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Economic Analysis of V2G Fleets for Grid Services, Part 2

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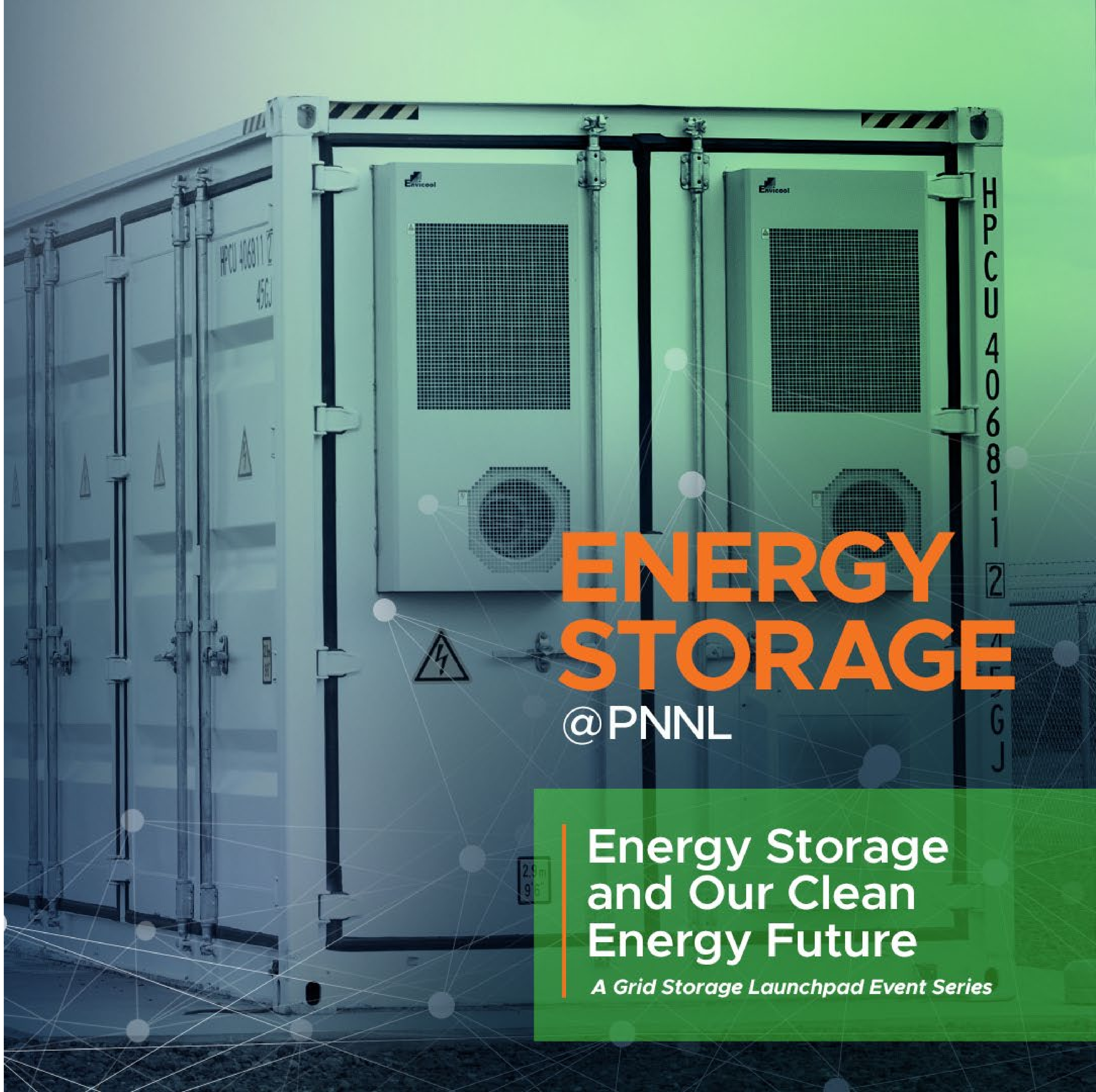


Initial research question

- 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

Original Team:

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

Agenda

- Project overview
- Initial results
- Part II updates
- New results
- Conclusions

V2G Economic Evaluation – Research Questions

Stakeholder-specific Questions

• Which grid services most benefit from fleet 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**

Fleet V2G Assessment Overview

Grid Services Modeled

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

Services Origin

Bulk Power

Distribution Utility

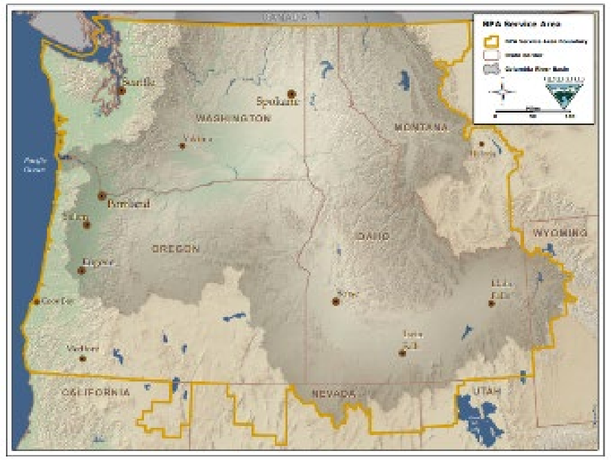
3rd Party fleet owner

Economic Analysis

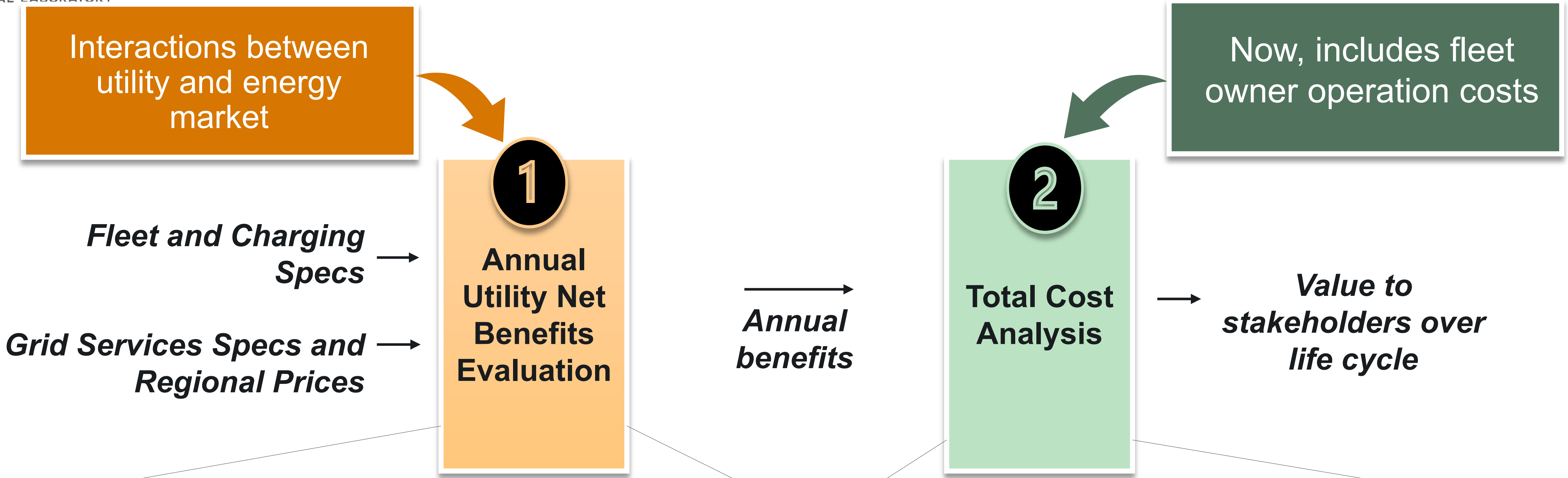
Market revenues from grid services

Compensation to fleet owners for additional battery use

Initial Location: Bonneville Power Administration



V2G Valuation Methodology



- ❑ Annual benefits evaluated using an optimization model - ESET
- ❑ 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
  - Financial assumptions
  - Battery replacement cost
- ❑ Output:
  - Benefits-cost ratio for all stakeholders
  - Identifying most influential variables that make V2G economically viable

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V2G – 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

Step 1 - Annual benefits estimation modeling

Maximize:

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

Constraints:

- Battery energy dynamics at EV level
- Battery limits 25% to 75%
- 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)
- Battery life cycle constraint with maximum number of cycles: $C_{\max} \sum_{t=1}^{T} p_i^{\text{batt}}(t)\Delta T \le (e_i^{\max} - e_i^{\min})C_{\max}$, for $\forall\, i$

$$e_i(0) = e_i(T) = 0.5e_i^{\max}$$

$$e_i(t+1) = e_i(t) - d_i^{\text{batt}}(t)\Delta T + p_i^{\text{batt}}(t)\Delta T$$

$$e_i^{\min} \le e_i(t) \le e_i^{\max}$$

$$d_i^{\text{batt}}(t) = \begin{cases} d_i(t)/\eta_i^{\text{b2w}} & \text{if } e_i(t) > 0 \\ 0 & \text{if } e_i(t) = 0 \end{cases} \forall i,\ t$$

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Assumptions for SnoPUD Net Levelized Cost of Electricity

$$LCOE_{k,v} = \frac{Net\ Present\ Value\ of\ V2G\ Electricity\ Cost_{k,v,t}}{Present\ Value\ of\ V2G\ Electricity\ Generated_{k,v,t}}$$

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

Economic Overview

The view in this analysis: all benefits go to SnoPUD, and all associated costs (except the energy purchases to fuel the V2G) go to the fleet owner

Note:
Not a DR analysis – fleet owners do not alter their driving in response to a demand call

Utility Perspective

Benefit/Cost Ratio – Present value of a grid service revenue stream/present value of all costs (utility + fleet owner).

- If the BCR<1, just purchase more wholesale power.

Fleet Owner

Levelized Cost of V2G Electricity – Fleet owner's operational costs per kwh of electricity used just for V2G

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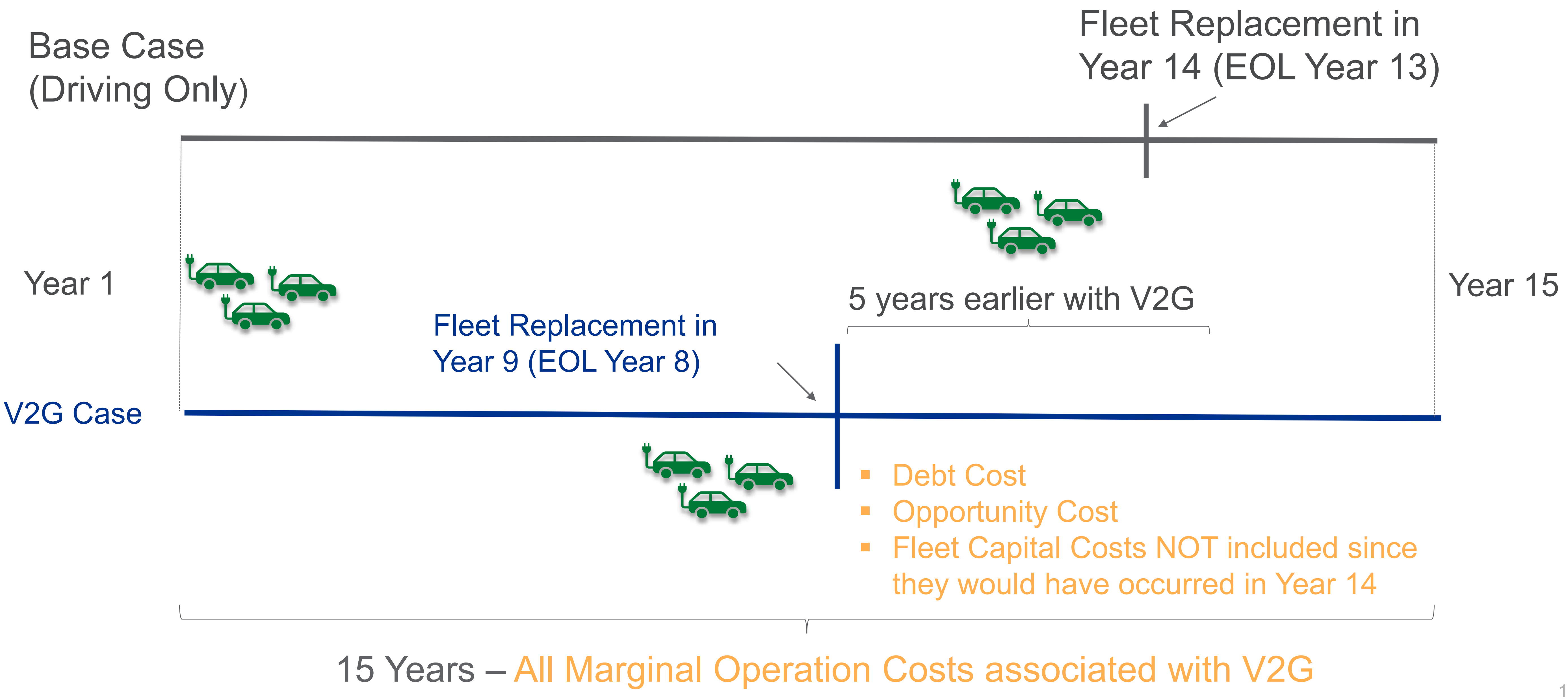
What should fleet owners receive to be compensated for V2G services?

Step 2 – Overview of Costs with and without V2G



Results – Cycles and Battery Life

Vehicle	Cycles Without V2G	Annual Cycles of V2G Service: 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

Vehicle	Battery Life from Driving Only	Battery Life: Driving + V2G: 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

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

Part II – Rerun with cycling constraint

- Does not allow battery to degrade
- Added marginal cost for bidirectional chargers
- Regional analysis now includes: BPA, CaISO, MISO, and NYISO

New Assumption	Value
Regional tax rates	0.039 – 0.051%
Inflation	2.4%
Discount rates	0.045 - .06
Marginal bidirectional charger	$750

Regional Annual (First Year) Net Revenues Discharge – Step 1

		BPA	CISO	NYISO	MISO
Bus	Energy arbitrage	$21,033	$ 39,706	$16,233	$30,299
	Demand charge reduction	$1,536	$ 1,536	$1,099	$1,589
	Frequency regulation	$231	$ 60,583	$21,096	$73,880
	Spinning Reserve	$107	$ 16,922	$6,536	$6,450
Truck	Energy arbitrage	$13,905	$ 22,801	$5,877	$15,894
	Demand charge reduction	$801	$ 932	$912	$807
	Frequency regulation	$102	$ 35,011	$12,049	$43,225
	Spinning Reserve	$32	$ 8,365	$3,708	$4,048
Van	Energy arbitrage	$10,975	$ 18,972	$2,874	$1,098
	Demand charge reduction	$927	$ 928	$807	$799
	Frequency regulation	$114	$ 33,056	$12,035	$42,991
	Spinning Reserve	$59	$ 5,061	$3,544	$3,283

Regional Full Benefit Cost Ratios – Step 2

		BPA	CISO	NYISO	MISO
Bus	Energy arbitrage	0.997	1.22	1.03	1.09
	Demand charge reduction	0.76	0.37	0.63	0.49
	Frequency regulation	0.35	1.29	1.06	1.15
	Spinning Reserve	0.20	1.14	0.99	0.91
Truck	Energy arbitrage	0.97	0.98	0.96	0.49
	Demand charge reduction	0.77	0.65	0.92	0.44
	Frequency regulation	0.32	1.00	0.99	1.05
	Spinning Reserve	0.20	0.93	0.98	0.82
Van	Energy arbitrage	0.98	0.97	0.97	1.00
	Demand charge reduction	0.82	0.79	0.82	0.42
	Frequency regulation	0.40	0.98	0.98	1.06
	Spinning Reserve	0.18	0.96	0.96	0.85

Regional Net Present Value

		BPA	CISO	NYISO	MISO
Bus	Energy arbitrage	($11,731)	$192,459	$20,303	$110,980
	Demand charge reduction	($76,854)	($71,730)	($69,604)	($74,063)
	Frequency regulation	($70,962)	$373,079	$74,168	$413,569
	Spinning Reserve	($70,942)	$57,149	($26,318)	($28,945)
Truck	Energy arbitrage	($90,330)	($51,256)	($116,419)	($86,111)
	Demand charge reduction	($80,728)	($78,384)	($87,813)	($77,177)
	Frequency regulation	($70,192)	$2,204	($180,233)	$158,549
	Spinning Reserve	($69,409)	($54,858)	($102,960)	($53,062)
Van	Energy arbitrage	($164,231)	($194,209)	($74,355)	$416
	Demand charge reduction	($81,719)	($81,445)	($77,342)	($76,278)
	Frequency regulation	($72,563)	($232,551)	($34,080)	$170,476
	Spinning Reserve	($70,225)	($105,224)	($58,448)	($47,673)

Conclusions

What cost factors do we need to consider?

- The financial success of a particular V2G application depends upon the price patterns in the different markets and the availability of the fleet.
- 23% of the applications studied have a positive benefit/cost ratio. Utilities can compensate fleet owners and still come out ahead.
- In most cases, the revenues from V2G applications could not overcome the basic hurdle costs.
- Buses had the highest number of viable applications due to having more ‘down time’.
- Frequency Regulation had the highest instances of a positive benefit/cost ratio.

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 (short or medium duration battery during outage?)

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Thank You

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