Vehicle-to-Grid Technology in the PJM Footprint
and implications for
Bringing small DER resources to wholesale markets

1 Oct 2020 presentation to

Emerging Technologies Forum, PJM

by

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EV R&D Group, U of Delaware

- Competencies
  - Electric Vehicle engineering—design and implementation
  - Electric standards—drafting, review & compliance (IEEE, UL, NEC, IEC, CE)
  - Policies at Federal, State and EU levels
  - Tariffs & requirements at RTO/ISO and EDC levels
- Our interest in these projects
  - Prove out cost-effective engineering, with allowed, cost-effective market entry
  - Apply appropriate new standards and rules
  - Work with partners (OEM, aggregator, EDC etc) for realistic feedback, maybe for commercial deployment

Delmarva Power and Exelon are collaborating with UD on V2G Demo

- Delmarva Power and Exelon are collaborating with UD on a V2G demonstration project in Delaware through the Exelon Partnership R&D program
  - R&D project launched in June 2020
  - This project will establish a fleet of V2G resources on EV sedan vehicles in Delaware as well as a V2G-capable electric shuttle bus at a community center in Wilmington
- Benefits from this R&D project collaboration
  - V2G fleet resources will provide both grid services and local decarbonization opportunities through supporting transport electrification within the community
  - Broad learnings for Exelon utilities about the value for customers from implementing V2G projects

Overview: Concept and Two projects

- Concept of Grid-Integrated Vehicles (GIVs) and Vehicle-to-Grid (V2G)
- UD Project (background illustrating barriers to aggregation of small resources)
  - Originally DSM, in queue for DR in muni
  - Example barriers to small, behind-the-meter storage participating in wholesale markets
- UD & Exelon Project
  - Will start with SG registration
  - General: If we can get kW-scale resources aggregated and interconnected behind retail meters, we will have solved many problems of aggregating MW-scale resources on medium voltage lines

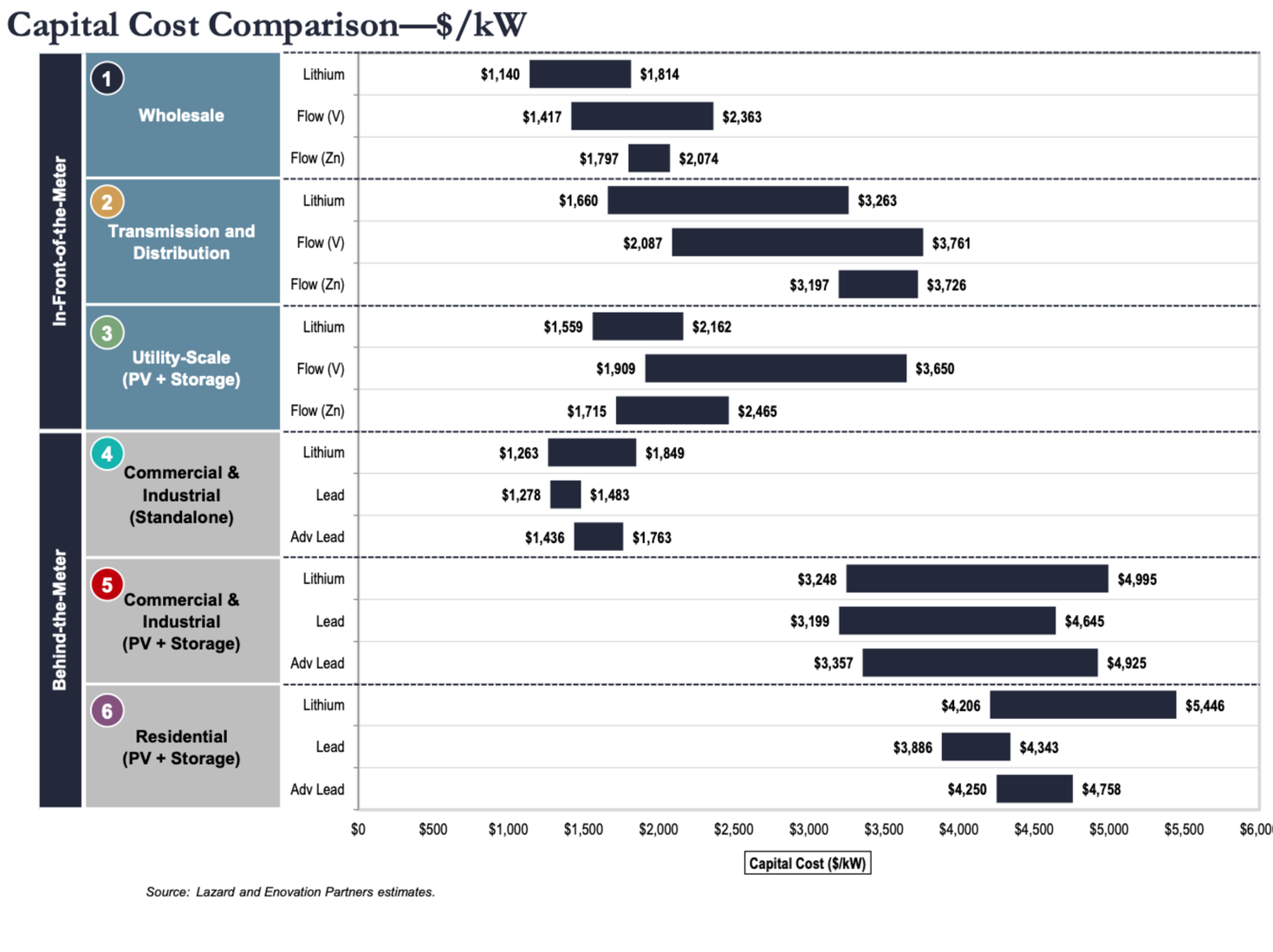
Grid-Integrated Vehicle (GIV) System Concept

- EVs already have both the battery and power conversion equipment (charger and motor drive) for grid storage
- The average light vehicle is parked 95% of the time, typically near a plug
- To provide grid services, existing components may need minor adjustments, e.g.:
  - Change charger to bidirectional charge and discharge (vehicle-to-grid, V2G)
  - Add controls and signaling to respond to grid, not just by time of day
- Aggregation means we can meet trip needs of any individual and, also, satisfy the aggregate need for balancing or reserves by RTO

Purpose-built Storage is expensive

Capital cost $1K - $5K / kW

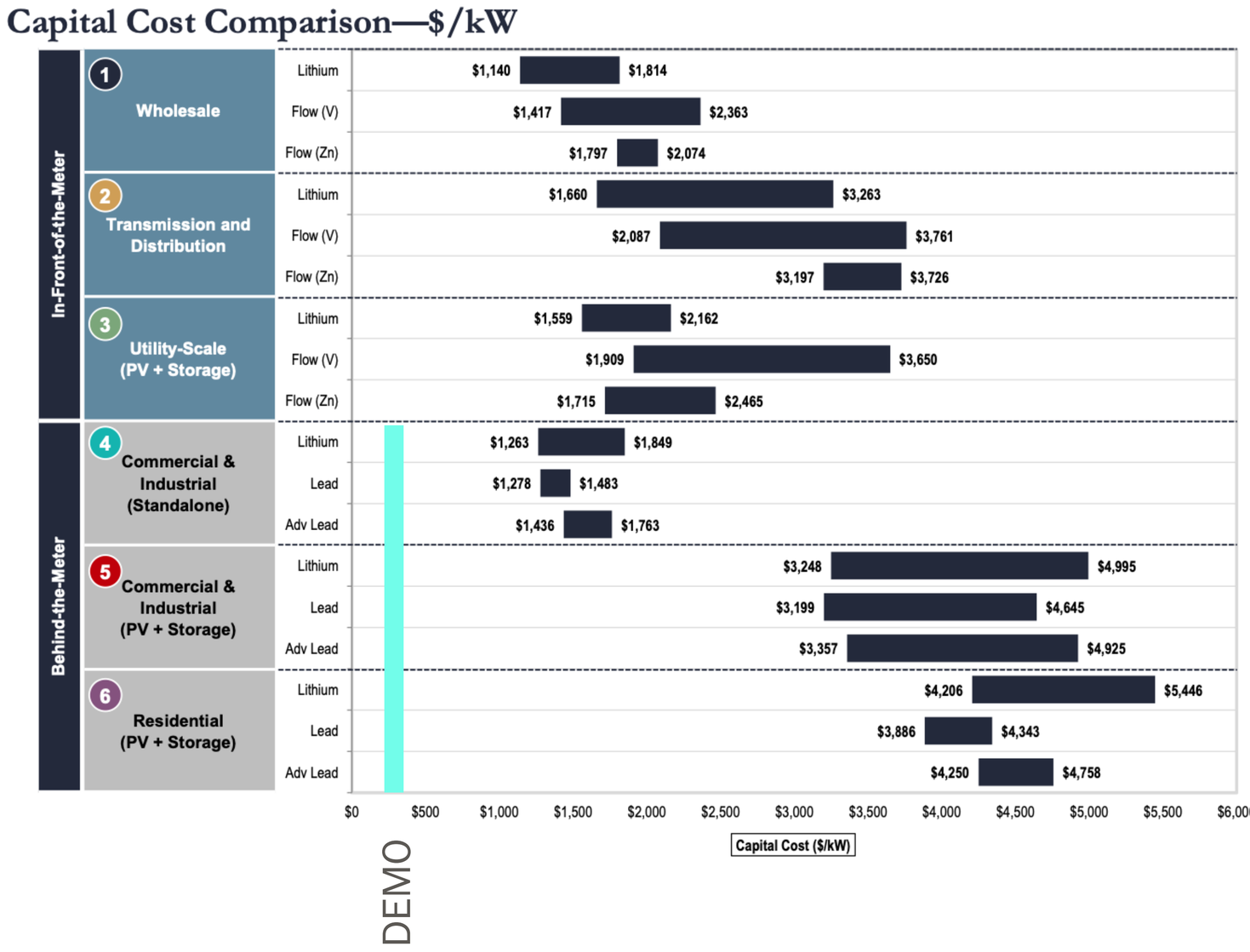
Lazard LCOS v4.0, 2018



Source: Lazard and Enovation Partners estimates.

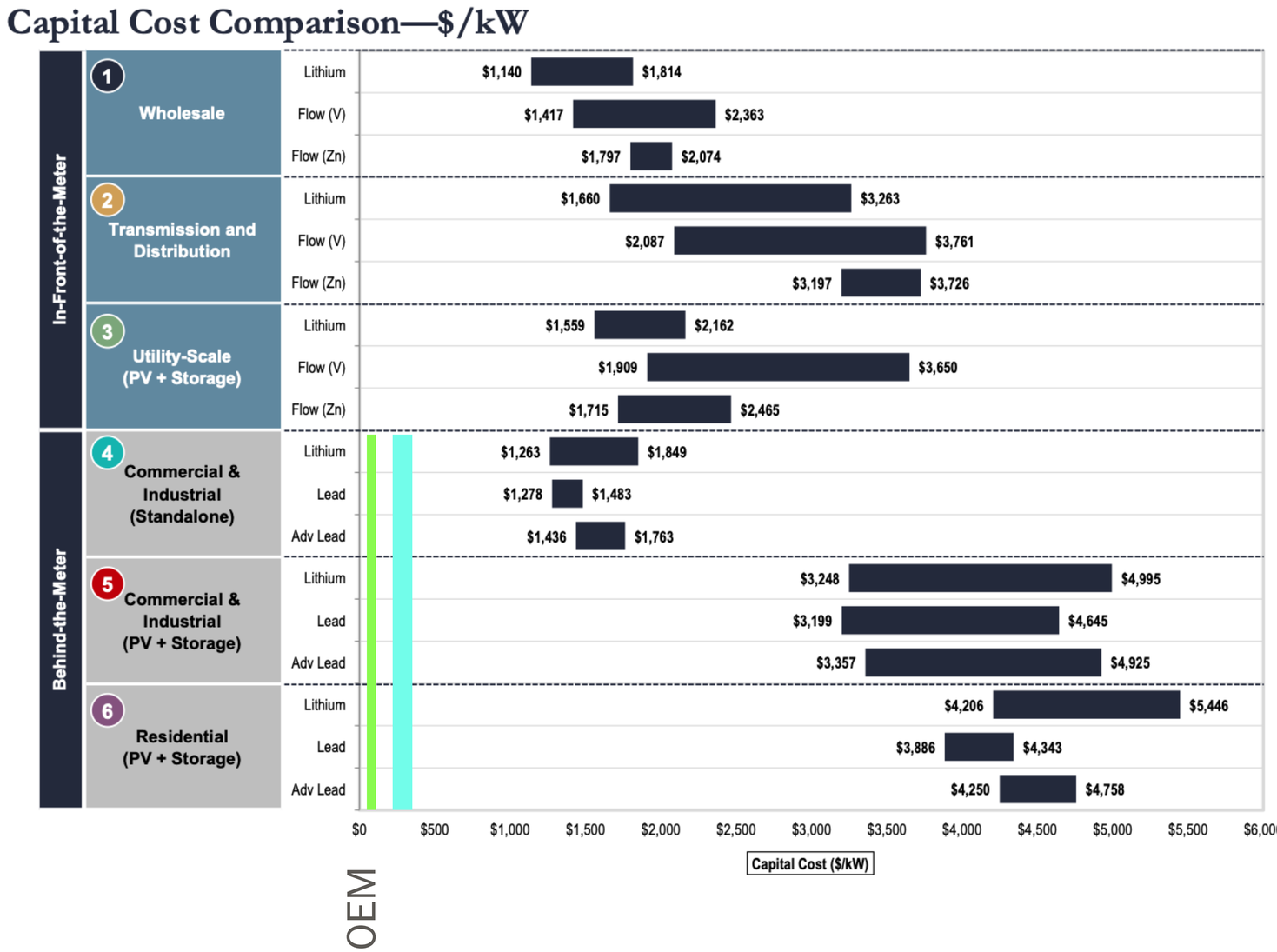
EV storage is not expensive

EV storage
Demo $227/kW



EV storage is not expensive

EV storage
Demo $227/kW
OEM production $45/kW



UD project in Newark, DE

GIV as DSM

- Original registration within a Muni in PJM (Newark City Electric)
- Much easier to register, no power flow study
- But can’t backfeed, and can’t participate in any RTO A/S market except regulation
  - Two-way power flow for regulation 13x value of managed charging (Thingvad et al 2016)
- Therefore, now switching registration to Small Generator (SG)

UD Small Generation Application

- submitted 28 Feb 2019, still in queue
- 37 EVSEs + 12 stationary batteries; now ~7 bidirectional EVs
- max capacity 0.99 MW, actual max 200 kW
- two site owners: private residents and UD campus
- SG approval will allow back feeding outside of munis, multiple services

What is the registered resource?

- In multiple jurisdictions, we have learned to register the EVSE, not the EV (battery)
  - EVSE has PJM-certified meter
  - A known, permanent location, always there for inspection or compliance audit
  - Prior position of PJM legal: The storage resource is battery in car, must register car
- How to resolve EVSE versus inverter vs. battery?
- Our position: EVSE and EV are together the resource, now reflected in Order 2222
  - Register the EVSE. When any certified, V2G-enabled EV plugs in to the registered EVSE, that combination, a GIV System, is the resource.
  - Ownership of EVSE determines owner of resource.

Complications in change from DR to SG

- Application process - cost & time
  - $27,000 to submit (only $500-$5000 if FERC jurisdictional)
  - = $10,800 deposit + $1,200 queue entry + $14,500 deposit for second study
- Queue timing for “resources less than 20 MW” nominally 18 months
  - Exhibit 6, p 42 of PJM Manual 14G, https://www.pjm.com//media/documents/manuals/m14g.ashx

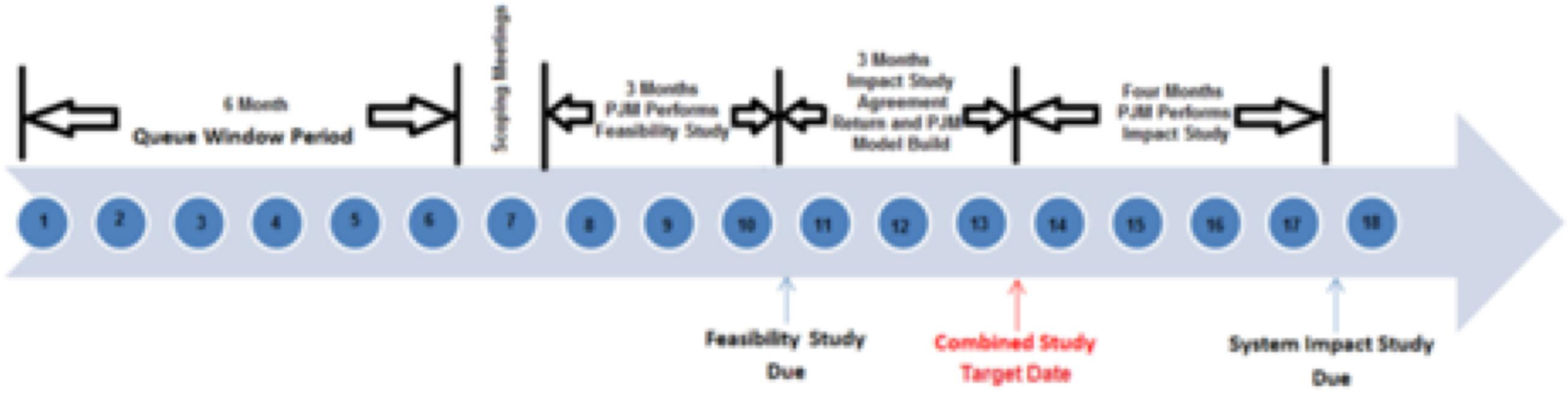


Exhibit 6: Combined Study Target Date

Aggregation

- Aggregating resources behind 16 EDC accounts
- Each one meets interconnection safety (e.g. IEEE 1547)
- BUT, as non-FERC jurisdictional within a muni or co-op, PJM legal says this is 16 PCCs,
  - NOT 3 POIs of the city medium voltage system, NOT 1 aggregated EDC resource
  - This requires 16 WMPAs
  - More cost for PJM project manager and for PJM legal labor for 16 agreements
  - Limits ability of DR to aggregate more than PCC, maybe POI

Ownership of Resource

- PJM interpretation of FERC (pre-2222) is that resource has to have a single owner
  - Site owner, EVSE owner, battery owner, and market participant — all same owner
- If EV (battery) owner is different from EVSE owner, there is a “sale of energy” and the charging cable must be a transmission system
- To accommodate this interpretation, we amended the project in queue so that the site owner also owns the project (luckily EDC account and most hardware already owned by UD)
- Requiring common ownership *de facto* precludes one aggregator across facilities

Interconnection Standards

- In this SG application, both EDC (Muni) and PJM required specific—and different—interconnection certification
  - PJM requirements for HV suggested should also apply to wholesale resources at LV
  - EDC's unofficial position is, why is PJM evaluating what we do on our distribution system?
  - Currently, EDC is determining which interconnection standards are applicable
  - State law lets EDC choose which are appropriate, SAE or UL (both based on IEEE1547)
- Our position
  - Charging station NEC and UL, if AC station also SAE J3072
  - Inverter compliance for DC is by UL1741; for AC, by SAE J3072
  - Especially at low-voltage, should be a non-FERC jurisdictional decision

UD-Exelon project (upcoming)

UD-Exelon Project Characteristics

- 9 EVSEs, 8 sedans + 1 bus, mix of 1 ph and 3 ph, total max 0.2 MW
- Two or three sites
  - IOU territory (DPL), bus at after school program
  - One or two more sites within DPL, possibly different substation
  - Would be proof of concept: IOU (outside muni), aggregate multiple types of GIV systems, SG allowing back feeding & participating in multiple wholesale markets
- Application process
  - DER subcommittee recently reduced the deposit to $2,000 to $4000 depending on time of year applied (previously $10,800)

Technical and Standards Demonstration

- Using inverter with high capacity for grid services (4-quadrant converter, IEEE 1547 -2003 through -2020)
- Using new standard for communication J3068 designed for GIV and 1ϕ or 3ϕ
- Low-cost AC charging stations with embedded PJM-certified meters & telemetry, mix of 19 kW 1ϕ and 52 kW 3ϕ
- Interconnection cert via J3072, already state law
- High efficiency, lower energy and standby costs
- Combination will give much lower capital cost, higher net revenue
  - And hopefully more streamlined registration/queue process…

Recommendations for PJM

Recommendations (1)

- Recognize that, per Order 2222
  - “electric vehicles and their supply equipment” are a distributed energy resources
  - “unreasonable and unjust barriers” to participation in wholesale markets need to be mitigated

“These resources may include, but are not limited to, resources that are in front of and behind the customer meter, electric storage resources, intermittent generation, distributed generation, demand response, energy efficiency, thermal storage, and electric vehicles and their supply equipment - as long as such a resource is “located on the distribution system, any subsystem thereof or behind a customer meter.” (Order 2222, pg. 91)

“...thereby ensuring that any resource that is capable of providing wholesale services through aggregation is eligible to do so, which enhances competition in the RTO/ISO markets …” (Order 2222, pg. 22).

Recommendations (2)

- Defer to the local EDC to determine which interconnection standards are applicable. Allow any standard referencing IEEE 1547
- This would include either UL1741 (DC charger) or SAE J3072 (AC charger)

  "...regulated distributed energy resource interconnections, have the requisite experience, interest, and capacity to oversee these distribution-level interconnections" (FERC 2222)
- Attachments Z and AA to PJM's OATT are in conflict

Z refers to specific standards including IEEE 1547 and UL 1741, among others. RTO Implementation plans should adopt the flexibility to defer to state policy by including the SAE standard on this list (reflects DE state policy).

AA requires certification by a NRTL. RTO compliance plans should modify attachment AA to reflect the purview limitations of OSHA-approved NRTLs that cannot certify planes, trains, and automobiles

Recommendations (3)

- Align non-FERC jurisdictional interconnections with jurisdictional procedures
  - Reduction in fee appreciated, but still way above LV DER and $/kW way higher than HV resources
- Our reading of 2222 is that LV resource can aggregated to a single resource, either be all within the LMP Node or all within the EDC, whether jurisdictional or non-jurisdictional
- Allow sensible bypass of study
  - Example: if the EDC to has a pre-application map, distinguishing distribution feeders with adequate capacity (“black lines”) with near-overloaded lines (“red lines”), connections up to 25 kW should be allowed to connect to black lines with NO RTO level study at all.

Recommendations (4)

- Fast-track pathways
  - Previous state or local approved BTM interconnection, should be automatically approved to provide wholesale services. Problem example:
  - Example: UD DR project has already been approved by the local muni,
    - Yet, for 200 kW, $25,000 for SG studies and queue, clock now at 1 year and running
- Therefore, Fees add $125/kW to a resource that otherwise would cost $45 to $230/kW
- Substantial time investment even with quicker 10 month process applicable to FERC-jurisdictional projects.
- Totally incompatible with serial:production, single installation in 1 day, fleet in 1-3 weeks

Recommendations (5)

- Concept: Powerflow study on aggregated resource as a group entering PJM system
  - EDC approves individual BTM connections, they know their own distribution feeders
  - No concern of RTO what occurs on distribution feeders or EDC's substation transformers
  - RTO approves, may study any changes reaching the high-voltage system

END

contact

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Questions

How GIV Systems Operate

1 PLUG IN YOUR CAR
to any charger

Courtesy NUVVE

2 CHARGE BATTERY
safely and efficiently in V2G Mode

Courtesy NUVVE

3 MAKE MONEY

by providing power capacity
and sending energy back
and forth to regulate the Grid

OR SAVE COSTS

by using stored energy from
EV batteries to reduce building
energy peak consumption

Courtesy NUVVE

4 YOU'RE READY TO DRIVE

with the charge you set for the day
with advance trip planning using a
mobile fleet management app

Courtesy NUVVE

How to further improve the economics

- On-board (AC) charger, **lower capital cost**
  - AC charging 1/3 to 1/2 cost of DC charging equipment
- Bidirectional (V2G), **higher revenue**
  - 13x revenue of controlled charging, but more complex.
- Higher power per car, **higher revenue**
  - Charging power is key (more kW in/out), may not need bigger kWh battery
- Consistency of driver plug-in when parked, **higher revenue**
- Policy amendments for **market access** (end slides)

Revealing the full stacked value

	Service	Gross Annual Revenue Range (Per 100 kW bid)	Gross Annual Revenue Range (Per 10 kW Car)	Hours per year needed or standby
BTM	Arbitrage	$500 - $3,000	$50 - $300	2,200
BTM	Customer Peak Reduction	$0 to $2,500	$0 to $250	100
DSO	Deferral of Distribution Upgrades	?	?	70
TSO	Capacity	$3,000 - $7,000	$300 - $700	?
TSO	A/S Regulation	$5,000 - $18,000	$500 - $1,800	8760 (or bid 24*n)
TSO	A/S Spinning Reserves	$2,500 - $4,000	$250 - $400	8760 (or subset)

GIV Systems
Now Operating Commercially

UD PJM DSR PILOT PROJECT

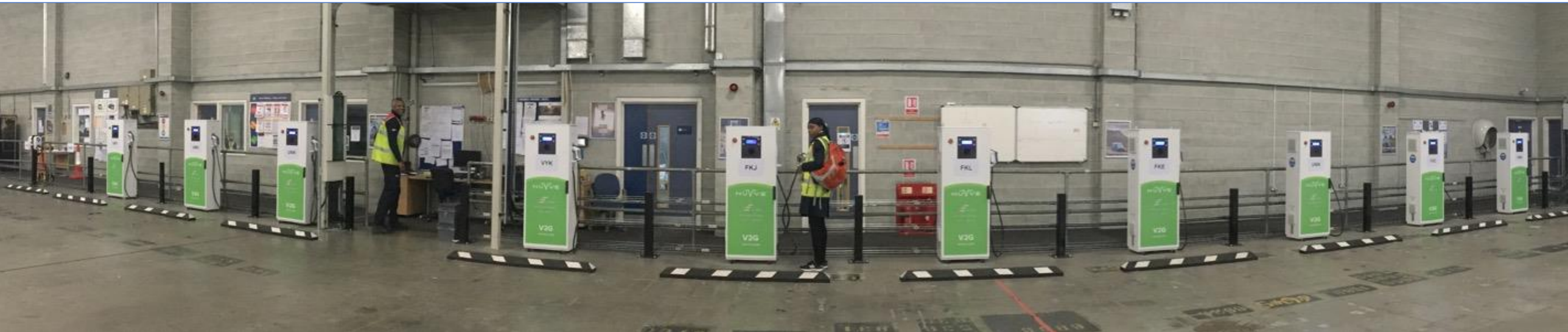
"Demand-side Resource"
PJM regulation: $1,200 / EV / year

DENMARK GIV installations, primary reserves market

Energinet.dk Primary reserves market, earning €1,600/EV/year

UK, Commercial GIV Fleets installed 2019-20

- Customers installed in London at GNEWT and Royal Borough Greenwich
- Real drivers using V2G every day
- Multiple grid services
- Nuvve Corp projects



US projects underway in California and PJM

V2G School Busses in California

Stationary storage in PJM

Controlled charging and V2G EVs on same EVSEs at U Del

US PJM regulation: $1,200 per EV per year

AC, three-phase charging + V2G

Tested to charging standards at National Renewable Energy Lab, Golden, CO

Participating OEMs

OEM= Original Equipment Manufacturer,
(i.e. Automotive Manufacturers)

"V2G AC Resources represent a potentially lower-cost form of mobile storage that supports renewable integration and improves vehicle-grid integration for the purposes of distribution planning."
– Auto Alliance in submission to CA PUC.

- BMW (demonstrations)
- Honda (Pre-production EVs with AC V2G built-in)
- Nissan Europe (selling Leafs & eNV200s warrantied for V2G via DC)
- The Lion Electric (selling AC V2G busses)
- BYD (40 kW AC V2G demonstration, 28 transit buses)
- Bluebird (DC V2G buses, pre-production)
- Renault (mass produced AC V2G capable vehicle)

Most of the above have done detailed studies of effect on warranty & battery life & decided that is not a problem.

Auto Alliance indicates need for 5-year lead time from design to mass production. **Regulators must demonstrate markets will be accessible.**

Calculating the Capital Cost of EV storage

- Assuming AC charging, power conversion on-board EV …
- Demo: Replace on-board charger with 15 kW bidirectional ~$3000 qty 300
- OEM build: Design change of 10 kW on-board charger for bidirectional flow, per-vehicle ~$300
- Add communications and logic to on-board charger and charging station (EVSE). Demo qty: ~$400 incremental cost. OEM: ~$150 per EVSE
  - Demo projects: Capital cost $3400 for 15 kW charger or $227/kW
  - OEM production: Capital cost $450/10 kW = $45/kW
- Service and customer support adds $150/year or $10/kW/year

Technology Definitions

- **Grid-integrated electric vehicle (GIV):**

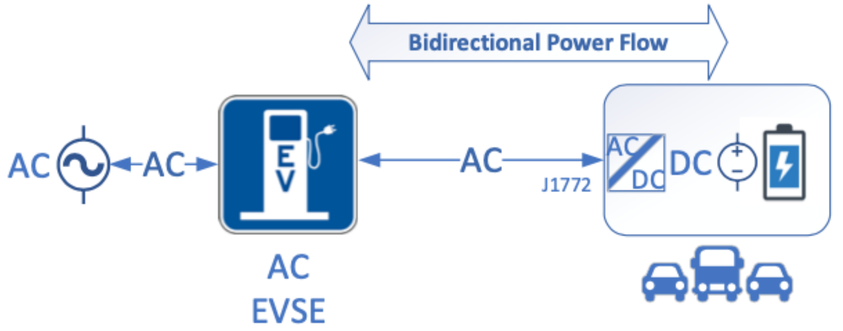
  A battery-run motor vehicle with the ability for two-way power flow (V2G) between the vehicle and the electric grid.

- **Grid-Integrated Vehicle Systems (GIVS):**

  The AC or DC charging station, its associated equipment with the ability for bidirectional power flow, communications hardware and software that allow for the external control of a vehicle's battery, and any certified, grid-integrated electric vehicle that connects to the charging station.

Technology Definition: AC vs. DC Charging

AC charging systems are site-installed equipment with the inverter located on the electric vehicle.



DC charging systems are site-installed equipment with the inverter located within the charging station itself.