MOBI

Building the new economy of movement

Blockchains for Electric Vehicles & Grid Integration Review

Mobility Open Blockchain Initiative

EVGI Working Group

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Contents:

Contributors

The Mobility Open Blockchain Initiative Electric Vehicle Grid Integration (EVGI) Working Group is a global, multi-stakeholder project working to co-design blockchain and distributed ledger technologies standards for connected mobility ecosystems. The project engages stakeholders across OEMs and other mobility industry players, technology solution providers, governmental and non-governmental entities. This report is based on numerous discussions, workshops, and research. Opinions expressed herein do not necessarily reflect the views of individual members.

Sincere thanks are extended to those who contributed their unique insights to this report.

Authors:
Lucy Hakobyan, Head of Program, MOBI
Griffin Haskins, Fellow, MOBI
Richard Kim, Pacific Gas & Electric Company
Christian Koebel, Honda
Anne Smith, IOTA Foundation
Kate Tomlinson
CK Umachi, Pacific Gas & Electric Company

Commentators:
Valentina Gatteschi, Politecnico di Torino
Sebastien Henot, Accenture

EVGI Working Group members:

Co-Chairs: Christian Koebel, Honda,
Massimiliano Melis, GM

Team Members: Joe Bannon, Kar Auction Services
Amy Fisher, R3
Valentina Gatteschi, Politecnico di Torino
Sebastien Henot, Accenture
Divyesh Jadav, IBM
Richard Kim, Pacific Gas & Electric Company
Shaowei Liu, CP Chain
Krasina Mileva, DOVU
Anne Smith, IOTA Foundation
Carsten Stoecker, Spherity
Jaywardhans Sawale, Koinearth
Kate Tomlinson
Mohamed Thaika, Accenture
Priya Tabaddor, Cognizant
Sukesh Kumar Tedla, Swedish Blockchain Association
Wayne Tian, CPChain
CK Umachi, Pacific Gas & Electric Company

Reviewers: Andreas Freund, Consensys
Matthew Yarger, IOTA

MOBI Team and Contact: Chris Ballinger, CEO
Tram Vo, COO
Michael Vo, CTO
Lucy Hakobyan, Head of Program
Griffin Haskins, Fellow
Matt Shi, Fellow
Eric Hou, Technical Writer

Contact: evgi@dlt.mobi

Executive Summary

The Mobility Open Blockchain Initiative (MOBI) is a global nonprofit organization working to improve mobility using blockchains, distributed ledgers, and related technologies. MOBI and its partners are creating simple ways of identifying stakeholders to streamline mobility transactions by promoting secure protocols for mobility data exchanges, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications and payments. Funded and directed by its members, MOBI provides a neutral community where companies openly innovate, share 'proof of concepts' and develop standards for blockchain in the mobility services industry.

MOBI working groups are staffed by subject matter experts from its membership, each designed to explore and address the value of decentralized ledger technology for particular use cases in mobility. The objective of the working groups is to create, release and publish technical specifications/standards and business reviews.

The Electric Vehicle & Grid Integration (EVGI) Working Group released its first technical specification in Q3, 2020 focused on three core use case areas: Vehicle to Grid Integration (V2G), Tokenized Carbon Credits (TCC), and Peer to Peer (P2P) applications. The EVGI Standard focuses on creating system specifications and standard data schemas required in each of the above use cases. The EVGI Standard is not meant to prescribe one particular application, rather, it ensures that all of the pertinent data attributes and functionalities of each use case are available for organizations to utilize in creating their own applications.

This business review document begins with an overview of the current state of affairs with regards to powering electric vehicles, the growth of decentralized renewable energy production, and carbon credit generation/trading. From there, it explains some key use cases that can be enabled by blockchain systems and explains the role of the standard to aid this development. The analysis is broken down based on each use case's expected time to market, with a short, medium, and long term outlook. Ultimately, this document explains the use cases that the EVGI Working Group focused on and evaluates the expected value they provide; operational efficiencies gained, new revenue opportunities created, and exciting new capabilities and services provided.

Current State of Affairs

Globally, hybrid and electric vehicles' market share have seen sharp increases over the last thirty years. There are a variety of factors that caused this trend. The looming threat of climate change has prompted strong efforts from both the public and private sector. In many countries, governments have introduced legislation to provide tax credits, deductions, and exemptions to both consumers and manufacturers of electric vehicles. Further, governments have mandated production of EVs and in some cases committed to fully electric fleets in the next decades.[1] The automotive industry responded in kind, with major automakers strongly ramping up electric vehicle production. Indeed, many governments and automakers have committed to making their entire vehicle offering have an electric or hybrid option, or even moving to an entirely electric fleet. The growth of electric vehicle adoption is very rapid today - US market share in plug-in electric vehicles, for example, nearly doubled between 2017 and 2018 and overall grew 1500% between 2011 and 2018.[2] This trend is projected to continue, with an estimated 27 million electric vehicles on the road globally by 2030, with a CAGR of 21.1%.[3] However, issues like range anxiety and charging availability persist, and if left unaddressed, will strongly hinder that growth.

As the use of electric vehicles continues to scale, the electric grid must bear a greater overall load, as well as heavier load fluctuations over time. While the grid's overall capacity is able to shoulder the burden, electric vehicles see much greater use in cities as opposed to rural areas. Within cities, suburban areas will have a much higher concentration of households using electric vehicles as opposed to more urban neighborhoods. All of those electric vehicles follow a similar charging schedule - unplugging to drive to work, and plugging back in when they return home.

Clean energy production has similarly increased as new energy production technologies achieve greater efficiencies. Solar energy production has boomed, particularly in "small scale" uses like on homes or commercial buildings. Additionally, the ability to generate electricity locally turns consumers into "prosumers", who both consume and produce electricity. Households and businesses are increasingly powering themselves, even to the point of producing excess electricity. During peak production times, these prosumers can produce more electricity than they consume. If consumers have charging infrastructure, then they can sell their excess energy (whether self produced or not) to EV users by allowing them to charge with their chargers. However, smaller scale prosumers struggle to charge reasonable prices for their electricity, and their prices are far less than what is charged by large electricity suppliers or large prosumers.

P2P systems that can match supply and demand in real time are key to improving this picture[4] - smaller prosumers can access demand for their electricity without bearing the transaction fees of the wholesale market or being forced to negotiate individual PPAs with each buyer. Implementation of these P2P systems would allow natural market forces to drive up the price of renewably generated electricity from small-scale prosumers; higher prices means better return on investment for everyday homeowners and bigger incentives for even more households to become energy prosumers. Although it was the growth of prosumer households that spurned development and research for these P2P systems, all households can benefit from their existence. In the case of non-prosumers, allowing P2P charging can reduce costs of infrastructure in the short term and enable new revenue opportunities in the long term.

A variety of instruments exist to reflect the generation of clean energy or reduction of carbon intensity in transportation fuels in forms of tradable certificates. These can take many forms depending on jurisdictions and government requirements. Governments award credits to green energy producing companies, scaled to the amount of clean energy they produce. Carbon producers are required to procure a minimum number of credits at the end of each year in order to offset their carbon production. Credits are banked and traded widely. However, the marketplace for these credits has strong barriers to entry for small-scale producers - transactions are bilateral and require a large volume of credits per transaction. Without established trading relationships and facilities to generate huge credit volumes, these smaller-scale producers are effectively boxed out of the market. Additionally, the procedure for claiming carbon credits can be onerous and require many manual processes. Auditing carbon credit generation is, therefore, cumbersome, expensive and often requires third parties, which can be very costly. Carbon credits markets are often very distributed and localized, resulting in liquidity deficiencies. Finally, the information required to register carbon credits is often held by different organizations in disjointed data silos. This increases costs from redundant data collection as well as increases the time required to register.

Why Blockchain?

As more and more electric vehicles drive on global roadways, key stakeholders in the EVGI space (OEMs, utilities, charging equipment providers, etc.) are transacting with each other and grappling with increasing quantities of data as part of these transactions. Charging session events can generate data that capture a rich variety of information - amount of electricity charged, duration of charge, location, trouble codes in case of equipment failure, and much more. Different stakeholders in the charging session capture different types of data - OEMs only capture data from the vehicles, while utilities only capture data from the grid or their charging stations. Similarly, different stakeholders seek different insights as they relate to their own business' needs. Utilities may be interested in evaluating the average time of day that charging sessions occur in order to best prepare for demand peaks. OEMs may be more interested in measurements of the impact of different charging schedules and usage factors on battery health. Transportation authorities may seek robust geographic maps of electricity demand from EVs in order to determine the best locations for new charging stations.

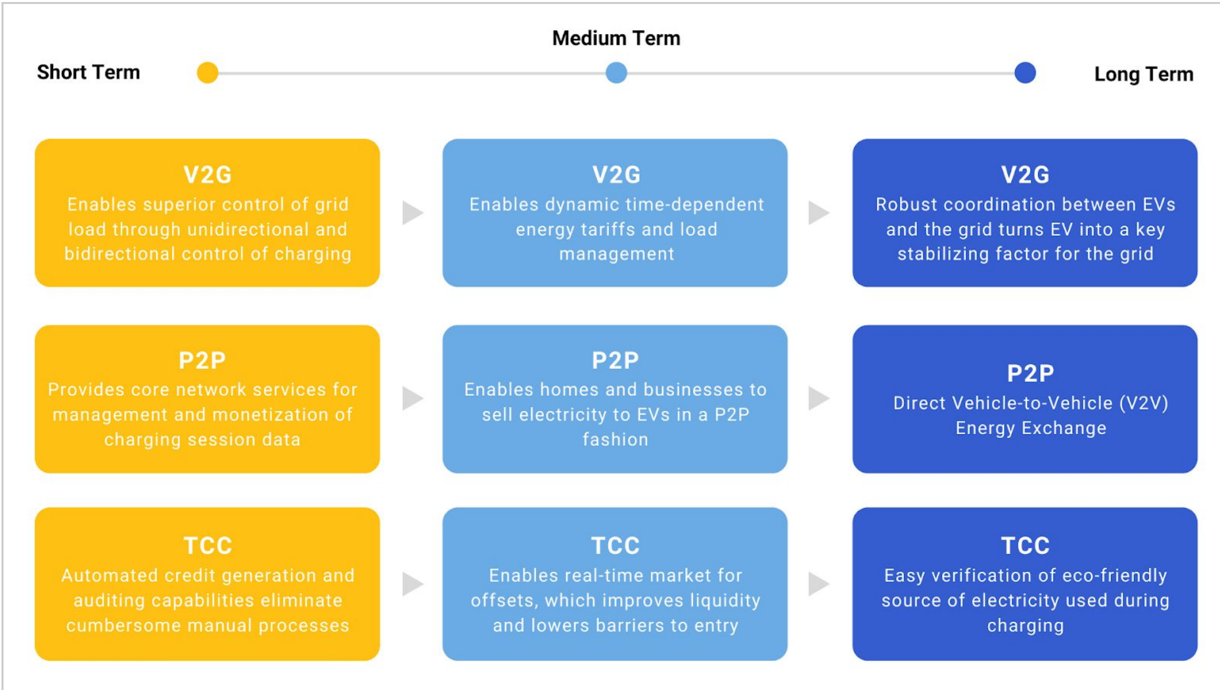
In order to produce the best insights and accomplish business needs, these players need to be able to access data from each other's siloes. These stakeholders can certainly capture value from their own data by extracting pertinent insights, but there is much more opportunity left untapped. When taken together, data captured by each stakeholder can provide much more context on a larger scale. The EVGI Standard provides the necessary infrastructure with core services like identity, security, or assurance that combine to allow for that information to be collected and made available in an interoperable manner. This provides all stakeholders with secure avenues to access more data, allowing them to better understand their equipment, customers, and more. Additionally, the ability to easily and securely share data is critical for monetization of that data - buying or selling data access requires robust access controls for proper security. Blockchains provide a secure avenue for these players to immutably record and securely expose their collected information.

Furthermore, to enable cybersecurity and authentication in a charging infrastructure, often a Public Key Infrastructure (PKI) is necessary, like the recently announced SAE EV Charging Public Key Infrastructure (PKI) project.[5] A blockchain-based identity management represents a serious alternative to these conventional, often costly PKIs with their centralized certificate authorities (CA). Singla et al.[6] compare blockchain-based approaches with CA-based PKI and conclude that blockchain-based IDs can provide a more robust and better scalable alternative.

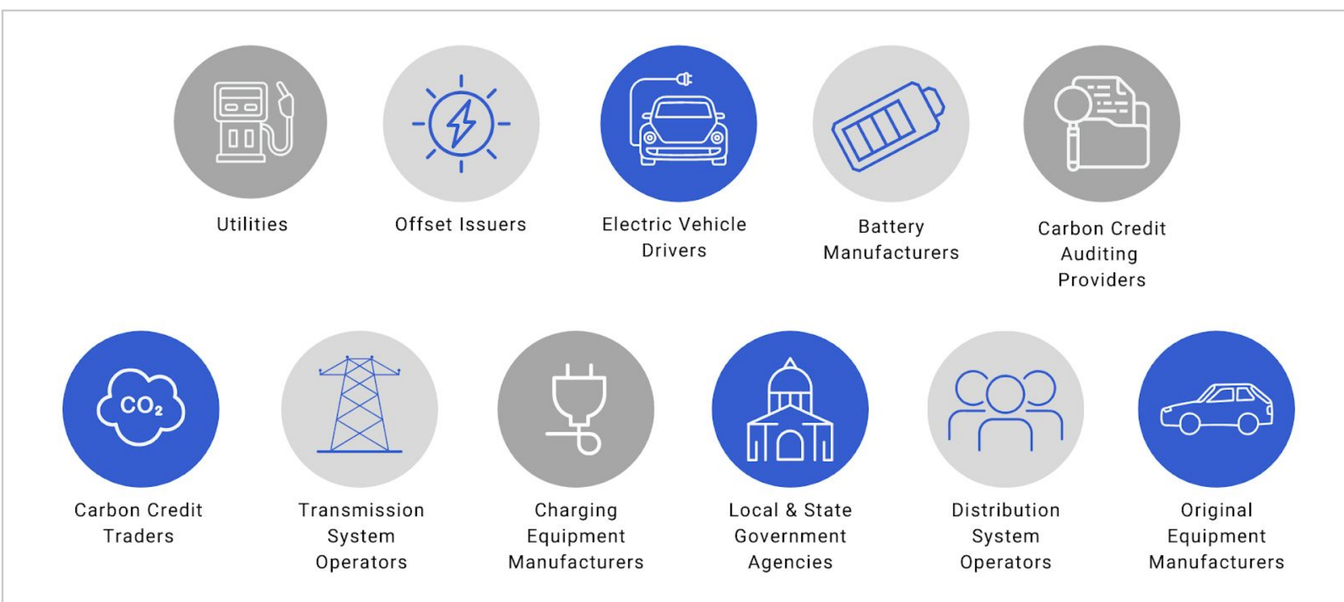
Transparency of data in an e-mobility ecosystem is also an enabler for a circular economy; a major trend and especially important for the automotive industry, with its complex value chains. Everything produced in future circular economies is optimized for maximum reuse, especially those resources of a scarce, or conflicting nature. Batteries typically contain such resources, hence their reuse after a “first life” in an EV is highly desired. In order to determine a suitable 2nd or 3rd life use of a battery, it is important to provide as much data as possible on a battery’s condition (e.g., number of passed charging cycles). Blockchain may unlock this data and enable tracking of battery health across it’s lifecycle, which directly contributes to circular (re)use.

The remainder of the document focuses on explaining what use cases are covered by the EVGI Standard and why their implementation provides value. With all of the use cases discussed below, blockchain is ultimately providing secure, decentralized systems for identity, data ingestion & management, and access rights. The sections below go into greater depth use cases in the V2G, P2P, and TCC categories. The graphics below summarize those use cases, as well as provide examples of key EVGI stakeholders.

EVGI Business Value Timeline and Summary



EVGI Stakeholders



Vehicle-to-Grid (V2G) Use Cases

With the demands put on outdated electric grids due to ever growing energy consumption, energy providers are increasingly having issues with balancing production and delivery on the grid to where it is needed in real time. Rolling blackouts and other disruptions are now relatively common, and these are only expected to get worse without significant investment in expensive infrastructure modernization and improvement.

Furthermore, the growth of electric vehicles presents an increasing load on the grid. This concentration of demand in highly localized areas presents a challenge for utilities, as it puts strain on the local infrastructure and increases incidents of costly failures. If a neighborhood has a high percentage of households using electric vehicles, not only will their average electricity demand be higher, but their peak demand as well. Electric vehicle charging follows a relatively predictable time frame. If everyone drives home from work and plugs their car in within a relatively short time, the sudden spike in demand can cause transformers to overload and fail. A single transformer can cost anywhere between $150k to $1m to install.[7]

It has been theorized for quite some time that electric vehicles could be used to balance the electric grid by taking the electricity stored in their batteries while they are not in use and putting it back in the grid when local demand is high. An existing business model for energy resource aggregators is to sell pool capacity to grid operators; modern EVs and EV fleets now allow the mobilization of such capacity.[8] While the hardware is ready, secure data provision is needed to enable efficient controls to manage pool capacity.

A 2018 study from the Lawrence Berkeley National Laboratory showed that with just uni-directional EV charging control “California can achieve much of the same benefit of its Storage Mandate for mitigating renewable intermittency, but at a small fraction of the cost. Moreover, EVs provide many times these benefits if two-way charging control becomes widely available. Thus, EVs support the state's renewable integration targets while avoiding much of the tremendous capital investment of stationary storage.”[9] Solving this problem by taking advantage of the charging capabilities only just now becoming available in electric vehicles (EVs) requires innovations in the areas of vehicle to grid (V2G) data gathering, governance and management, as well as collaboration between cities, smart charging hardware manufacturers, electric grid operators, EV manufacturers, and consumers. All these actors form an ecosystem for e-mobility with numerous business opportunities.

These new charging capabilities will enable several new business cases within this ecosystem, based on the usage of electricity stored in the batteries of EVs and the data about the usage that can now be provided. By utilizing data on planned, current, and past charging activities provided by electric vehicles, our cities, electricity providers, and consumers will each see benefits.

Since the data generated by these business cases is both valuable and sensitive as it potentially involves private personal data, a core component of the solution will be utilizing digital identities and data governance that maintains trust, privacy, and security of the data, while still making it useful for analysis and decision making. Digital Ledger Technologies (DLTs) inherently provide data trust, privacy, and security, and must be a core component of the solutions.

The EVGI standard has been drafted with modularity and flexibility in mind, to match the broad service landscape in the energy and e-mobility sector. The standard contains key specifications to allow stakeholders the design of interoperable systems for V2G services. In the following, some of these services are analyzed closer regarding their business value and feasibility over time.

V2G Short-Term

Implementing those aspects of the EVGI standard specifically tailored for V2G can show some immediate benefits for all stakeholders involved, from those in the energy sector, to OEMs, to consumers. It enables the integration of the EV's battery system and chargers with several layers of grid control systems for managing load through control of charging, both unidirectional and bi-directional**.** While bi-directional charging hardware is now introduced by numerous OEMs and suppliers (for example, vehicles or chargers need a DC/AC inverter), and a secure V2G charging standard is in the making (ISO 15118-20), a widespread, scalable data ingestion & management layer to make use of the hardware is still missing.

Different eMaaS stakeholders and actors, such as energy aggregators, TSOs, DSOs, infrastructure providers, OEMs, etc. are interested in different data sets for data analysis and to determine which V1G/V2G services can be offered. Using the V2G standard to make the capabilities of vehicles and charge points visible on the network will provide exactly the type of data required by these stakeholders, and provide the trust such data requires through the use of a DLT to create an immutable secure record of it.

Utilities will be better able to manage estimated grid loads of locations based on reported routes and charger reservations and actual charger usage. This can be achieved by utilizing V2G network data provided by EVs. Some immediately implementable use-cases of this are in the growing field of electric trucking, predicting daily grid-wide fluctuations based on EV charging behavior of commuters, as well as in weekday vs. weekend charging transactions of passenger electric vehicles.

In addition, the V2G standard will alleviate any concerns around unauthorized use and incorrect payments or billing due to the on-chain tracking of complete charging sessions as well as distributed access control to a network for transactions.

Transparency of transactions, and showing them in near real-time will delight consumers and make the day-to-day operations of utilities much more efficient. With the data provided by implementing the V2G standard, development of user interfaces to track V2G transactions, activities, and benefits will make this simple. These user interfaces can be for end-users, utilities, charge point owners, etc. and could be applications available in-vehicle, on mobile devices, via the web, or wherever needed.

V2G Mid-Term

The uni-directional coupling of vehicles to the grid (“V1G”) can be seen as an intermediate step towards full fledged V2G services. V1G typically implies controlled charging, where a charging session may be interrupted on purpose. This already enables several services which grid operators and EV owners both can benefit from: When charging in a certain region is not convenient for the grid (for example, at times of heavy load), charging is interrupted. If the EV owner is willing to accept such minor inconveniences, he or she is compensated. This is typically realized with custom energy tariffs with time-dependent pricing, or acceptance of switchable load. Again, the EVGI standard provides data on vehicles and battery capacities, but also allows to design interfaces for controlled charging, as well as tariff mapping in smart contracts.

In addition, utilizing the EVGI standard to implement such a system would be significantly less expensive than upgrading the grid to accommodate the additional load. A study of the grid in Hamburg showed that if 97% of the vehicles in the city are electric, there would be congestion at many of its feeders and that upgrading the grid to alleviate the problem would cost €20 million. However if the grid were to use a smart charging system with the electric vehicles, which temporarily omits charging at times of heavy load, the congestion could be prevented for only €2 million.[10]

Facility managers of commercial, or municipal buildings have the possibility to install local load control with V1G, to optimize charging schedules of several vehicles parked on site. Optimization can be done in a way that load peaks of that building are avoided, or to guarantee a fair charging scheme among vehicles. Facility management especially seeks to omit peaks, as they lead to out of scale costs.

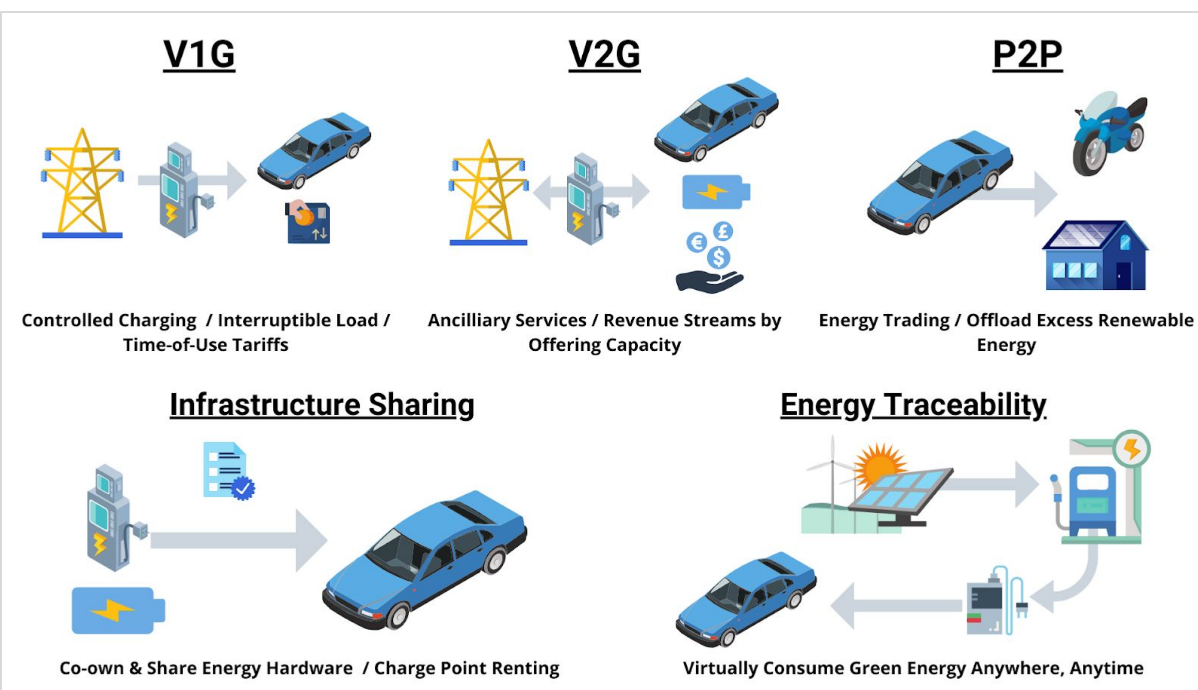
Another category of mid-value services require bi-directional charging, but do not involve the grid. For example, house owners can transfer excess solar energy into the EV and at the same time use the EV’s battery as a temporary storage system, which reduces consumption of regular energy coming from the grid. Blockchain can keep track of this self-consumption of PV energy and even help with optimizing energy flows between vehicle and home (for example, via a third party dapp). Furthermore, loyalty programs based on blockchain tokens may incentivize usage of self-generated green energy for mobility. Data attributes in the EVGI standard pose an effective resource to model such functions and processes.

V2G Long-Term

In the long term, electric vehicles with bi-directional charging capabilities will be able to receive energy from, and feed it back to the grid wherever capacity is needed and hence become an important asset for utilities to stabilize the grid. As with the aforementioned V1G services, the EV owner can be compensated based on mechanisms (e.g., special tariffs) on the blockchain, enabling trust for all parties. Through large scale data sharing of routing information in EVs, degree of charging infrastructure utilization and available capacities in a region, utilities and grid operators are better able to predict and manage grid loads. Use-cases of this can be found in electric trucking/logistics and weekday vs. weekend charging behavior. EVGI standard provides the specification for data generating energy peers and is a key enabler for V2Network data sharing.

Smart contracts play a special role in long term V2G scenarios, as they may host the aforementioned intelligent energy tariffs. According to a Fraunhofer position paper on smart contracts[11], the lack of trust between arbitrary actors on the decentralized energy market calls for trustless value exchange based on smart contracts. While there is even potential for smart contract marketplaces to rise, the future will show to which degree smart contracts will be used in typically highly regulated energy markets.

EVGI Use Cases - Graphic Summary



Peer-to-Peer (P2P) Use Cases

Households and businesses are getting increasingly more equipped for the next peer to peer applications of mobility in the context of electric vehicles. Excess energy is seen as a new revenue opportunity by allowing external peers to use this energy in the form of charging their electric vehicles. Smart home chargers are now able to be shared for public pay per use and short term lease of charging points, creating a sharing economy for EV charging infrastructure. In order to facilitate such trade, chargers need to become visible and usable for the public. In a distributed system, charger identity will be key to this solution. Although today, there are no easy ways to process such transactions, track usage and energy consumption or standardized technology, both software and hardware to implement, blockchain smart contracts offer a high potential for P2P registering, offering, leasing and billing of charge points.

Implementing the EVGI Standard provides a variety of benefits for players on all sides of the electric vehicle and charging ecosystem. Electric vehicles, chargers, and electricity producers can have a secure identity, communicate with a standard messaging format, and record transactions on a distributed ledger (like charging events, electricity generation reporting, electricity exchange events, etc.). These core network services all provide value by enabling secure, decentralized communication and immutable recordkeeping between data generating energy peers.

P2P Short-Term and Medium-Term

The interoperability enabled by EVGI Standard provides strong value to electric vehicle drivers, prosumers, and the utilities that keep them powered. With a basic set of schemas for communication between electric vehicles, chargers, and the grid, electric vehicles will be able to share data and communicate with chargers, regardless of the manufacturers that built them. With robust P2P systems that can match supply and demand, the possibilities are endless.

For example, electric vehicle chargers in homes and small businesses can become publicly available charging stations. Prosumers and non-prosumers alike would be able to provide their electricity to the public and bring compensation that will offset infrastructure costs in the short term and create new revenue opportunities in the long term. Systems that are able to match local supply and demand will result in better energy prices for consumers and prosumers alike. Furthermore, direct prosumer - consumer energy exchange reduces load on the grid, which reduces maintenance costs for utilities, as well as reduces transaction costs from avoiding grid fees. With multiple prosumer homes pooling their electricity, they can form microgrids that can achieve enormous cost savings, as they are effectively generating their own power. That cost savings is not only for the homes within the microgrid, but also passed to the EV drivers in the form of cheaper electricity, which also vastly expands the pool of available chargers. There are multiple microgrid communities growing around the world, and this trend is only projected to continue.[12]

There are benefits for all players in the EVGI space, but the greatest benefit would be for the electric vehicle drivers. If there is substantial adoption of P2P smart home chargers, the amount of available chargers for electric vehicle drivers would increase enormously. Abundant, well geographically distributed electric vehicle chargers enable people to drive their electric vehicles much further, with no fear of running out of power and no charging station in sight. Range anxiety is considered one of the biggest barriers to the adoption of electric vehicles.[13] Greater adoption of electric vehicles means more sales for the automakers, greater electricity demand for the utilities, and a greener environment for all.

P2P Long-Term

Peer-to-peer smart home chargers certainly represent a major milestone in the decentralization of electricity distribution for EVs. From there, the next clear milestone is the direct exchange of electricity between the EVs themselves. Consider a large random sample of EV drivers in a given city. All of those drivers will have varying schedules, commute distances, and vehicles. Moreover, all of those vehicles will be parked at different locations in the city, for different lengths of time, all throughout the day. Drivers with short commute times will find a consistent excess of electricity, while those with much longer commutes may have to stop at a charging station during their trip. Even within a single parking lot, there will be different electric vehicles with different charge levels, and varying degrees of available excess electricity; there is a clear opportunity to match the supply and demand in this situation. Drivers purchasing electricity could achieve enormous cost savings, estimated to reach up to 71%.[14] Drivers that are selling their excess electricity also see value - they can earn a return on energy.

In order for the above scenario to be achieved, each step requires the ability for different EVs to communicate and coordinate- from the authentication between EVs to begin charging sessions, to submitting buy/sell orders for certain quantities of electricity at certain prices, to coordinating to begin the charge session. That coordination is not just bilateral - there must be consensus within that mesh network of EVs that matches buy and sell orders. With blockchain, these EVs can easily and securely identify themselves and each other; secure digital identities are key to the P2P messaging and coordination required by a direct electricity exchange. The EVGI Standard ensures that the EVs are able to share with each other their pertinent data (current charge level, trouble codes, etc.). Direct P2P energy exchange between vehicles will require a strong, robust application layer to implement the order matching engine, buy/sell order submission process, coordination of drivers to execute trades, and much more. But the EVGI Standard is the first key step - providing the core building blocks of these applications so that engineers have the data and core network services they need.

Tokenized Carbon Credits Use Cases

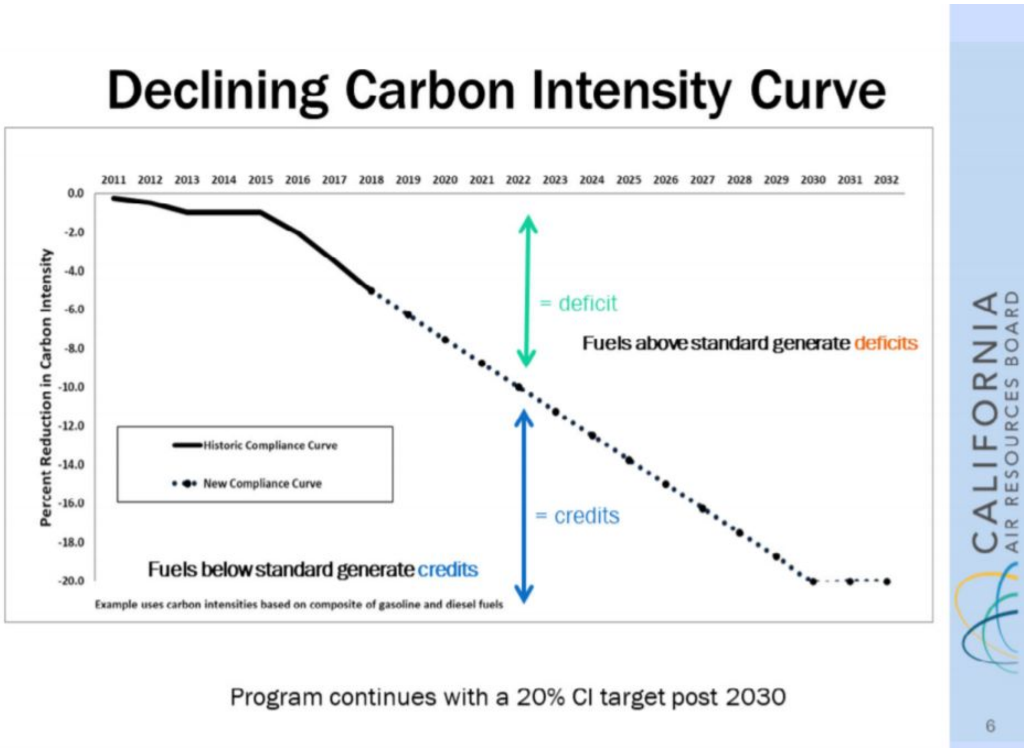
Tokenization of carbon credits has received increasing attention from the mobility industry as a way to introduce efficiencies and new ways in managing carbon credits. Carbon credits are certificates or permits that represent the right to emit fixed volumes, typically one metric ton, of CO2e (carbon dioxide equivalent). The carbon credits are typically able to be transacted in carbon markets, which can take various forms. The term ‘carbon credits’ is used (often inappropriately) to cover a wide range of programs and incentive schemes including carbon offsets, carbon production permits, renewable energy certificates, guarantees of origin, cap and trade programs and other green attribute tracking mechanisms. The Low Carbon Fuel Standard program is one such mechanism, and the focus of this standard as the most directly applicable one to the mobility industry.

Low Carbon Fuel Standard (LCFS) programs utilize market-based incentives to encourage reductions in the carbon intensity of transportation fuels. By setting carbon intensity goals, regulators administering LCFS programs can mandate importers and refiners of carbon-intensive fuels to lessen their environmental impacts by either reducing the carbon intensity of their fuels or purchasing LCFS credits from generators of lower carbon-intensity fuels (i.e. electricity, biofuel, renewable diesel). The program therefore also incentivizes the production of those lower carbon-intensity fuels. The State of California in the United States, for example, was one of the first ones to adopt the LCFS program in 2009 and it has seen many enhancements since then. Many other states and countries have either adopted or are exploring similar programs including British Columbia, the United Kingdom and European Union. Some states like California, Oregon, Washington, and British Columbia strategically align policies to reduce greenhouse gases and promote clean energy. “Over time, these LCFS programs will build an integrated West Coast market for low- carbon fuels that will create greater market pull, increased confidence for investors of low carbon alternative fuels, and synergistic implementation and enforcement programs. Other regions including Canada and Brazil are also noticing California’s success and developing LCFS-like performance standards for transportation fuels”.[15]

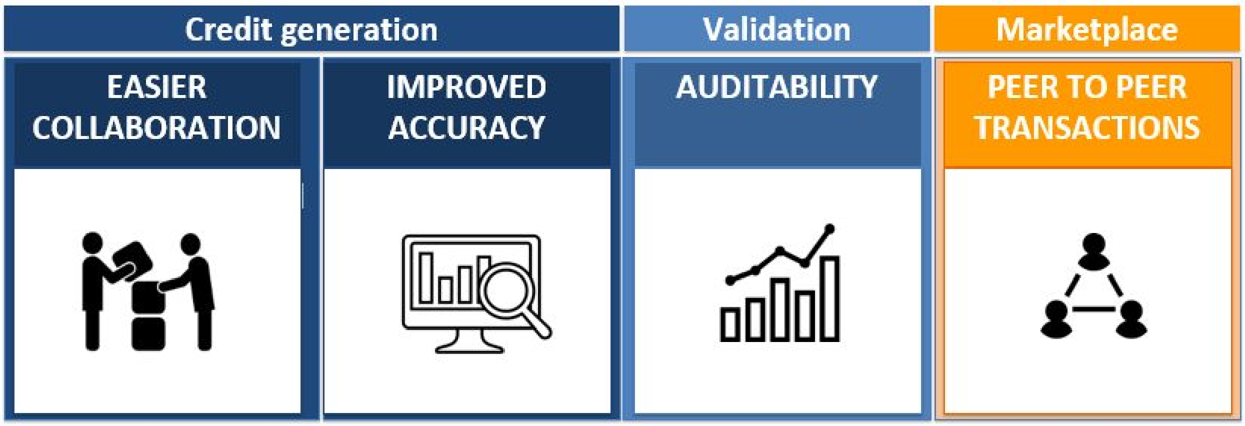
Fuels in the transportation fuel pool that have a carbon intensity (CI) lower than the target established by the regulator generate LCFS credits. Those fuels in the transportation fuel pool with CIs higher than the target generate deficits. A fuel producer with deficits must have enough credits through generation and acquisition to be in annual compliance with the standard. Petroleum importers, refiners, and wholesalers are Regulated Parties (RPs) under the LCFS. Regulator approved alternative fuels producers can opt-in to the program; these participants are also referred to as RPs. When transportation fuels are imported, refined, or sold in California, for example, RPs and opt-in RPs enter the transaction level information into the regulator's central data system for the standard, the LCFS Reporting Tool (LRT). The LRT tracks each transaction of fuel with its corresponding credit or deficit position, and sums for each RP. Credits are retired when used to cover deficits per annual compliance report. LCFS credits do not have a vintage and do not expire. Credit transactions are reported to the LRT, including the transaction price in units of million tonnes (MT) of LCFS credits. Credit owners can only sell or trade their credits with other RP deficit holders. Parties outside the 230 RPs are not allowed to hold LCFS credits.[16]

The chart below, for example, shows how the limit of compliance for fuel carbon intensity is getting more strict over time in the state of California. Transportation fuels high in carbon, such as gasoline, sit near the top of the chart, and thus these importers and refiners accrue a credit deficit. Fuels with a lower carbon intensity, like electricity from renewable resources, sit well below the compliance standard and therefore generate a credit surplus. In this way, an exchange marketplace is set up between parties with credit deficits and those with a credit surplus.

[California Air Resources Board - Declining Carbon Intensity Curve]



There are 3 major phases of the LCFS process considered in this document as shown in the diagram below: 1) credit generation 2) auditing / validation of credit generation 3) credit marketplace. Note: While this document is solely focused on electric vehicles, there are other fuels (ethanol, hydrogen, etc) that this process could potentially be applied to. These other fuels have not been included due to limited exploration into those fuels, but portions of the standard could potentially be utilized for tokenized carbon credits based on those fuels as well.



- Ability to share data in decentralized fashion
- Better sources of data like vehicle telematics & charger data

- Better data like near real time marginal emissions data
- Smart contracts execute credit calculation automatically

- Blockchain tech inherently provides audit trail
- CARB can easily validate credits for a wide array of stakeholders

- Cost-effective transactions enable more participants
- Real-time settlements reduce verification steps for utilities

TCC Short-Term

In the short term, the framework laid out in this standard could be used to create blockchain based applications which can help with the credit generation and auditing portions of the LCFS process. Credit generation refers to the process of pulling data related to charging of a specific vehicle and quantifying the numbers of credits based on calculations defined within the LCFS program. These are typically set by the regulatory body overseeing the program.

These applications can help streamline and standardize the collection of data needed to quantify carbon credits while providing an immutable audit trail for data used in the quantification of carbon credits. This could be valuable to both LCFS credit producers and regulators.

Credit producers could benefit from these applications to quantify carbon credits in more real time through standardizing automated pulls of charging data. One challenge for small companies who are eligible to claim credits, is the time and effort needed to collect this data and fill out the relevant forms to submit credits on regular intervals. Additionally, many credit producers struggle to understand how many credits they have accrued at any given time. Utilizing these applications, the credits can be quantified and created in more real time.

Auditing of the credits generated is important to avoid any manipulation of the program as a significant amount of money can be accrued. In fact, ~$2.7 billion was transacted in California's LCFS program in 2019. The California Air Resources Board (CARB), for example, notes 5 examples of settlements for incorrect reporting including a payment of $1,365,000 from Tesoro Refining and Marketing LLC, for misreporting volumes in its quarterly and annual LCFS reports.[17] That particular incident did not appear to be due to manipulation as the errors were self disclosed. Additionally, CARB has noted several account balance adjustments including one in 2017 for 109,226 credits. At today's market prices of ~$200/LCFS credit, today those credits would be worth around ~$21 million. These incidents show that there is a fair amount of money riding on auditing these LCFS submissions.

For regulators, auditing the credits and deficits produced can be an issue. One area where utilizing the blockchain for auditing carbon credits can be beneficial is in ensuring that records at the meter haven't been falsified. Storing the data from the meter or charger through an immutable ledger, whether the data is stored on-chain or off-chain, can help to ensure that records aren't manipulated afterwards. Additionally, double counting of charge sessions (i.e. 2 entities claiming for the same charge session) can be caught through tracking charge sessions using a blockchain based ledger.

The framework laid out in the standard could be utilized to create an immutable and auditable ledger of charging data which regulators could audit. The standard outlines a process for registering assets which can then be used in the TCC process. The standard notes certain data fields which would be required or likely desired in a DLT based credit generation application. These same data fields and structures will also support implementing auditing capabilities for regulators. Systems created could set permissions for regulators to see all credit activity in real time, while protecting data privacy of individual credit claimants.

TCC Medium-Term

In the medium term, blockchain could be further leveraged to create a more real time marketplace for transacting credits.

Credit marketplaces are important to enable transactions between credit buyers and sellers. Credits can be transacted in many ways but for sellers with smaller numbers of credits, they typically must go through an aggregator or broker because of their limited volumes of credits, which can be costly. The current LCFS credit trading process in California takes data from a number of siloed databases, and, since 2018, relies upon a third party to verify and confirm credit transactions. This requirement for third party verification was added by CARB in 2018 to "ensure data completeness, accuracy, and conformance with the regulation"[18]. Regulators run the system, and need to be able to be able to see how many credits each party owns, and have the authority to resolve any disputes arising within the network. The current system relies on complex contracts and manual processes that result in smaller players being excluded from the market; because the barriers to entry and cost of transactions is high enough to prevent parties with only a small number of credits from engaging in the exchange.

Current existing marketplaces are illiquid. A lot of stakeholders have the desire to participate, but cannot due to low volumes of credits and difficulty establishing relationships with a buyer. One challenge for many small credit producers, is the ability to sell their credits. Choices for small credit producers typically only include paying aggregators or brokers large fees to exchange their tokens. Waiting to accrue enough credits to transact with deficit producers is often not feasible. A blockchain based marketplace could enable larger deficit producers to purchase multiple small batches of credits while avoiding exorbitant broker fees ranging from 1 to 5% based on volume. A tokenized credits marketplace can enable the exchange of credits between surplus and deficit holders, in near real-time without a bottleneck intermediary. Getting the credits on a DLT network is the first step to achieve this.

This framework laid out in the standard supports the creation of token marketplaces by outlining a process for initializing and then finalizing TCC contracts. This process could enable users to compensate each other using the tokenized carbon credits without the direct need for a broker or aggregator.

TCC Long-Term

In the long term, the tools used to build out the credit generation, audit, and marketplace components of carbon credit and LCFS ecosystems could also be leveraged to expand to other programs or processes. One example is linking together the tracking systems for Guarantees of Origin (GO) / Renewable Energy Certificates (REC) that track MWh of green energy with the LCFS program, to verify and enable green charging. A clear standard of inputs and outputs for each system would make the process of linking this tracking system infrastructure together significantly less complex. This would include an extension of the infrastructure used to quantify carbon credits. This same infrastructure could also be used to create applications for providing incentives to charge with green energy.

Furthermore, these systems could enable live incentivization of green energy charging and usage through users collecting carbon credits as incentives in their wallet. Incentive / token reward for each km travelled with green energy. However, these programs would have to be created by regulators or other entities who would ensure the incentives are aligned and the business case for giving the incentives is properly structured.

Conclusion

For eMobility, the grid, and carbon offset markets, blockchain technology offers a variety of benefits, both in reduction of costs and in the enablement of new revenue opportunities, for players on all sides of the ecosystem. Though vehicle-to-grid coordination may seem quite different than peer-to-peer electricity trading, the processes that underlie those applications are similar. They have the same needs for *core network services* - digital identity, permissioning, data exchange, and more. At its core, blockchain provides a trust layer, which perfectly complements the mutual business interests between utilities, charging service providers, property owners, and electric vehicle drivers. Additionally, blockchain enables these parties to create a shared ledger of data, a single source of truth of paramount information to facilitate interactions, a secure and trusted marketplace where transactions can be facilitated without intermediaries through efficient and automatic smart contracts.

While each of these use cases would certainly provide value in and of themselves, the exciting prospect is what happens when all those applications can interact and share data with each other. The value of distributed ledger technologies is directly determined by their network effects. Such scale can only be reached if all the stakeholders are able to build applications that are interoperable from the bottom up. Without standards and coordination, these DLT applications will struggle to reach production. And that delay in their time-to-market comes at an ever increasing cost. The pain points addressed by these applications are ultimately symptomatic of legacy systems that are struggling to handle larger and more complex workloads. Until new systems are put into place, that friction will only continue to get worse.

The trust layer brought by distributed ledger technologies will have an enormous impact on eMobility. But that impact won't just be felt by the institutional players operating the grids, charging stations, etc., but will affect *all* the EVGI stakeholders. And those stakeholders are many, at all scales - OEMs, households, and individual drivers are all stakeholders in the EVGI ecosystem. As distributed ledger technologies continue to mature, all stakeholders will receive streamlined workflows, reduced costs, and exciting new capabilities and services. But most importantly, these technologies will be key for our systems to reach the scale demanded by the "all electric future" we're approaching.

Bibliography

1. CNBC, *Colorado joins California in requiring automakers to sell more electric cars*, Retrieved (07.15.2020): https://www.cnbc.com/2019/08/26/colorado-joins-california-in-requiring-automakers-t

o-sell-more-evs.html; Quartz, *Nine countries say they'll ban internal combustion engines. So far, it's just words.*, Retrieved (07.15.2020): https://qz.com/1341155/nine-countries-say-they-will-ban-internal-combustion-engines-none-have-a-law-to-do-so/

2. Wikipedia, *Plug-in electric vehicles in the United States*, Retrieved (06.16.2020): https://en.wikipedia.org/wiki/Plug-in_electric_vehicles_in_the_United_States#cite_note-Sales2012US-6
3. MarketsandMarkets, *Electric Vehicle Market by Vehicle (Passenger Cars & Commercial Vehicles), Vehicle Class (Mid-priced & Luxury), Propulsion (BEV, PHEV & FCEV), EV Sales (OEMs/Models) Charging Station (Normal & Super) & Region - Global Forecast to 2030*, Retrieved (06.16.2020): https://www.marketsandmarkets.com/Market-Reports/electric-vehicle-market-209371461.html
4. International DOI Foundation, *Business model innovation in electricity supply markets*, Retrieved (06.16.2020): https://doi.org/10.1016/j.enpol.2016.02.019
5. altenergymag.com, *SAE International to Launch Industry Driven SAE EV Charging Public Key Infrastructure Project*, Retrieved (06.16.2020): https://www.altenergymag.com/news/2020/05/14/sae-international-to-launch-industry-driven-sae-ev-charging-public-key-infrastructure-project/33118/
6. A. Singla and E. Bertino, *Blockchain-Based PKI Solutions for IoT*, Retrieved (06.16.2020): https://ieeexplore.ieee.org/document/8537812
7. FleetCarma, *The impact of growing electric vehicle adoption on electric utility grids*, Retrieved (06.16.2020): https://www.fleetcarma.com/impact-growing-electric-vehicle-adoption-electric-utility-grids/
8. S. Amamra and J. Marco, *Vehicle-to-Grid Aggregator to Support Power Grid and Reduce Electric Vehicle Charging Cost*, Retrieved (06.16.2020): https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8930487
9. IOPscience, *Clean vehicles as an enabler for a clean electricity grid*, Retrieved (06.16.2020) :https://iopscience.iop.org/article/10.1088/1748-9326/aabe97/meta
10. Forbes, *Electric Vehicle Batteries Could Dwarf the Grid's Energy Storage Needs*, Retrieved (06.16.2020):

https://www.forbes.com/sites/jeffmcmahon/2020/01/29/electric-vehicle-batteries-could-dwarf-the-grids-energy-storage-needs/#315745605929

11. Fraunhofer, *Blockchain und Smart Contracts*, Retrieved (06.16.2020): https://www.iml.fraunhofer.de/content/dam/iml/de/documents/OE260/Fraunhofer-Positionspapier_Blockchain-und-Smart-Contracts.pdf
12. Brooklyn Microgrid (BMG) Marketplace, Accessed (06.16.2020): https://www.brooklyn.energy/
13. Insideevs, *Here's Precisely Why People Avoid Electric Cars*, Retrieved (06.16.2020): https://insideevs.com/news/366349/top-reasons-people-avoid-evs/
14. Hermana, Roberto & Fraile-Ardanuy, Jesus & Zufiria, Pedro & Knapen, Luk & Janssens, Davy. (2016). *Peer to Peer Energy Trading with Electric Vehicles*, Retrieved (06.16.2020): https://www.researchgate.net/publication/305877531_Peer_to_Peer_Energy_Trading_with_Electric_Vehicles/citation/download
15. California Air Resources Board, *Low Carbon Fuel Standard*, Retrieved (06.16.2020): https://ww3.arb.ca.gov/fuels/lcfs/background/basics-notes.pdf
16. Stillwater Associates, *LCFS 101 - A Beginner's Guide*, Retrieved (06.16.2020): https://stillwaterassociates.com/lcfs-101-a-beginners-guide/?cn-reloaded=1
17. California Air Resources Board, *LCFS Enforcement*, Retrieved (06.16.2020): https://ww3.arb.ca.gov/fuels/lcfs/enforcement/enforcement.htm
18. California Air Resources Board, *LCFS Verification*, Retrieved (06.16.2020): https://ww2.arb.ca.gov/lcfs-verification