: https://engage.ieee.org/IEEE-Blockchain-Transactive-Energy-Position-Paper-Sign-Up.html

What is Tokenization?

Tokens are digital assets or digital representations of physical assets.

- Created, tracked, and destroyed on a blockchain.

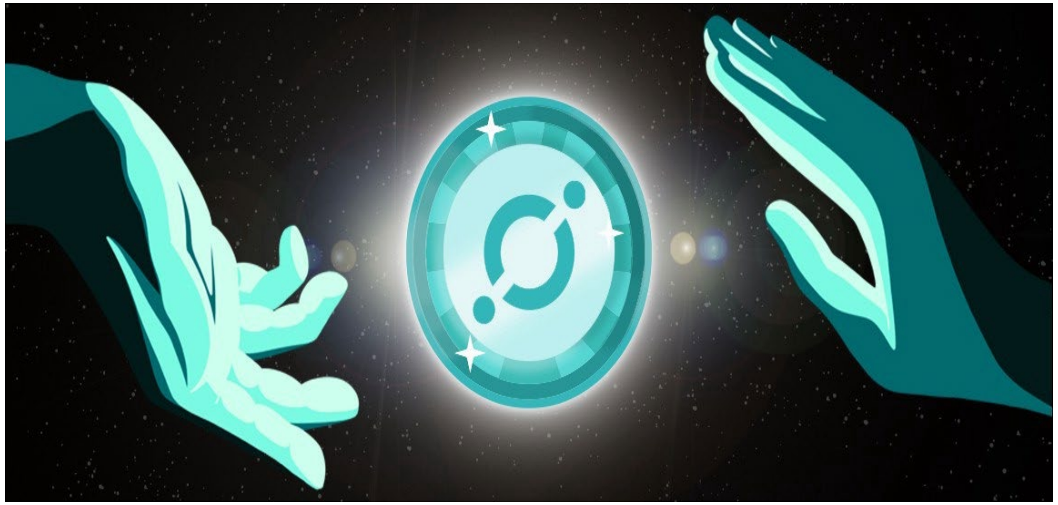
Two basic types of tokens:

- Fungible Tokens (FT).
  - Can be subdivided down to a smallest unit like money
  - Each token is identical to any others
  - Example: Bitcoin
- Nonfungible Tokens (NFT).
  - Each token is unique.
  - Cannot be subdivided.
  - Example: Tokenization of digital artwork.

Example uses of tokens in energy systems:

- A FT convertible to cryptocurrency used to incentivize distributed consensus validator nodes for proof of stake.
- A NFT representing 1 MWh of energy generated at a particular time and having a particular carbon content.

Tokens are used heavily in existing BCTE services/pilots.



Source: medium.com

Near term BCTE use cases

Use Case 1: Peer-to-Peer (P2P) Energy Trading

Prosumers trade energy with neighbors and record price and quantity on blockchain.

- Started with the Brooklyn Microgrid Project in New York City in 2017.
  - Exergy blockchain originally run by LO3Energy.

Benefits to the grid:

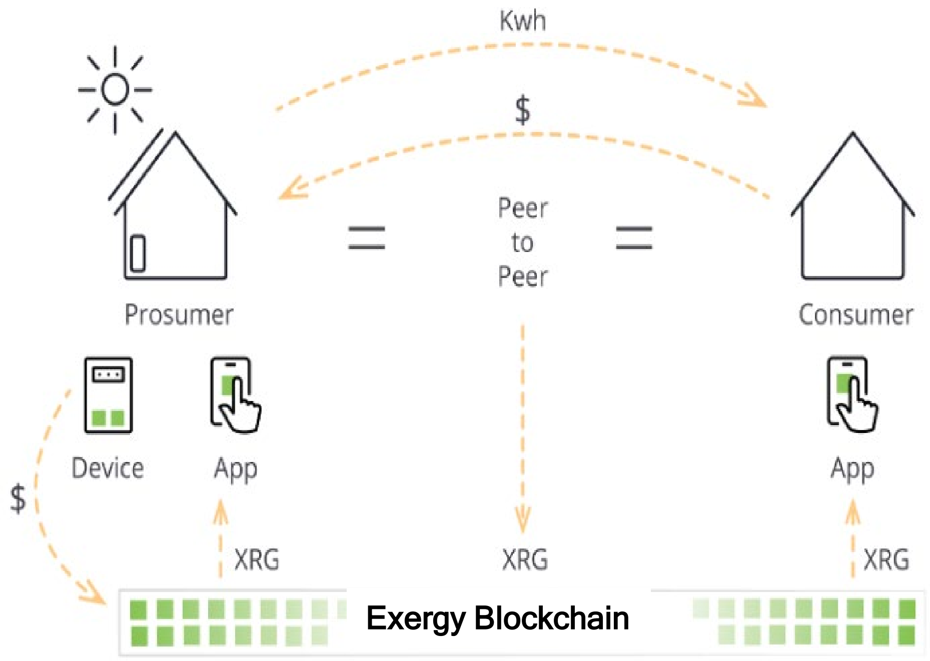
- Eliminates 6% power loss between transmission (high voltage) and distribution (low voltage) grids.
- Local energy markets can be more resilient to wide area disruptions like hurricanes, wildfires, and earthquakes.

2017 saw a bubble in transactive energy startups.

- $184m raised for peer-to-peer transactive energy blockchain startups.
- 57% of total for energy blockchain startups in general.
- Mostly through initial coin offerings
  - Declared illegal by the SEC in late 2017.

Regulatory issues:

- Peer-to-Peer energy trading is possible in Europe and Australia
- Prohibited by utility franchise laws in Japan and most US jurisdictions with the exception of Texas
  - Utility has monopoly on selling electricity.



Source: lo3energy.com, frontlinegaming.org

Use Case 2: Peer to Market Energy Trading (P2M)

Utility runs the market and acts as the market maker.

Local energy markets on the distribution feeders run by the incumbent utility:

- Producers sell energy to the utility at the real time market price.
- Consumers similarly buy energy at the real time market price.

Transactive nodes run on energy gateways at the customer premises and at the substation.

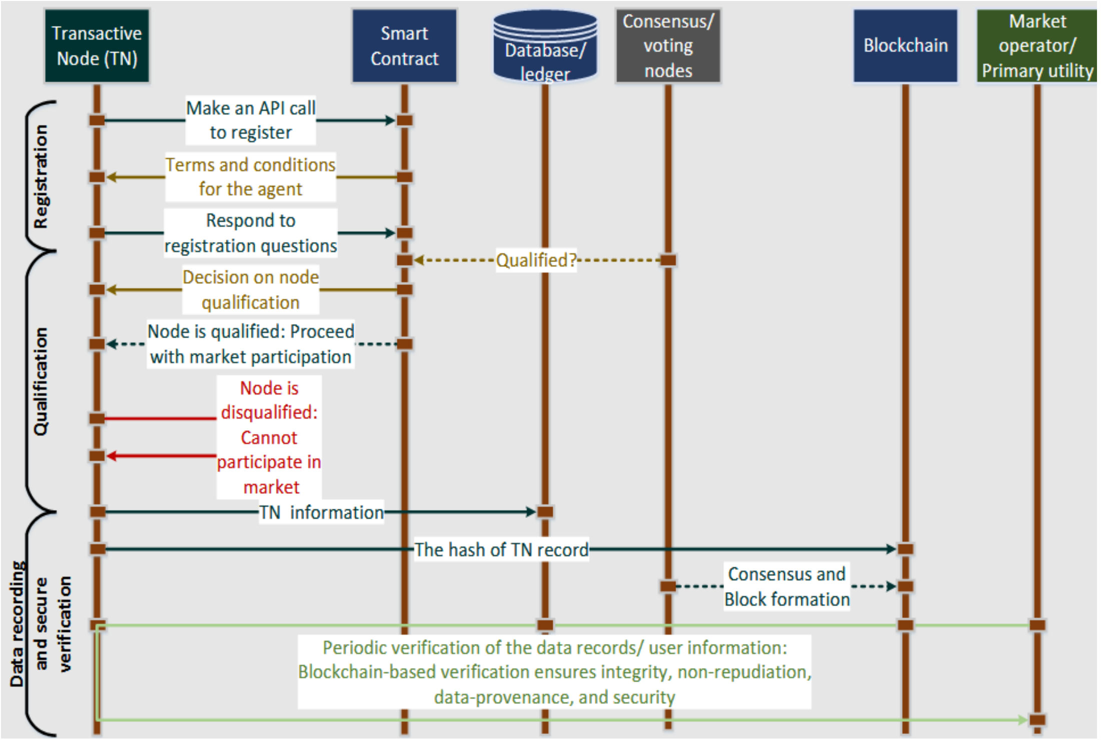
- Producer/consumer gateway is an add-on to smart meters.

Why not simply use a centralized database?

- Decentralized system can handle real time traffic from thousands of local nodes in a more scalable manner than a centralized database.
- If internet connection is arranged to keep traffic local, local transactive market can survive wide area internet outages.

Resilience benefit to the grid:

- If transmission grid connection is severed, distribution feeder could still stay up.
  - Acts like a microgrid.
- Controlling flexible loads could allow load reduction to match reduced power availability from local DERs only.



Source :https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-29017.pdf

Use Case 3: Implement FERC Order 2222 With Behind The Meter (BTM) Resources

TSOs/ISOs have been hesitant to allow BTM DERs to participate in the wholesale market.

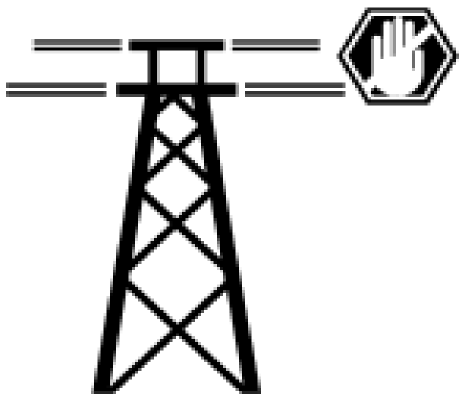
- Example: CPUC Rule 21-2018 in California specifically forbids BTM DERs from participating in both the wholesale and the retail market.
- Expensive and time consuming metering requirements for wholesale market participation have eliminated any BTM participation.

Yet in the 2020 August 14 & 15 grid emergency in California, the only reason the emergency didn't last longer was retail customers.

- Many *voluntarily* reduced load without compensation.
- Others did so in response to aggregator OhmConnect's OhmHour notifications.
  - Participants are paid to shed load during grid events.
- Total of 1 GW load shed after 8/15, enough to make rotating outages unnecessary.

The issue for utilities is double counting.

- A BTM flexible load or battery might try to get both retail NEM credit *and* wholesale market payment for the same kwh sold.
- Utilities don't trust aggregators to do proper accounting.



Source: thenounproject.com

BCTE For Aggregators, The Utility, And The ISO

But double counting was ***exactly the problem*** blockchains were designed to solve!

- Example: Absent any other measures, a fraudster could spend a Bitcoin twice since Bitcoin is a digital asset.
- Distributed consensus prevents this.

Solution: Aggregators, utilities, and the ISO run a transactive energy blockchain.

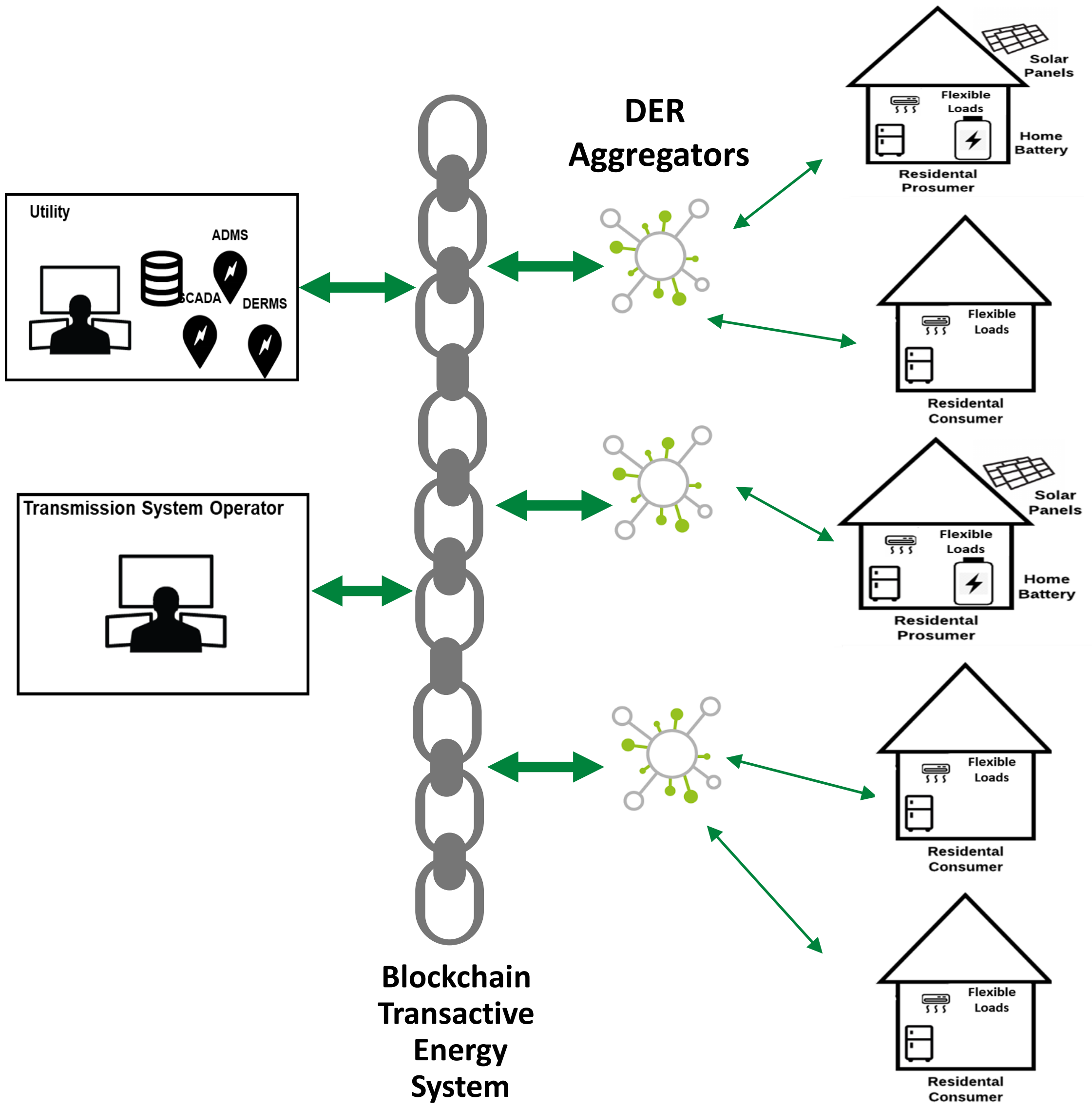
- Aggregators sign up retail customers to participate.
- Record on the blockchain whether the customer was participating in the wholesale or retail market.

No trust issue, blockchain records are tamper resistant and transparent.

- If there is a dispute between the aggregator and the utility, regulators can examine the record.
- Regulator might also run a BCTE node.

No need for transactive nodes at the customer premises.

- IEEE 2030.5 used between the customer premises and aggregator.
- DERs provisioned with a public key certificate and communications signed with a private key.



Use Case 4: Countering Power Factor Deterioration

Most PUCs require large commercial and industrial customers to correct for low power factor.

- Example: CPUC in California requires correction for facilities with loads over 400 kw and synchronous generators over 100 kw.

Prior to 1990, residential customer circuits had power factor above 0.95 and were considered ideal (resistive) loads.

- Appliances with inductive motors had built-in power factor correction.
- Incandescent lighting was fundamentally resistive.

Power factor on residential circuits has been deteriorating for years due to inductive and capacitive loads.

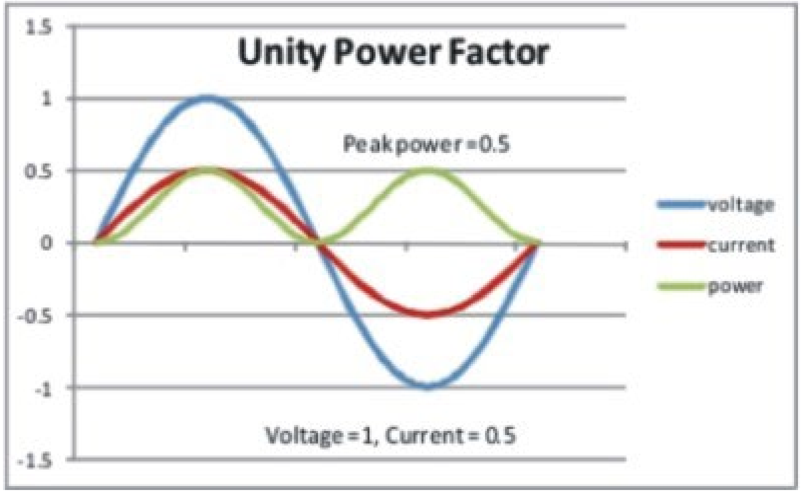
- Variable speed DC motors in HVACs, switched electronic power supplies, and LEDs generate more harmonics.
- Appliances are more efficient but cause the power factor to drop from 0.95 to 0.8.

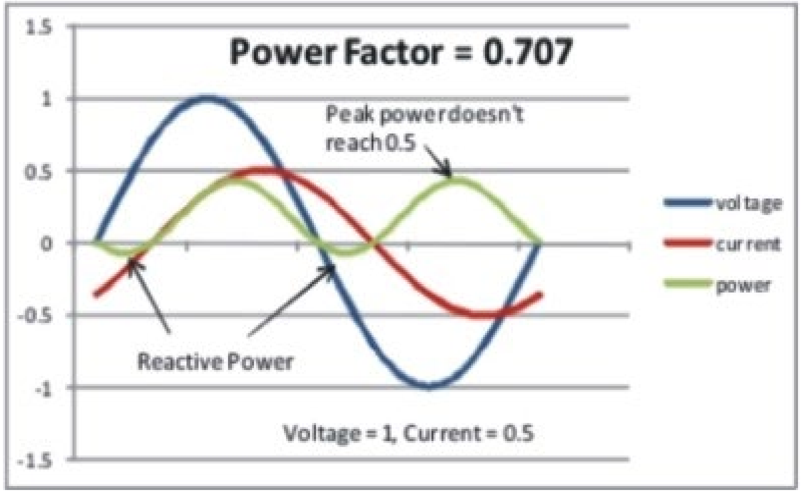
Residential DERs only make the problem worse.

- Only supply active power back to the grid reducing the power factor to near 0.5.
- Adjusting power factor closer to 1 could result in 12-16% improvement in distribution grid efficiency according to a study by Pecan Street.

Smart inverters are required to have the capability to generate reactive power.

- But there is no incentive structure in place for rewarding prosumers who do so.





Source: michaelsenergy.com

The "Wires Alternative"

Existing solution for adjusting power factor

The "Wires Alternative" is to solve the problem with hardware.

- Capacitors generate reactive power.
- Install capacitors on utility poles.

Capacitors in shunt (parallel) configuration:.

- Decrease the line current, reducing resistive losses.
- Increase line voltage, increasing energy delivered to load.

Disadvantages:

- Limits distribution grid solar deployments to how quickly the DSO can deploy hardware.
  - Administrative paperwork, ordering and shipping of equipment, etc.
- Cost of purchasing the hardware and truck rolls to deploy.
- Cost of maintaining the hardware.

Source : electrical-engineering-portal.com

The "Non-Wires Alternative"
A Decentralized Market for Reactive Power

DSO runs a local, decentralized transactive market for reactive power on feeder circuits.

- Prosumers' energy gateways run blockchain transactive nodes that bid into a real time reactive power market.
- Power factor drops -> inverters produce more reactive power.
- Power factor increases -> inverters produce less reactive power

Enables deployment of more solar on the distribution grid.

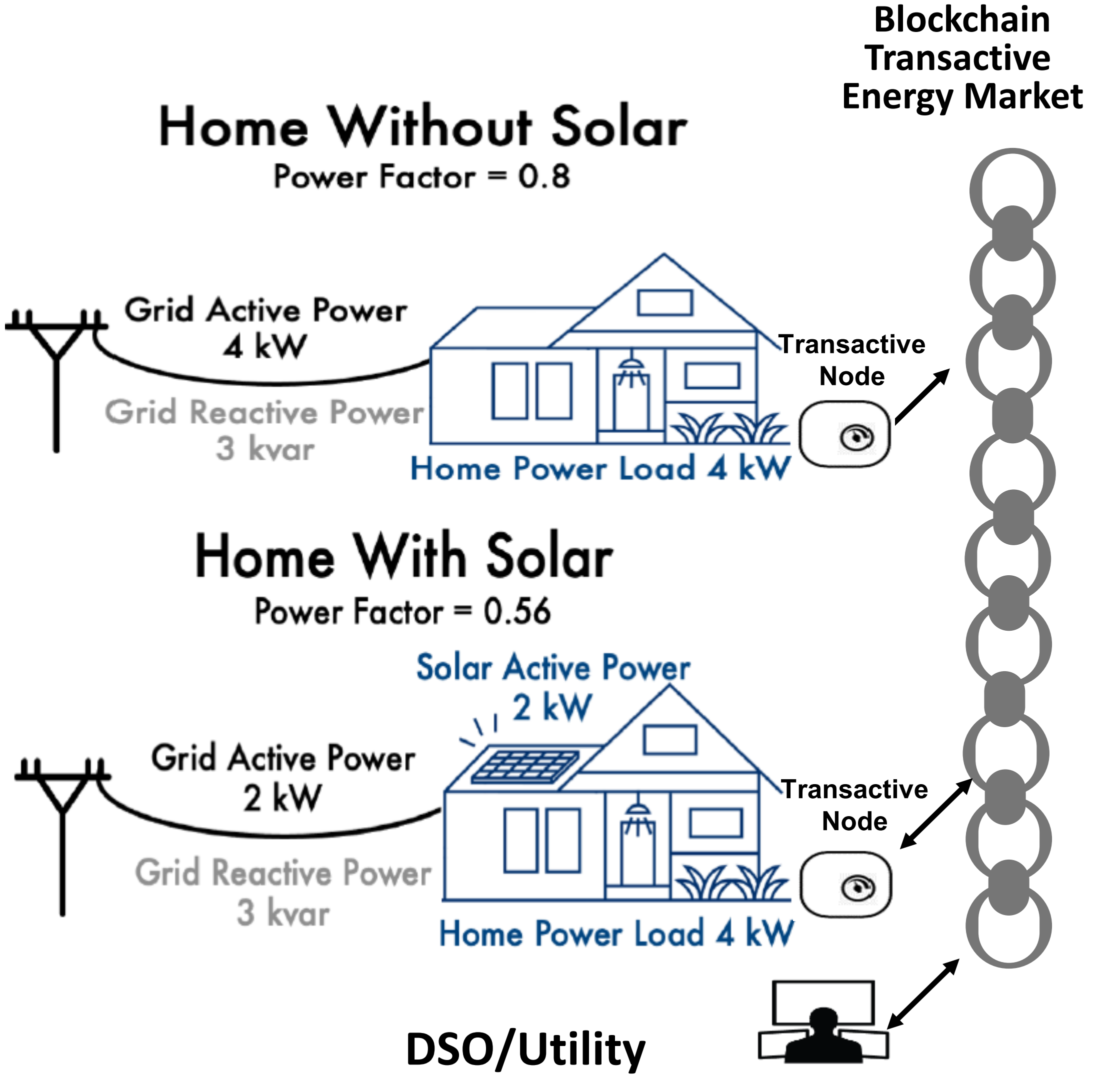
All customers continue to receive a subscription to a fixed amount of reactive power at a fixed price.

DSO manages the blockchain and acts as the market maker.

- Injects reactive power on a feeder if the DERs can't supply enough.
- Arranges for billing and settlement.

Additional advantages of blockchain:

- Incremental cost to the utility is a fraction of the wires alternative in time and money.
    - Transactive Node is just a Raspberry Pi-class device ($200)
- Enables near realtime billing and settlement through using energy tokens, cryptocurrency, a stablecoin, or central bank digital currency (CBDC or "digital dollar").
- Blockchain's decentralization and transparency could improve DSOs' operational efficiencies.



Source: https://www.pecanstreet.org/2021/08/power-factor-whitepaper/

Example BCTE Services

Energy Web Foundation

Nonprofit spinoff from Rocky Mountain Institute.

- Based in Switzerland.

Energy Web Chain is an open source fork of Ethereum that uses Proof of Authority (low energy consumption) distributed consensus.

- Smart contract mechanism to store Decentralized Identifiers (DIDs).
  - Blockchain-based credentials that take the place of public key certificates.
- Executes smart contracts that implement decentralized applications deployed by utilities, startups and others.

Energy Web Token (EWT) trades on the international cryptocurrency exchanges.

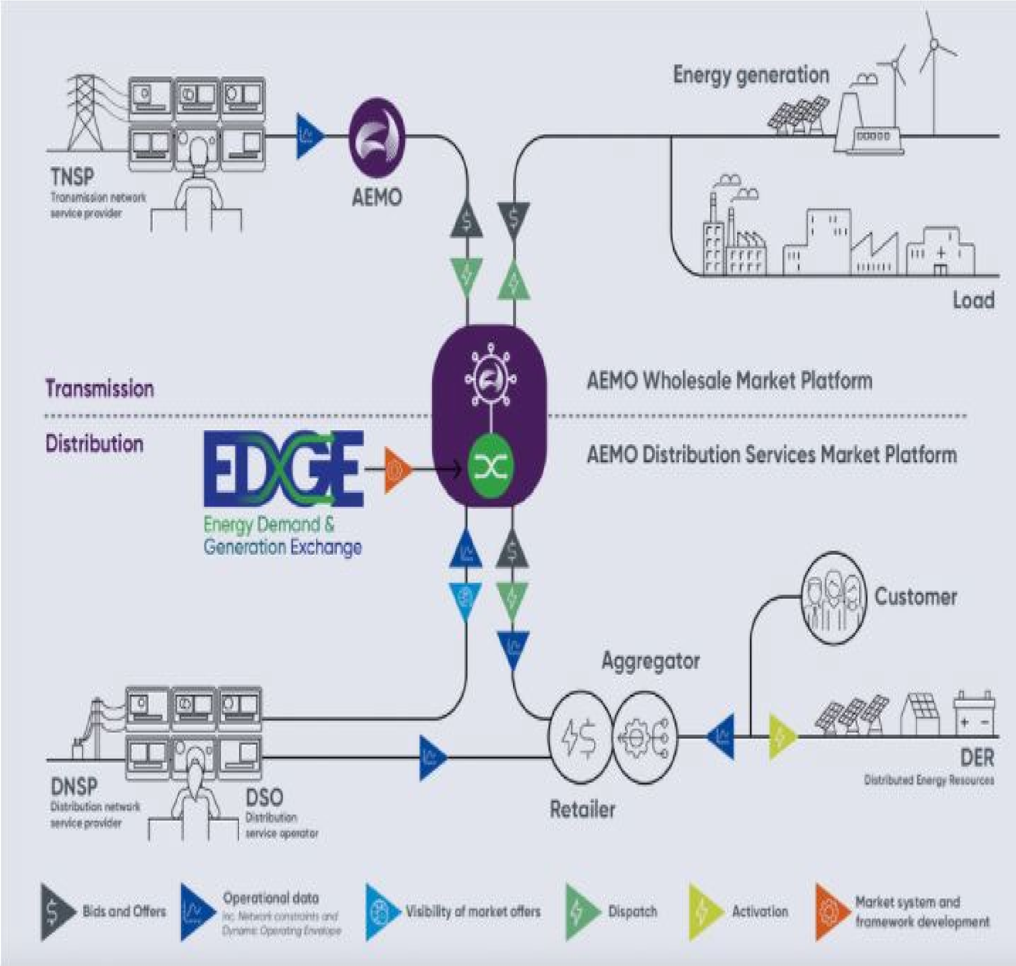
- Used to incentivize validator nodes.

Decentralized transactive energy concept:

- Decentralized Autonomous Area Agent (D3A) market model
- Reduces the distinction between the transmission and distribution markets.

EDGE proof of concept trial for D3A in Australia:

- Collaboration between AEMO transmission system operator, Mondo aggregator, and AusNet distribution system operator.
- Utilizes EWF's stack together with market intelligence software from PXiSE and runs in Microsoft Azure.
- Initially involves 50 residential customers in Victoria's Hume region, but then will scale up to 1000 residential, commercial and industrial customers.
  - 25% of Australia's homes nationally have rooftop solar.
  - 40% of the electricity in South Australia comes from rooftop solar.



Power Ledger

Power Ledger is an Australian company founded in 2016 to develop a blockchain based, peer-to-peer energy trading platform.

Blockchain platform history:

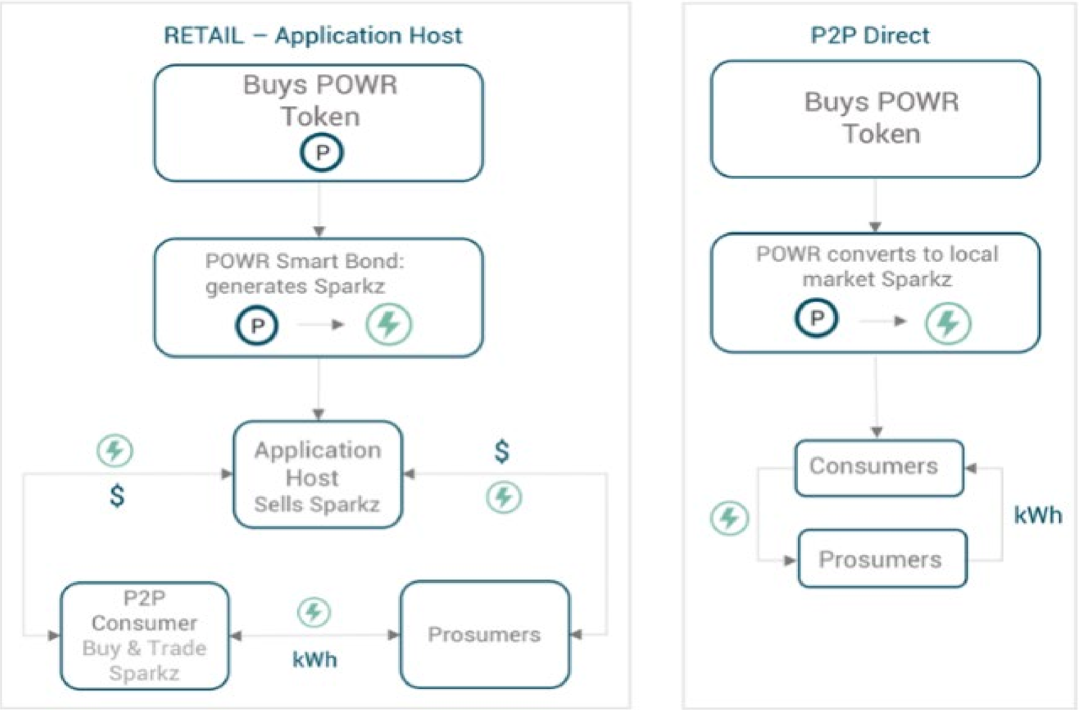
- Until 2021, Power Ledger deployed onto two platforms:
    - Ethereum 1.0 permissionless/public platform.
    - Ecochain private blockchain based on Proof of Stake distributed consensus.
- In 2021, switched public blockchain to Solana:
    - Ethereum transaction times were becoming too long and transactions costs too high.
    - Ethereum 1.0 uses energy wasting Proof of Work distributed consensus while Solana uses Proof of Stake and Poof of History.

To incentivize participation, Power Ledger uses two tokens:

- POWR ERC-20 token initial coin offering in 2018, peaked at $1.79 in January 2018 and now worth about $0.50 still trades on Ethereum
- Sparkz private token denominated in the local currency as a stablecoin and only trades on Ecochain.

Three peer-to-peer BCTE products:

- xGrid allows utility commercial and residential prosumers to trade energy directly with other customers.
- uGrid allows peer to peer trading between participants in microgrids, including shopping centers, housing estates, etc.
- PowerPort is similar to uGrid but for Electric Vehicle charging stations, allowing cheap and secure electricity metering, settlement, low-cost payment, user IDs, and integration with existing protocols.



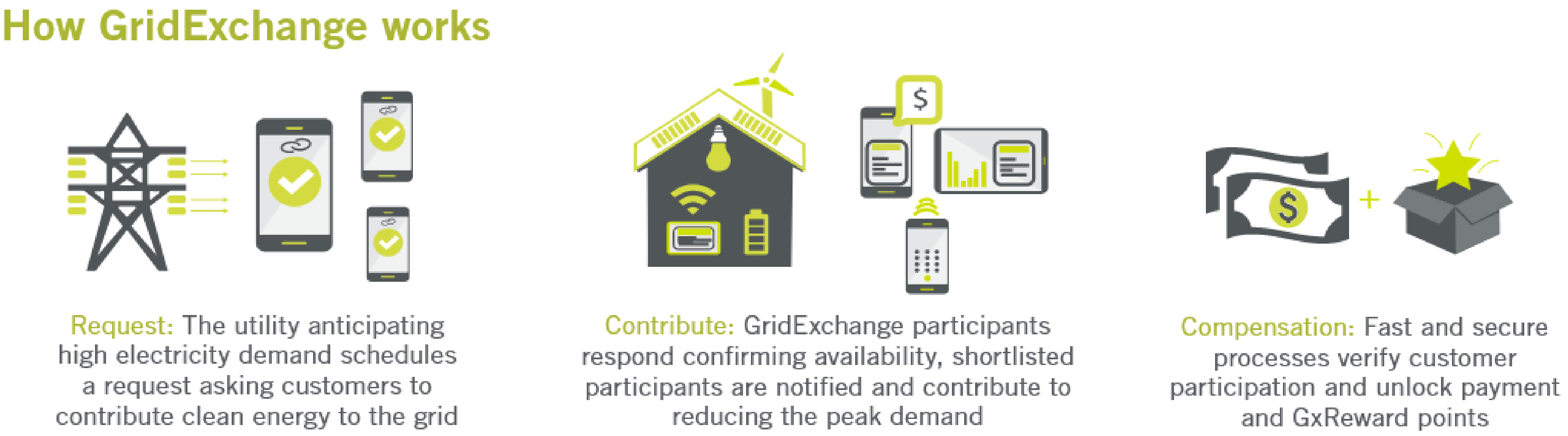
Source: ttps://medium.com/trivial-co/power-ledger-powr-analysis-of-the-token-and-business-model-7bee0ca1908a

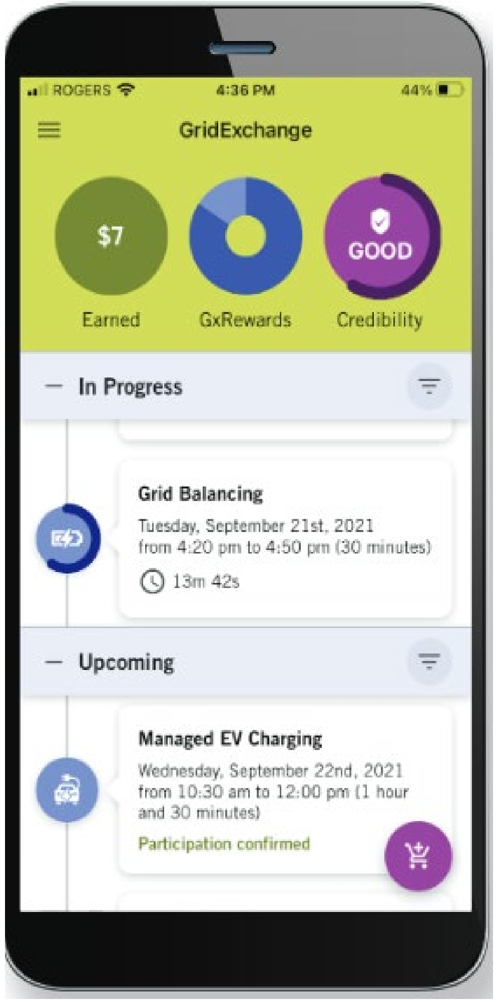
GridExchange by Alectra Power

Municipal Utility in Toronto

Three month BCTE pilot by the largest municipally owned utility in Canada.

- Launched November 2021.
- 21 households participated.
- Prosumers receive tokens for energy that they can exchange for products and services at local businesses.
- Based on the Hyperledger Fabric platform.





Summary

Summary and Conclusions

Transactive energy in general and blockchain transactive energy in particular holds promise to solve many of the problems in grid transformation.

- Allowing DERs in the distribution grid to participate.
- Co-ordinating DERs and flexible loads at scale.
- Increasing grid efficiency and resiliency.
- Support deployment of more distributed renewables, batteries, EVs, and flexible loads.

Despite promising proof of concept studies, widespread deployment has been lagging.

- In the US, regulatory issues and mismatch to utility's capital focused business model have hindered deployment.
- More progress in Europe and especially in Australia with the EDGE study.

IEEE BCTE Initiative is running a competition for BCTE demos:

- Deadline is July 1.
- Two categories:
  - Large company/utility.
  - Small company/academic/nonprofit.
- $10,000 for selected proposals, 4 proposals per category.
- Instructions for applying are here: https://attend.ieee.org/bcte/demonstrations/


Thank you
for Listening!