U.S. DEPARTMENT OF ENERGY | Office of Technology Transitions

P3 Conference Hosted Industry Roundtables

Bi-directional EVs and Charging Infrastructure

January 23, 2020

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NOTICE

Event Overview

On Wednesday, December 4, 2019, at the P3 Conference, the Department of Energy (DOE) and Argonne National Laboratory facilitated two industry roundtables and a panel aimed at discussing bi-directional (BD) Electric Vehicles (EV) and bi-directional electric vehicle charging infrastructure investments. These events were hosted by the P3 Conference, who extended invitations to participants for the roundtables. The roundtables followed Chatham House rules to encourage participation. Participants included representatives from government organizations, car and battery manufacturers, associations, utilities and research organizations. There were two roundtables, organized as follows:

- **Session 1**: Considerations for Bi-directional Electric Vehicle Infrastructure Investments and Wireless EV Charging
- **Session 2**: Is There a Business Case for Bi-directional Electric Vehicles

Key Take-Aways

- The U.S. electric grid lacks storage options and struggles to manage the flow of electricity. Bi-directional EVs could solve these problem areas.
- Participants viewed range-anxiety and the cost of an EV as the biggest obstacles for EV and bi-directional adoption.
- EV adoption creates new load opportunities but also creates significant reliability issues that the grid is not prepared to absorb and manage based on current technologies, architecture and business models.
- The average home uses 30kWh of power per day, so an EV battery could supply a home during a blackout for 2-3 days. Other practical bi-directional (grid) use cases exist.
- European companies already offer consumers bi-directional EVs, but in the U.S., the only option is the Nissan Leaf.
- EV makers have warned of a warranty void for (EV) batteries used in bi-directional charging.
- The safety of the utility lines and workers and protecting the grid are imperative.
- Bi-directional utility vehicles like buses, police cars and garbage trucks, and other fleet operators such as USPS or Amazon, are viewed as potential early adopters.
- User experience and continued reliability of the grid are imperative.
- Consumer education of benefits and subsidies available are necessary, including full-lifecycle considerations for the business case (e.g., recycling).
- Blockchain and AI may play a key role in bi-directional EVs future.
- China is strongly considering a bi-directional electric grid.

Participants discussed potential and innovative use cases to analyze bi-directional electric vehicle infrastructure investments and the end-consumers business case for bi-directional vehicles. The meeting provided participants with an opportunity to provide feedback regarding different frameworks while sharing relevant sources and data for on-going analysis and discussion. The discussion guide, available in Appendix I, included considerations of timing, cost, degradation, location, and various use cases to help inform buyers/users and suppliers of bi-directional electric vehicles and bi-directional electric vehicle charging infrastructure. Although this report and the discussions were based on bi-directional electric vehicles, many of the considerations could apply to other bi-directional mobile storage technologies if they were enabled (e.g., hydrogen-fueled vehicles).

Who can offer any examples of bi-directional EV or EV charging infrastructure providing ancillary services or demand response, locational energy arbitrage or responding to emergencies?

There was discussion surrounding what "infrastructure" actually included; some discussants thought the vehicle battery should be included in the definition while others viewed it as purely the charging infrastructure and connecting grid. It was mentioned that a consortium of utilities in Finland, Norway, and Denmark co-invested in a company that provides incentives and services to electrify fleets owned by businesses. These fleet owners receive price signals that help them decide when to charge, discharge, or use their vehicles for their primary business operations. Vehicle to grid opportunities, such as discharging a bi-directional electric vehicle battery, provide fleet owners with new revenue streams that has attracted adoption of bi-directional electric vehicles in these markets. Worth noting, Nissan is the only bi-directional electric vehicle being deployed for this purpose. China is also aggressively pursuing a bi-directional grid which has been discussed by some academics in recent literature.

> *Instead of sitting idle all summer, overnight and in the middle of the day, bi-directional electric school buses could be used as generation during emergencies or storage of cheap energy that could be sold back to the grid during peak demand.*

Multiple participants said they were looking into car to grid opportunities for the city's fleet of vehicles and saw a future for utility vehicles to be bi-directional. They are working on planning efforts, exploring how it can work into emergency plans for municipalities. Examples included how BD vehicles can be utilized during a blackout to create microgrids or power emergency shelters. Like a school hosting people in its gym during a hurricane. Electric school buses could help manage that overlay and avoid diesel generation so that the community could use diesel during hurricanes. Similarly, vehicle to grid opportunities exist for fleets owned by USPS, UPS, Fedex, and Amazon.

Discussants provided another hypothetical example: when a traffic light goes out, officers could pull up a municipality fleet vehicle and get the light back on until the larger issue can be resolved.

Although utilities were excited about the new load opportunity, Utility and ISO operators both equally expressed significant concern regarding reliability concerns once a certain tipping point in EV adoption is reached. This tipping point will vary depending on the market and region. Multiple utilities and ISOs have admitted that the grid is not prepared to absorb and manage a certain level of load under current frameworks and business models. However, within a managed system with new technologies, upgraded architecture and new business models, reliability could be achieved, as demonstrated in some European and Japanese markets.

If there's a future where all cars are on-demand, and no one owns, then participants could see the original equipment manufacturers owning a fleet of bi-directional EVs.

What are the different ownership models your companies and organizations are considering now?

Utilities see consumers adopting EVs and in-house charging infrastructure themselves, similar to the fast adoption of new technologies like smart thermostats. These "behind the meter" changes cause utilities to become inadvertently affected by consumer behaviors within their homes or businesses. However, to simplify operations in an increasingly complex grid and profit off the charging infrastructure, utilities are developing business cases together to control behind-the-meter infrastructure investments.

Others see mass adoption of EVs most likely to happen with consumers who don't have garages to park in, like apartment dwellers. These urbanites rely more on fleet systems such as car shares and rideshares. Discussants viewed current trends among younger generations and boomers, like less standalone and large home sales, as indicative of disinterest in owning significant assets and more substantial interest in city living, where EVs and the necessary infrastructure can thrive.

The possibility of companies with no legacy vehicles entering into the market with a subscription-type service was also explored. "Car-2-Go" or "ZipCar" offer subscription services in which users could have sole access to a car or participate in car-sharing. A similar business structure with bi-directional EVs would create a market for utilities or third parties to manage vehicle fleets to serve the mobility needs of consumers, and goods (e.g. Amazon and USPS), as well as benefit the grid.

If there's a future where all cars are on-demand, and no one owns, then participants could see the original equipment manufacturers owning a fleet of bi-directional EVs, who only produce new vehicles as they retire old ones. However, it was noted that this concept would upend a lot of industries: insurance, airbags, car dealers, parking, etc.

Another ownership model that was suggested was municipalities owning a fleet, which will be paid for by local taxes.

Where does disruptive technology fit in?

Participants offered Blockchain and artificial intelligence (AI) as potential disruptions to current thinking in the transportation sector. Blockchain could be used in bi-directional situations to ensure the consumer was paid for giving energy back to the grid. AI could be leveraged to provide dynamic pricing at the distribution level.

> *Better incentives for apartments, shopping centers, gyms, etc. would encourage consumers to purchase EVs.*

Autonomous vehicles are expected sooner rather than later, which supports the on-demand and subscription models previously discussed. Though there was some skepticism of this technology, participants saw older adults appreciating the extra years of solo-transportation while younger adults are just quick to adopt new technology in general.

AI could enable everything to be a subscription service down to your tires.

What public policies limit deployment?

Utilities currently struggle to accommodate innovation in light of market design and regulatory requirements. For example, spot prices, which are ultimately governed by various local, state or federal agencies, make integrating variable loads onto the grid difficult. Trading markets become essential in this context, or technology upgrades are necessary to accommodate the bi-directional flow. The changes have been profound in recent years. Utilities now buy and sell so much between themselves, and they have a whole trading floor setup for this. If every end-user has the option to exchange energy, it will make this process incredibly difficult. These conditions are also very different in regulated versus deregulated, merchant markets, adding additional complexity to developing a nationwide system. New technologies will be needed to support this type of grid.

As a result, interconnection agreements could pose a problem. Right now, anyone connected to the grid or acting as generation has an interconnection agreement with the utility or RTO/ISO. So, something that will need to be discussed is if everyone who enables bi-directionality needs an interconnection agreement with the grid. Utilities will need to have protections in place, similar to solar. When you go from energy consumer to generator, there’s a different type of agreement.

Car warranties will also need to evolve. Currently, enabling bi-directionality voids a car’s warranty for most car makers. However, Nissan is the exception. In most cases, car warranties cover 100,000 miles which could be used as a benchmark for bi-directional usage.

It was suggested that utilities currently could not spur investment, which is limiting deployment.

The lack of incentives is also seen as a deterrent for adoption. Better incentives for apartments, shopping centers, gyms, etc. would encourage consumers to purchase EVs.

Others suggested that a significant issue stymying adoption is general awareness. Consumers aren't aware of the subsidies available to them. A great example of this is that the highest subsidies right now are in Colorado, where there is virtually no EV adoption.

Most notable, range-anxiety was cited as one of the largest obstacle for electric vehicle adoption – second to cost. However, public policy that provides incentives and enables new business models to support strategic infrastructure investments could help address range-anxiety.

At what times and under what circumstances do utilities need grid support services (e.g., ancillary services, load shifting, and demand response)?

The grid's current lack of storage poses various challenges, like grid operators' ability to manage load peaks. Bi-directionality can relieve grid issues and make EVs more cost-effective for the consumer.

> *Storage assets will provide many opportunities at many levels, like improving load factors, decreasing peak demand, providing more grid flexibility, saving peaks, spreading usage to valleys and better utilizing already paid for resources.*

Increased storage provided an opportunity to stabilize the grid systems, which is a significant concern right now for utility operators. Storage assets will offer many opportunities at many levels, like:
improving load factor, decreasing peak demand, providing more flexibility, spreading usage to valleys and better utilizing already paid for resources.

The grid also needs assistance during emergencies or blackouts. Not only can energy storage be easily distributed to pain points, but it can decrease municipalities' use of diesel generation, which will increase diesel availability in the community.

Should EV adoption increase as expected, utilities are concerned that EV owners will plug in their cars at their homes around the same time in the evenings, which would put more demand on the grid during an already difficult time of day. Some experts expect approximately 30 million electric vehicles on the road in the U.S. by 2030 creating concern for how demand will be handled. Grid support will be needed to alert consumers when it is the correct time to charge their vehicle, which will help smooth out variabilities with renewables and right price signals. If this type of support is implemented throughout a state, it will solve infrastructure problems of moving energy as well. At the same time, bi-directional electric vehicles (that charge during the day at the office) could address the problem that electric vehicles create (when plugged in at home during the early evening hours when most people get home and start using more electricity). Bi-directional electric vehicles could be called upon through proper price signals to discharge. Through proper aggregation and innovative systems management, this could have profound benefits to unlock significant mobile storage potential. An asset (electric vehicle) that is normally idle over 90% of the time, can suddenly provide new found utility during that time.

Under what conditions would owners be willing to offer their charging infrastructure to provide such services?

> *Vehicles are the second most expensive investment, and it immediately depreciates. According to participants, if bi-directional batteries can add a second revenue stream, adoption by the younger generations is inevitable.*

Vehicles are one of the most expensive investments for consumers, second only to their homes. Moreover, they immediately depreciate. According to participants, if bi-directional batteries can add a second revenue stream, adoption by the younger generations is inevitable. Younger adults are not only interested in the adoption of new technologies, but they're interested in "side-gigs." A future was explored where someone would buy the car for transportation for themselves, but also work as an Uber driver part-time, complete a last-mile package delivery, and then get a signal from a building that they would pay an EV to plug in to meet their demand. All of a sudden, a car can give revenue, and that is going to be attractive to people.

The user experience is imperative; because the primary purpose of a car is transportation; in a bi-directional future, consumers will have to have the ability to opt-out of connecting to the grid at any given time.

Others noted that more significant incentives would also encourage the installation of infrastructure to enable bi-directionality.

How can electric vehicle charging infrastructure with energy storage or microgrids be used for locational energy arbitrage?

The group deferred this question to a conversation about EV potential under fleet management versus consumer management. Utilities noted that they could tell if a home has installed an EV charger by reviewing the usage data. However, the anticipation of locational pricing remains dependent on regional market design. Fleet designs would allow utilities to exert greater control over the reliable flow of electricity than consumer-led models. However, here is software currently available that would alert consumers to when it is the correct time to charge their vehicle, which will help smooth out variabilities with renewables and provide the right price signals.

How can electric vehicle charging infrastructure with energy storage or microgrids be used for responding to emergencies and for restarting the grid?

Multiple participants saw an immediate future for utility or public-use vehicles (e.g. school bus) to be bi-directional and, because the utility, state or municipality owns them, there would not be a user compliance issue. Although bi-directional utility vehicles might initially be seen as a considerable expense, they would provide a second use for an asset that is sitting unused for the majority of the time as well as be an asset during an emergency. Examples included using a school bus to power a shelter in a school's gym.

Are consumers willing to consider different ownership models? What would it take for consumers to accept the levels of risk associated with varying models of ownership?

The majority of the group agreed that the user would be the hurdle. Statistics for EV adoption are high in California where subsidies have disappeared but low in Colorado where subsidies are high. However, subsidies are still viewed as a driver for adoption. A "high" of 10 percent market penetration will not fulfill some of the ambitious goals set out for electrifying vehicular traffic. Trends point to broad acceptance of different ownership models. They flagged the lower rate of homeownership, an increase in rentals, high interest in subscription services and the charging of micro-mobility scooters as evidence.

Others noted that the second revenue stream that a bi-directional battery can add to car ownership would also help increase consumer acceptance. A couple participants suggested that OEMs or some other third-party aggregator may be interested in selling EVs and retaining ownership of the batteries in the EVs which would instead be leased to vehicle consumers. Depending on the location, earnings were estimated between $3,000 and $9,000 per year per BD EV for selling energy services to either the grid or some other load entity. In theory, such opportunities may exist for some early adopters which could pay for a new battery within the first year and still provide a few more years of battery life.

Under battery leasing or buy-back programs, degraded, but useable, batteries are reused for grid services as owners are provided with fresh batteries.

Multiple participants saw a tremendous opportunity for second-use batteries. When a car battery retires, it's likely still 75% operational; it just can't correctly fuel the car anymore. However, it was noted that battery manufacturers would need to be a part of the battery's second life because it is proprietary technology.

Suggestions for other uses ranged from standalone power generation for a house to the building of shipping containers with multiple batteries that can be moved around and provide peak demand when and where needed most.

Researches noted that EV batteries would need to be redesigned to be recycled and reused correctly. However, Argonne's ReCell Center, in collaboration with other national laboratories/partners, is looking into this situation.

Conclusion

Future Actions for Consideration

Participants gave the session high ratings, despite bringing differing expectations into the discussion. The diversity of participants brought varying levels of policy and technical knowledge. As people contributed to the conversation, it became apparent more interaction is necessary to allow all parties to understand the state-of-the-art not only in automotive technology but also in terms of consumer behavior, grid management, and business mechanisms in the nexus between energy and transportation. Not only did the majority of participants express interest in bi-directional technology, but they also saw various opportunities in terms of future use-cases. However, it was emphasized that the industry would need some type of technology and policy standardization to ensure that everyone is on the same path and that the appropriate infrastructure is in place. A common theme emerged during the discussion: mobile storage assets could provide many opportunities at many levels; they could: improve utility load factor, decrease peak demand purchased energy, provide more grid flexibility, save peaks, spread usage to valleys and use resources that electric utility consumers are paying for anyway.

Largely, questions about pricing and fleet ownership were left unanswered. There were also disagreements about who should own bi-directional infrastructure, with many saying it depended on the situation.

The conversation quickly evolved from the pre-determined discussion guide, with participants asking others in the room about the capabilities of the technology, including the cost of building out the infrastructure needed to enable it. Although in the minority, a couple of participants were skeptical that consumer behavior would adapt to support bi-directional EVs altogether.

The discussion pointed to specific areas for continued exchanges of information:

- Connecting the utility industry and transportation sector to collaborate.
    - For example, energy 101 for mobility advocates, automotive suppliers and OEM to explain how utilities manage electricity flow and energy markets, with attention to the differences between the merchant and regulated markets.
- Sector comparisons on consumer acceptance data regarding energy and automotive technologies.
- Futurist sessions highlighting emerging technology options provided by AI and distributed ledgers like Blockchain.
- Further development of relevant use cases, business models, and supporting policies or incentives

Appendix I

Discussion Guide

Session 1: Considerations for Electric Vehicle Infrastructure Investments and Wireless Charging

(1:15PM - 2:30PM)

Description - DOE, Argonne, and U.S. DOT will provide participants an opportunity to ask questions regarding the Argonne's GIS mapping tools. The capabilities these tools offer could help state DOT's and other electric vehicle infrastructure investors weigh trade-offs or identify new opportunities that create additional value when selecting locations for electric vehicle infrastructure. For example, these tools can highlight where electric storage may be valuable to the grid to provide resilience or offset intermittency from renewable energy to stabilize the grid. Also, this roundtable will help connect the OEMs to state transit agencies who may be potential customers and also have significant electric vehicle infrastructure investment opportunities to reduce range anxiety. P3 opportunities and updates from DOE on wireless EV charging will also be discussed.

1:15 Welcome for fleet operators, auto suppliers, battery makers, certain public agencies, and the OEMs.
Rima Kasia Oueid, OTT, U.S. Department of Energy

1:25 Vehicle Technology Office

1:35 Argonne presentation with Q&A

2:05 Potential Cases for Bi-directional Electric Vehicle Charging Stations

I'm going to ask you for a quick take on this topic before we get started. On the notecard in front of you, write a couple of words to answer this question:

Who should own bi-directional electric vehicle charging infrastructure?

We know that’s a hard question. That is why we’re here to explore possible use cases for charging stations. I’d like structure today’s conversation around these three:

1. Electric vehicle charging infrastructure **provide ancillary services or demand response** to the power grid.

2. Electric vehicle charging infrastructure with energy storage or microgrids are **used for locational energy arbitrage.**

3. Electric vehicle charging infrastructure with energy storage or microgrids **are used for responding to emergencies and for restarting the grid.**

Can anyone share their experience with an example of one of these use cases?

We started with the question of ownership. What are the different ownership models your companies and organizations are considering now?

- Who should pay and for which component of the project (e.g., interconnection, operations, maintenance, etc.)
- Who pays for the bi-directional EV charging infrastructure if it includes storage or a microgrid that is beneficial to the grid: end-users, ratepayers, or market participants?

Where does disruptive technology fit in?

- Autonomous vehicles; Blockchain; Remote sensors

What public policies limit deployment?

1. Electric vehicle charging infrastructure provide ancillary services or demand response to the power grid.
    i. Individually, Individually by a third party, Aggregation by the utility or third-party.

    - At what times and under what circumstances do utilities need grid support services (e.g., ancillary services, load shifting, and demand response)?
    - Under what conditions would owners be willing to offer their charging infrastructure to provide such services?
        i. How much additional storage would be needed?
        ii. What is the additional marginal cost for storage relative to the additional potential revenue stream opportunities?
        iii. What is the additional marginal cost for bi-directional electric vehicle infrastructure to become a microgrid, and what is the added benefit from the additional potential revenue stream opportunities?
        iv. How does this vary by region or location?
    - Where on the grid is the greatest potential value? For example, where would utilities see value in this to help them offset infrastructure upgrades?
        i. Based on grid congestion

ii. Based on other grid vulnerabilities

iii. Based on access renewables (e.g., heat maps)

iv. Based on savings to utilities to offset

2. Electric vehicle charging infrastructure with energy storage or microgrids are used for locational energy arbitrage.

   - Can charging infrastructure investments anticipate locational pricing?

   - How would plans for locational pricing for resilience affect the prospects for bi-directional electric vehicle charging infrastructure?

3. Electric vehicle charging infrastructure with energy storage or microgrids are used for responding to emergencies and for restarting the grid.

   - Would such infrequent events justify the needed capital investment?

   - Are vehicle owners likely to comply in an emergency?

   - Could fleet operators be deployed under such circumstances?

Session 2: Is There a Business Case for Bi-directional Vehicles and Updates on Wireless EV Charging

(Dec 4th - 2:45PM – 4:30)

Roundtable for fleet operators, auto suppliers, battery makers, certain public agencies, and the OEMs.

Description - Participants will discuss a proposed framework and potential use cases to analyze the end-consumers business case for bi-directional vehicles. The meeting will provide participants with an opportunity to provide feedback regarding the framework and potential use cases as well as an opportunity to provide data and participate in the on-going analysis. This analysis may consider timing, cost, degradation, location, and various use cases to help inform buyers/users and suppliers of bi-directional vehicles. In addition, this roundtable will help connect the OEMs to different U.S. based fleet operators and state transit agencies who have significant infrastructure investment opportunities where P3 opportunities may exist.

- Let's talk about the consumers for electric vehicles. Are these end-users or service providers? In the first session, we focused on the charging infrastructure from the perspective of utilities. How does this model change when transportation becomes a service?

Ownership models

- Are consumers willing to consider different ownership models? What would it take for consumers to accept the levels of risk associated with varying models of ownership?

1. Fleet users maximize revenue by shifting from the delivery of people and goods to grid services.
    - What types of fleet would have such scheduling flexibility?
    - What price is needed to persuade fleets to shift to grid services?
    - Are there times of the day when fleet operators would most likely shift? What grid services are needed at those times?
2. Business owners (e.g., manufacturers) pay employees to draw power from their vehicles to reduce demand charges.
    - How can employees be assured of having take-home power?
3. Batteries or vehicles are owned by a company, which are leased to the consumer. (Context: for electric vehicles, fuel cost is ~7% of overall vehicle cost per mile. That leaves only a marginal incentive for owners to provide grid services. Company ownership may provide greater incentives for grid participation. Alternatively, companies could provide active management to extend battery life.)
    - At what price level would companies be willing to sacrifice battery life for grid services?
    - How would companies track the state of health of batteries leased to consumers?
4. Under battery leasing or buy-back programs, degraded, but useable, batteries are reused for grid services as owners are provided with fresh batteries.
    - What monitoring and modeling are needed for leasing companies to optimize the time of battery replacement? How do pricing structures affect those decisions?
    - What would a “certified pre-owned” battery program look like to certify the state of health?

Innovative Use Cases

We’ve discussed how ownership models influence the business case.

- What public policies limit innovative uses for batteries? (For example, can consumers of electricity also be producers? Can utilities own generation? Is energy storage classified as “generation.”?)

Let’s revisit our three potential Strawman Use Cases

5. Electric vehicles provide ancillary services or demand response to the power grid.

    i. Aggregation by the utility or Aggregation by a third-party.

- At what times and under what circumstances do utilities need grid support services (e.g., ancillary services, load shifting, and demand response)?
- Under what conditions would owners be willing to offer their vehicles to provide such services?
- Alternatively, given when electric vehicles are likely to be connected, what is the value of grid services at that time? Would vehicle owners be willing to participate?
- How do battery use cases affect battery life?
- How would participation affect battery warranties provided by (a) the automaker and (b) the battery suppliers to the automakers?

6. Mobile energy storage is used for locational energy arbitrage.

- Can charging infrastructure investments anticipate locational pricing?
- How would plans for locational pricing for resilience affect the prospects for bi-directional vehicles?

7. Mobile energy resources responding to emergencies and for restarting the grid.

- Would such infrequent events justify the needed capital investment?
- Are vehicle owners likely to comply in an emergency?
- Could fleet operators be deployed under such circumstances?

General Question

How risk-averse are auto and battery makers to new technologies and use cases? How might technology mitigate those risks?

On the notecard in front of you, write a couple of words to answer this question: What technology or policy is needed to transform bi-directional vehicle future?

APPENDIX 2

Resources

ARGONNE'S ENERGY ZONES MAPPING TOOL

- ARGONNE'S ENERGY ZONES MAPPING TOOL (EZMT): A map-based tool for identifying areas within the United States that may be suitable for power generation and energy corridors. Users can run default models, modify them for their preferences, or design new models using any of over 70 siting criteria. The EZMT also hosts large repository of mapping data for energy resources, energy infrastructure, siting factors, and reference layers such as transmission lines and substations.
  - Link: https://ezmt.anl.gov/

ARGONNE'S LIFE-CYCLE ANALYSIS OF VEHICLE AND FUEL TECHNOLOGIES

- Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025-2030) Technologies. This study analyzed the full-cycle levelized cost of ownership of different vehicle powertrain technologies.
  - Link: https://greet.es.anl.gov/publication-c2g-2016-report

ARGONNE'S ALTERNATIVE FUEL LIFE-CYCLE ENVIRONMENTAL AND ECONOMIC TRANSPORTATION (AFLEET) TOOL

- AFLEET help stakeholders estimate petroleum use, greenhouse gas (GHG) emissions, air pollutant emissions, and cost of ownership of light-duty and heavy-duty vehicles.
  - Link: https://afleet-web.es.anl.gov/home/

ARGONNE'S AGENT-BASED TRANSPORTATION MODEL

- Compass – formerly known as A-TEAM – models the complex behavior and interactions between travelers, agencies and service providers for long-term infrastructure planning, technology adoption (such as bi-directional technologies) and systems optimization (e.g., reducing cost, risk and interruption while increasing benefits).
  - Link: https://www.anl.gov/tcp/compass-transportation-energy-analysis-model

ARGONNE'S BLOCKSIM: A GENERALIZED MODEL FOR BLOCKCHAIN SYSTEM

- The aim of this paper is to illustrate the essential elements and functioning of a Blockchain system, implement a generalized simulation and a measure of Blockchain efficiency from an agent choice and energy cost perspective. Our preliminary results indicate that mining choice (transaction block to verify) coupled with proof of work incentives are critical for energy efficiency

- Link: https://www.informs-sim.org/wsc18papers/includes/files/083.pdf

- Reference:

  Kaligotla, Chaitanya, Charles M. Macal (2018) “A Generalized Model for Blockchain and Blockchain Applications,” Proc. Winter Simulation Conference 2018, M. Rabe, A.A. Juan, N. Mustafee, A. Skoogh, S. Jain, and B. Johansson, eds., Pages 1001-1012. December 9-12, Gothenburg, Sweden. IEEE Press.

Argonne’s Least-Cost Electricity Analysis Framework

- Modeling and analysis of emerging technology integration into power transmission/distribution grid and electricity markets in the context of short-term operations, long term planning, economic, reliability and environmental analysis.

  - Reference:

    Guo, Zhaomiao, Zhi Zhou, and Yan Zhou. "Impacts of Integrating Topology Reconfiguration and Vehicle-to-Grid Technologies on Distribution System Operation." *IEEE Transactions on Sustainable Energy* (2019).

    Jenkins, J. D., Z. Zhou, R. Ponciroli, R. B. Vilim, F. Ganda, F. De Sisternes, and A. Botterud. "The benefits of nuclear flexibility in power system operations with renewable energy." *Applied energy* 222 (2018): 872-884.

    Zhou, Zhi, and Audun Botterud. "Dynamic scheduling of operating reserves in co-optimized electricity markets with wind power." *IEEE Transactions on Power Systems* 29, no. 1 (2013): 160-171.

    Wu, Jing, Audun Botterud, Andrew Mills, Zhi Zhou, Bri-Mathias Hodge, and Mike Heaney. "Integrating solar PV (photovoltaics) in utility system operations: Analytical framework and Arizona case study." *Energy* 85 (2015): 1-9.

Argonne’s Grid Storage Modeling and Analysis

- From development of advanced algorithms and models to applications & deployment, integrating details of ES design and degradation

  - Reference:

    deStisternes, Fernando; Jenkins, Jesse; Botterud, Audun. “The value of energy storage in decarbonizing the electricity sector”, Applied Energy 175 (2016); 368-379.

    Wankmuller, Florian; Thimmapuram, Prakash; Gallagher, Kevin. “Impact of battery degradation on energy arbitrage revenue of grid-level energy storage”, Journal of Energy Storage 10 (2017) 56-66.

Wang, Ying; Zhi Zhou, Botterud, Audun; Zhang, Kaifeng. "Stochastic coordinated operation of wind and battery energy storage system considering battery degradation" J. Mod. Power Syst. Clean Energy, Oct. 14 (2016).

Argonne's Collaborative Center for Energy Storage Science

- Argonne wields a comprehensive, world-class array of capabilities and facilities to address energy storage problems at every step of the energy storage chain: from analysis of raw materials to design of new materials and cells, to cell testing to full system design, as well as battery end of life and recycling.

    - **EADL** – Electrochemical Analysis Discovery Laboratory - The EADL undertakes battery testing and post-test analysis to provide reliable, independent, and unbiased evaluations of battery performance and life and the identification of physical and chemical changes related to reduced performance in aged batteries.

    - **Post- Test Facility** – Enables researchers to dissect cycled battery cells and performance analysis to determine reasons for performance decline and failure.

    - **AI/ML for accelerated cycle and calendar life testing** – a nascent program focused on big data analytics for highly accelerated cycle life testing and battery state-of-health characterization. High speed evaluations enable assessment of complex use scenarios.

    - References:

      Shkrob, Ilya; Rodrigues, Marco-Tulio; Dees, Dennis; Abraham, Daniel Fast Charging of Li-ion Cells: Part 2. Nonlinear Contributions to Cell and Electrode Polarization *Journal of the Electrochemical Society* (2019)

      Barai, Anup; Uddin, Kotub; Dubarry, Matthieu; Somerville, Limhi; McGordon, Andrew; Jennings, Paul; Bloom, Ira A comparison of methodologies for the non-invasive characterisation of commercial Li-ion cells *Progress in Energy and Combustion Science* (2019)

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Argonne's Repast Agent-based Modeling Toolkit

- An agent-based modeling toolkit emphasizing capabilities to model human behavior and decisions regarding technology adoption and use, market interactions, and mobility choices. Including human behavior into a modeling tool is essential for understanding bi-directional possibilities and business use cases.

    - Link: https://repast.github.io/

Argonne's EV-Smart Grid Interoperability Center

- Argonne's EV-Smart Grid Interoperability Center is advancing its mission to demonstrate new EV charging and electric grid technologies, including bi-directionality. It enables realistic smart grid studies that combine Argonne's capabilities in grid modeling and simulation with Argonne-developed sensing, communication and control technologies. It integrates solar power and battery storage with smart charging and controllable building systems to minimize total energy use and operate as an isolated micro-grid if needed.
    - Reference: https://www.anl.gov/sites/www/files/2018-02/SuccessStory_RenewableEnergy.pdf

APPENDIX 3

Participant Drafted Responses

BEFORE THE TWO DISCUSSIONS BEGAN, PARTICIPANTS WERE ASKED TO WRITE DOWN ANSWERS TO A QUESTION. THEIR RESPONSES ARE BELOW.

Who should (and who will) own bi-directional electric vehicle charging infrastructure?

1. Depends
    a. At home: homeowner
    b. At the workplace: the building owner
    c. All cases: could be the utility
2. Depends
    a. Individuals should own what's on their property
    b. Utilities should own what is on their lines and easements, etc.
3. Depends
    a. For fleets: vehicle owners
    b. For the general public: utilities or network operators
4. There is no one-size-fits-all solution. Utilities should have an active role and should be able to own/operate chargers if they want. They are in the best position to optimize/integrate.
5. Everyone
6. 3rd party aggregates
7. Depends
    a. Near term: utilities
    b. Long term: site hosts/private market
8. The members (share) and Investor
9. The utility for peak demand control capability

10. Whoever purchases the EVSE (could be a utility, consumer, service station, etc.)
11. Grid Utility and private sector
12. Utilities of the vehicles owned by consumers.
13. Charging stations should be owned by businesses, not power utilities and not governments
14. User or utility/provider of energy services
15. Utilities (unless they don't own the grid currently)
16. Bidirectional charging only makes sense at long-dwell-time charging stations. Therefore, ownership should be by households or workplaces (end-users for electricity/utility customers)
17. Private sector buildout of infrastructure with government incentives/friendly markets
18. Utilities/coops and/or independent companies
19. Charging network operators

What technology or policy is needed to transform the bi-directional electric vehicle's future?

1. Need the business case/business model for how consumer/car owners can make money via bi-directional from plugging into the grid, building, etc.
2. Interconnection policies
3. Heavy-duty fleet charging infrastructure
4. Understanding the answer to this question is important; is there a utility-focused market for bi-directional charging? We currently have utility-scale solar and distributed solar – if distributed solar makes sense, why is there still utility-scale? Similarly, if there are utility-scale storage solutions (mostly ion batteries, Gwh-scale), why would the grid want to deal with individual customers?
5. "One technology"
6. Wireless charging
7. Simplicity will enable many things in the bi-directional decision for consumers. But the utilities need to commit to it (or be incentivizing it)
8. Degradation mitigation

9. Provide accessible data on EV performance and cost along with the system-wide capability to take advantage of charging/market opportunities

10. More regulation on utilities requiring interconnection with bi-directional batteries

11. Allow utilities to manage and own bi-directional infrastructure and incentivize utility in deploying and promoting this infrastructure

12. Strong policies/incentives to fund initiatives & companies developing open source tech for V2G efforts

13. The low carbon fuel standard

14. More business use models

15. Highway trust fund to help pay for highway corridor EV charging with bi-directionality

16. Need blockchain/AI to complete business case

17. All new homes to require an EV charge hookup (outlet)

18. Policy Gamechanger: Tax credits for bi-directional chargers made in the USA.

19. Value to the customer – if the customer can make money, the customer will adopt