Economic Analysis of Vehicle-to-Grid Fleets for Grid Services

-Phases I and II in BPA and NYISO regions

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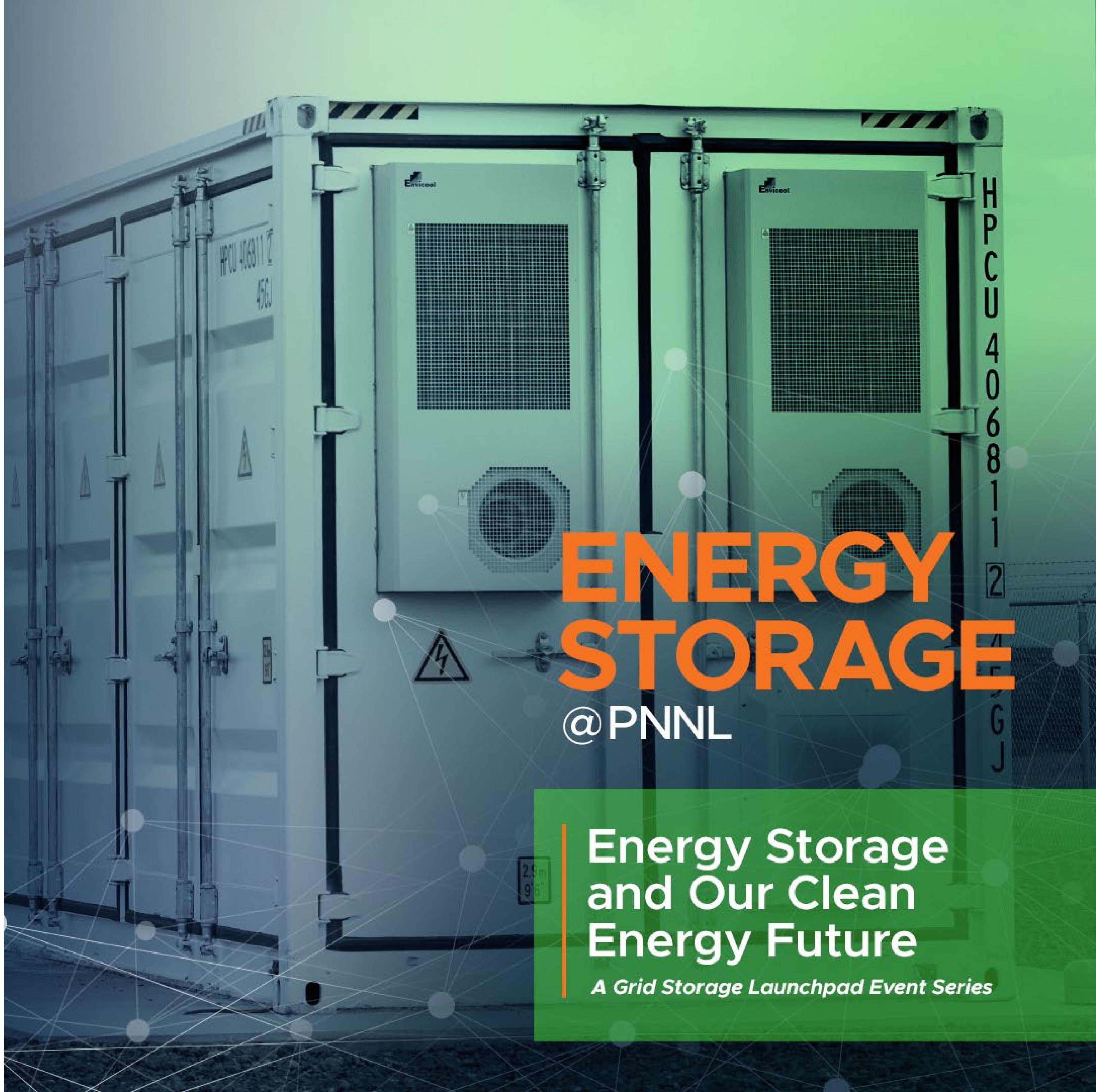

Research questions

- Could 3rd party-owned fleet V2G be an economically viable resource in support of grid services
  - Stems from a PNNL-Snohomish PUD partnership - Arlington microgrid

Team effort:

- Sid Sridhar, PNNL, engineer, project lead
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- Bowen Huang, PNNL, engineer, distribution system optimization between the fleet and markets
- Di Wu, PNNL, engineer, optimization consultant
- Vish Viswanathan, PNNL, engineer, battery consultant, cycling and end-of-life analysis
- Charlie Vartanian, PNNL, engineer, consultant on electric distribution systems
- Jeremy Twitchell, PNNL, policy and market specialist
- Scott Gibson, Arlington Microgrid Manager, use-case feedback
- Consultants from Mitsubishi and Nissan

Fleet V2G Assessment Overview

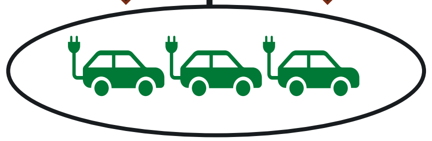
Grid Services Modeled

- Energy arbitrage
- Demand charge reduction
- Frequency regulation
- Spinning reserve

Services Origin

Bulk Power

Distribution Utility

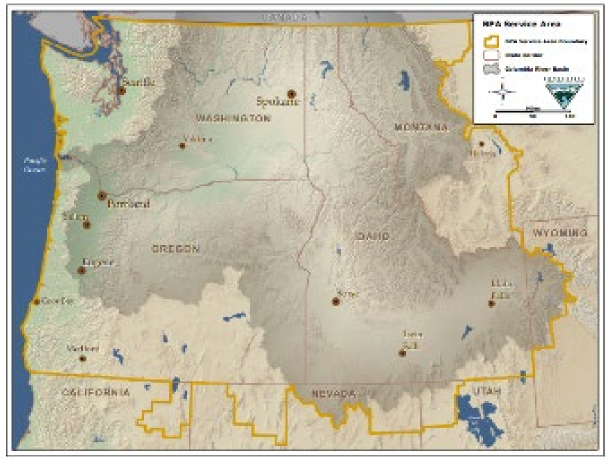


3rd Party fleet owner

Economic Analysis

- Market revenues from grid services
- Compensation to fleet owners for additional battery use

Location: Bonneville Power Administration

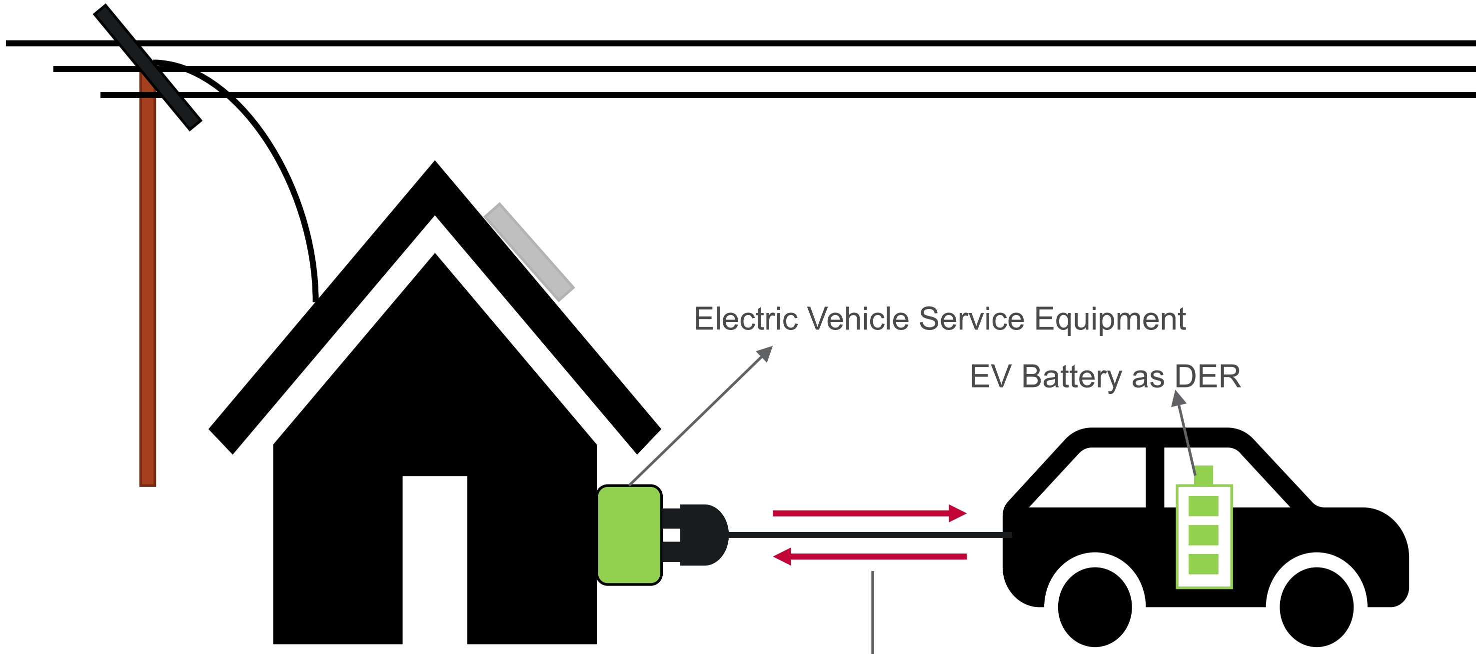


Vehicle-to-Grid (V2G) Technology Overview

❑ What is it?

V2G tech enables reverse flow of energy from the Electric Vehicle (EV) back to the grid, in addition to traditional flow from grid to EV.

- Fleets provide a potential grid resource



❑ How does it help the grid?

- Renewable energy integration
- Resilience
- Grid services
- T&D upgrade deferral

❑ What EVs/EVSEs are V2G ready?

- LDV EVs – Nissan Leaf, Ford F150 Lightning, Tesla, Lucid Air
- EV buses – Lion, Blue Bird, Thomas Built
- EVSE (requires a bidirectional charger) – Nuvve, Rhombus, Fermata Energy, Mitsubishi

V2G Pilots in the U.S.

❑ V2G Using School Bus Fleets

- White Plains School District, NY: ConEdison testing V2G pilot with five Lion electric school buses and Nuvve chargers for stress relief
- Beverly Public Schools, MA: Thomas Built school bus used for peak shaving for over 50 hours in summer 2021 by National Grid
- Cajon Valley Union School District, CA: Five Blue Bird buses with Nuvve bi-directional chargers will be used to evaluate additional revenue streams by the school district

❑ V2G Using Light-Duty Vehicles

- Snohomish PUD (SnoPUD), WA: V2G using Nissan Leaf EVs with Mitsubishi V2G chargers as DER at Arlington Microgrid
- National Grid, RI: Electric From Company’s Nissan Leaf used with Fermata Energy V2G chargers for peak shaving
- Roanoke Electric Cooperative, NC: Two Nissan Leaf EVs with Fermata Energy chargers used at utility HQ for peak shaving and back up power
- Duke Energy, Charlotte, NC: Demand response pilot using Ford F-150 Lightning trucks; reduced vehicle lease payments

V2G Stakeholders

Priorities

Priorities	Stakeholder
▪ Sell reasonably-priced EVs with V2G ▪ Battery cycling for V2G shouldn't degrade EV performance and life	Vehicle OEMs
▪ Make a profit from V2G after deducting infrastructure investments and compensation to EV operators.	Power Utility
▪ EVs ready for primary purpose: moving people and goods ▪ Compensation for battery degradation & replacement	Fleet Operator
▪ Make a profit after infrastructure investment	Third Party Aggregator
▪ Increase adoption of EVs for decarbonization and grid resilience	Policy Makers

Challenges and Opportunities

- **Business models yet to be developed:** Driver compensation, discounts on energy, replacement batteries.
- **Regulations vary by state.** Makes nationwide rollout of technology difficult.
- **Fleet participation**: Range anxiety, guaranteed minimum SOC levels for primary function
- **Battery Degradation:** Who would cover the cost of battery degradation/replacement?
- **Standards:** V2G standards need electric power system and vehicle standards organizations to work together.
- **Incentive schemes:** Clear understanding of location-specific V2G need and economic viability

V2G Economic Evaluation – Research Questions

Stakeholder-specific Questions

- What grid services most benefit from V2G?
- What are the annual benefits to a utility?

- How is vehicle battery life impacted?
- What is the net long-term cost/benefit to the fleet operator?

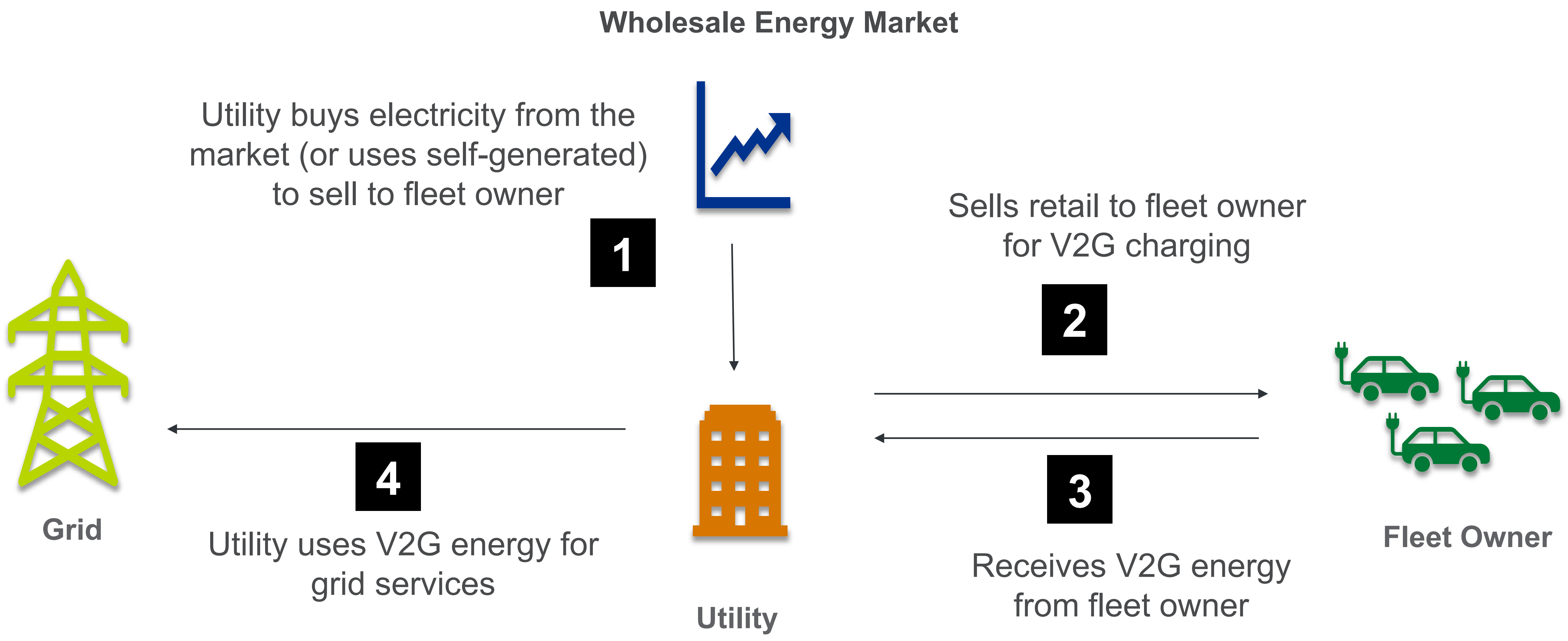
- What are the most influential factors that amplify V2G benefits?
- How do costs/benefits line up against other policy options?

Power Utility

Fleet Operator

Policy Makers

Conceptual V2G Market Overview



V2G Economic Evaluation – Fleet Assumptions

Fleet 1: Delivery Vans

- Rivian delivery van
- Battery size per EV: 180 kWh || Total fleet: 9 MWh
- Max power in/out: 11 kW
- FleetDNA has data for 553 delivery days for 36 vans

Fleet 2: Maintenance Trucks

- Ford F-150 Lightning
- Battery size per EV: 170 kWh || Total fleet: 8.5 MWh
- Max power in/out: 22.5 kW
- FleetDNA has data for 29 days of operation for four trucks

Fleet 3: School Buses

- Lion-C Electric school bus
- Battery size per EV: 210 kWh || Total fleet: 10.5 MWh
- Max power in/out: 19.2 kW
- FleetDNA has data for 857 school days and 204 bus routes
- Available 24*7 for three months in the summer

Fleet size of 50 vehicles assumed for all fleet types

V2G Economic Evaluation - Methodology

Interactions between utility and energy market

Now, includes fleet owner operation costs

Fleet Specs →

Grid Services Specs →

1 Annual Utility Benefits Evaluation

→ ***Annual benefits***

2 Total Cost Analysis

→ ***Value to stakeholders over life cycle***

- ❑ Annual benefits evaluated using an optimization model
- ❑ Objective: Maximize utility benefits from grid services
- ❑ Constraints:
  - Battery energy dynamics at EV level
  - Power and energy limits
  - Energy and battery balance at fleet level

- ❑ Annual benefits received as input from Step 1
- ❑ Other inputs:
  - Variable and fixed operating costs
  - Battery replacement cost
- ❑ Output:
  - Benefits-cost ration for all stakeholders
  - Identifying most influential variables that make V2G economically viable

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Economic Overview

The view in this analysis: all benefits go to SnoPUD, and all associated costs go to the fleet owner

Utility Perspective

Net Present Value (NPV) - Net Present Value is the present value of future cash flows at the required rate of return

Fleet Owner

Levelized Cost of Electricity – Cost per kwh of electricity used for just for V2G

?

What should fleet owners receive to be compensated for V2G services?

Step 1 – Annual Benefits Estimation Model

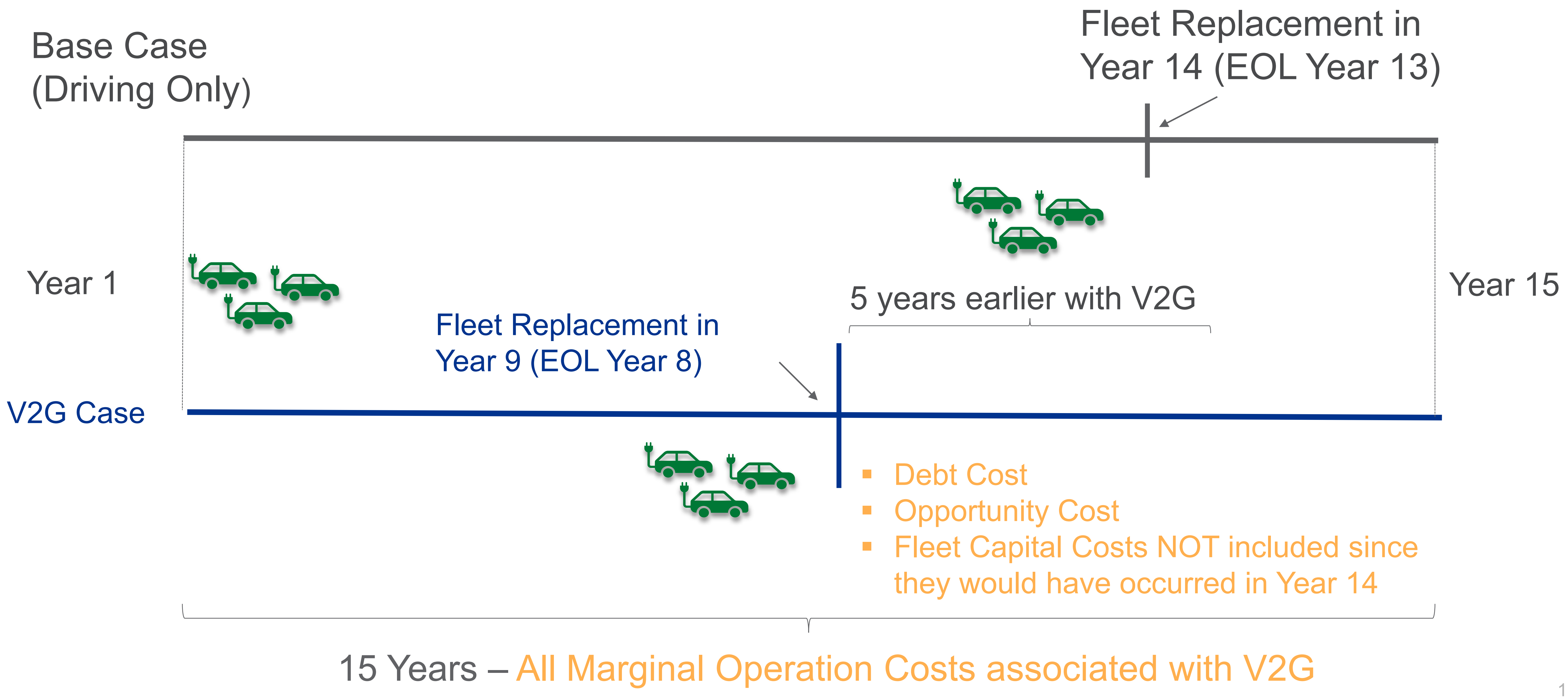
Maximize revenues from individually and jointly optimized grid services:

- Energy arbitrage benefits
- Frequency regulation benefits
- Spinning reserve benefits
- Demand charge cost (peak load based on load profile from SnoPUD)

Subject to Constraints:

- Battery energy dynamics at EV level
- Recommended state of charge and depth of discharge
- Power and energy limits
- Energy and battery balance at fleet level
- Non-negativity constraints
- Driving mode constraints based on daily trips
- Individual services constraints (frequency regulation, spinning reserve, and demand charge reduction)

Step 2 – Overview of Costs with and without V2G



Net Present Value

Net Present Value is the present value of future cash flows at the required rate of return of your project (discount rate). It's a way to calculate your return on investment.

$$NPV = \frac{C_t}{(1+r)^t}$$

C_t = Marginal, Net cash flow – V2G Only
t = time of cash flow in years: 1, 2, 3, …, 15
r = discount rate

C_t

Marginal Gross Revenues – V2G only, 15 years

Marginal Costs – V2G only, 15 years

- Capture the cost difference b/n replacement years of 'driving only' versus 'with V2G'
- Additional 'Bulk' purchases to "fuel" the batteries for non-driving purposes

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Net Levelized Cost of Electricity

$$LCOE_{k,v} = \frac{\sum_{t=1}^{n} \frac{Debt\ Cost_t + Opportunity\ Cost_t + O\&M\ Cost_t + Charging_t - Revenue_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Electricity_t}{(1+r)^t}}$$

k = energy service

v = fleet type

r = Discount rate

t = 15 years

Cost for a 50 Vehicle Fleet ($2020)	
Bus	$19,100,000
Van	$4,200,000
Truck	$3,450,000

Other Assumptions	
Federal Tax Rate	0.21
Utility Tax Rate	0.039
% Financed with Equity	0.2
% Financed with Debt	0.8
Discount Rate	0.045
Inflation Rate*	0.02
Annual Labor Fee Interactive Controllers and Software(24 hrs @$200/hr)	$4,800
Variable O&M for Battery Usage ($/kwh)	$0.00052

Results – Market Revenues (Step 1)

Vehicle	Energy Service	Annual Cash Flow - V2G only* Revenue	Charging Cost	Net Revenue
Bus	Energy arbitrage	$357,854	$334,498	**$23,356**
	Demand charge reduction	$26,890	$25,135	**$1,755**
	Frequency regulation	$4,076	$3,810	**$266**
	Spinning Reserve	$2,237	$2,091	**$146**
Van	Energy arbitrage	$658,064	$643,083	**$14,981**
	Demand charge reduction	$46,167	$45,116	**$1,051**
	Frequency regulation	$7,028	$6,868	**$160**
	Spinning Reserve	$2,152	$2,103	**$49**
Truck	Energy arbitrage	$358,147	$345,107	**$13,040**
	Demand charge reduction	$28,152	$27,127	**$1,025**
	Frequency regulation	$4,202	$4,049	**$153**
	Spinning Reserve	$2,005	$1,932	**$73**

*First year only ($2020). Revenues and costs decline according to degradation rates.

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Results – Cycles and Battery Life

		Annual Cycles of V2G Service			
Vehicle	**Cycles Without V2G**	Energy arbitrage	Demand charge reduction	Frequency regulation	Spinning Reserve
Bus	191	582	475	192	182
Van	422	664	475	192	183
Truck	401	696	466	190	182

		Battery Life: Driving + V2G			
Vehicle	**Battery Life from Driving Only**	Energy arbitrage	Demand charge reduction	Frequency regulation	Spinning Reserve
Bus	13	9.15	10.62	13	13
Van	13	6.51	7.88	11.51	11.69
Truck	13	6.44	8.15	11.96	12.13

Implications BESS Cycling and Early Fleet Replacement

Buses Used for **Arbitrage**		
Battery Life	9 Yrs	
Fleet Replacement Cost in 2031	$15,237,430	
Present Value		**% of Cost**
Foregone Interest on alternative use of equity (4 Yrs)	-$2,543,513	25%
Debt on Earlier Loan (4 Yrs)	-$4,326,465	42%
Operating Cost (includes taxes)	-$3,487,278	34%
Total Costs	**-$10,357,255**	

Buses Used for Frequency **Regulation**		
Battery Life	13 Yrs	
Fleet Replacement Cost in 2035	Net zero	
Present Value		**% of Cost**
Foregone Interest on alternative use of equity (4 Yrs)	$0	0%
Debt on Earlier Loan (4 Yrs)	$0	0%
Operating Cost (includes taxes)	-$127,178	100%
Total Costs	**-$127,178**	

Results – BPA Total Cost Analysis (Steps 1 & 2)

How does the analysis look?

All Costs and Revenues of V2G			
Fleet Type	**Service**	**Net Present Value of V2G ($)**	**LCOE ($/kWh)**
Bus	Arbitrage	($10,026,501)	$0.224
Bus	DemCharge	($4,739,606)	$0.130
Bus	FreqReg	($84,038)	$0.006
Bus	SpinRes	($84,004)	$0.006
Truck	Arbitrage	($3,995,416)	$0.087
Truck	DemCharge	($2,475,894)	$0.080
Truck	SpinRes	($490,559)	$0.041
Truck	FreqReg	($490,908)	$0.039
Van	Arbitrage	($3,684,064)	$0.089
Van	DemCharge	($2,396,648)	$0.081
Van	FreqReg	($551,967)	$0.037
Van	SpinRes	($549,496)	$0.048

Phase II – Rerun with cycling/discharge constraints

- Do not allow battery to degrade beyond typical life span

DRAFT BPA Net Revenues and Battery Discharge – Step 1

Vehicle	Energy Service	Annual Cash Flow - V2G only* Revenue	Charging Cost	Net Revenue
Bus	Energy arbitrage	$322,262	$301,229	$21,033
	Demand charge reduction	$23,534	$21,998	$1,536
	Frequency regulation	$3,539	$3,308	$231
	Spinning Reserve	$1,639	$1,532	$107
Van	Energy arbitrage	$610,799	$596,894	$13,905
	Demand charge reduction	$35,185	$34,384	$801
	Frequency regulation	$4,481	$4,379	$102
	Spinning Reserve	$1,406	$1,374	$32
Truck	Energy arbitrage	$301,431	$290,456	$10,975
	Demand charge reduction	$25,460	$24,533	$927
	Frequency regulation	$3,131	$3,017	$114
	Spinning Reserve	$1,620	$1,561	$59

MWh of V2G

		Year 1	Year 6	Year 11
Bus	Energy arbitrage	$ 3,301	$ 3,136	$ 2,979
Bus	Demand charge reduction	$ 3,101	$ 2,946	$ 2,799
Bus	Frequency regulation	$ 1,232	$ 1,170	$ 1,112
Bus	Spinning Reserve	$ 1,152	$ 1,094	$ 1,040
Van	Energy arbitrage	$ 3,193	$ 3,033	$ 2,881
Van	Demand charge reduction	$ 2,186	$ 2,076	$ 1,973
Van	Frequency regulation	$ 1,271	$ 1,207	$ 1,147
Van	Spinning Reserve	$ 922	$ 876	$ 832
Truck	Energy arbitrage	$ 3,534	$ 3,357	$ 3,189
Truck	Demand charge reduction	$ 2,771	$ 2,632	$ 2,501
Truck	Frequency regulation	$ 939	$ 872	$ 828
Truck	Spinning Reserve	$ 802	$ 762	$ 724

DRAFT BPA Full Cost and Benefits Results – Step 2

V2G Economic Analysis					
Vehicle	Service	LCOE ($/kwh) V2G Electricity	Present Value Costs	Present Value Benefits	Benefits to Cost Ratio (BCR)
Bus	FreqReg	$0.0041	($89,698)	$37,485	0.42
Bus	SpinRes	$0.0044	($69,594)	$17,402	0.25
Bus	DemCharge	$0.0018	($307,355)	$249,252	0.81
Bus	Arbitrage	($0.0002)	($3,406,075)	$3,413,094	1.00
Truck	SpinRes	$0.0061	($67,789)	$17,130	0.25
Truck	FreqReg	$0.0054	($84,589)	$33,147	0.39
Truck	DemCharge	$0.0022	($331,515)	$269,537	0.81
Truck	Arbitrage	$0.0020	($3,262,700)	$3,191,121	0.98
Van	FreqReg	$0.0041	($101,262)	$47,449	0.47
Van	SpinRes	$0.0054	($66,472)	$14,997	0.23
Van	DemCharge	$0.0028	($435,585)	$372,616	0.86
Van	Arbitrage	$0.0044	($6,613,923)	$6,468,443	0.98

DRAFT New York ISO Net Revenues and Battery Discharge – Step 1

New York ISO		Annual Cash Flow - V2G only*		
Vehicle	Energy Service	Revenue	Charging Cost	Net Revenue
Bus	Energy arbitrage	$ 120,456	$ 104,223	$ 16,233
	Demand charge reduction	$ 8,155	$ 7,056	$ 1,099
	Frequency regulation	$ 156,542	$ 135,446	$ 21,096
	Spinning Reserve	$ 48,500	$ 41,964	$ 6,536
Van	Energy arbitrage	$ 160,011	$ 154,134	$ 5,877
	Demand charge reduction	$ 24,831	$ 23,919	$ 912
	Frequency regulation	$ 328,054	$ 316,005	$ 12,049
	Spinning Reserve	$ 100,957	$ 97,249	$ 3,708
Truck	Energy arbitrage	$ 253,760	$ 250,886	$ 2,874
	Demand charge reduction	$ 71,254	$ 70,447	$ 807
	Frequency regulation	$ 1,062,630	$ 1,050,595	$ 12,035
	Spinning Reserve	$ 312,917	$ 309,373	$ 3,544

*First year only ($2020). Revenues and costs decline according to degradation rates.

		MWh of V2G		
		Year 1	Year 6	Year 11
Bus	Energy arbitrage	4888	4643	4411
	Demand charge reduction	2220	2109	2003
	Frequency regulation	1219	1161	1103
	Spinning Reserve	1186	1129	1073
Van	Energy arbitrage	4914	4668	4435
	Demand charge reduction	2747	2609	2479
	Frequency regulation	984	937	890
	Spinning Reserve	848	808	767
Truck	Energy arbitrage	4644	4411	4191
	Demand charge reduction	2832	2690	2556
	Frequency regulation	1289	1074	1020
	Spinning Reserve	1115	929	883

DRAFT New York ISO Full Cost and Benefits Results – Step 2

V2G Economic Analysis					
Vehicle	**Service**	**LCOE ($/kwh) V2G Electricity**	**Present Value Costs**	**Present Value Benefits**	**Benefits to Cost Ratio**
Bus	Arbitrage	($0.00)	($1,248,687)	$1,266,233	1.01
Bus	DemCharge	$0.00	($138,036)	$85,726	0.62
Bus	FreqReg	($0.01)	($1,580,597)	$1,645,565	1.04
Bus	SpinRes	$0.00	($526,060)	$509,832	0.97
Truck	Arbitrage	$0.00	($2,829,245)	$2,685,956	0.95
Truck	DemCharge	$0.08	($3,037,981)	$754,198	0.25
Truck	FreqReg	$0.08	($8,822,330)	$7,873,289	0.89
Truck	SpinRes	$0.01	($3,452,790)	$3,312,321	0.96
Van	Arbitrage	$0.06	($4,808,810)	$1,693,728	0.35
Van	DemCharge	$0.08	($2,529,984)	$262,835	0.10
Van	FreqReg	$0.06	($4,036,999)	$3,472,475	0.86
Van	SpinRes	$0.06	($1,616,777)	$1,068,713	0.66

Conclusions

What cost factors do we need to consider?

- Number of cycles drives early replacement cost – oftentimes the largest part of cost.
- Arbitrage, followed by demand charge, consistently has the highest market revenues, highest number of cycles, and correspondingly highest fleet lifecycle costs in BPA.
- Frequency regulation and spinning reserve have the lowest cycles (lowest depth of discharge) and lowest fleet costs in BPA.
- Frequency regulation and spinning reserve have the best over-all economic value when cycles were not constrained in BPA.
- With cycling constraints – Arbitrage and Demand Charge Reduction perform the best in BPA
- With cycling constraints – Freq Reg performs the best in NYISO; Arbitrage is cost effective for bus fleets.
- Currently, no V2G application to grid services is economically viable if **batteries have to be replaced prematurely**

Fleet V2G – Future work

What questions do we need to ask now?

- Allow for increased/decreased market price volatility with known resource and demand additions
- V2G for grid resilience (medium duration battery during outage?)
  - How much resilience could the fleet provide with no lead time?
  - How much lead time would you need for 4 – 6 hours of power
  - What kind of controls are necessary?
  - What kind of coordination is necessary?
  - How can you triage loads?
  - What kind of controls are necessary at the EVSE level?
- Examine other regions: MISO, CISO

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Thank You

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