Vehicle-to-Grid Power Economics from a Fleet Perspective

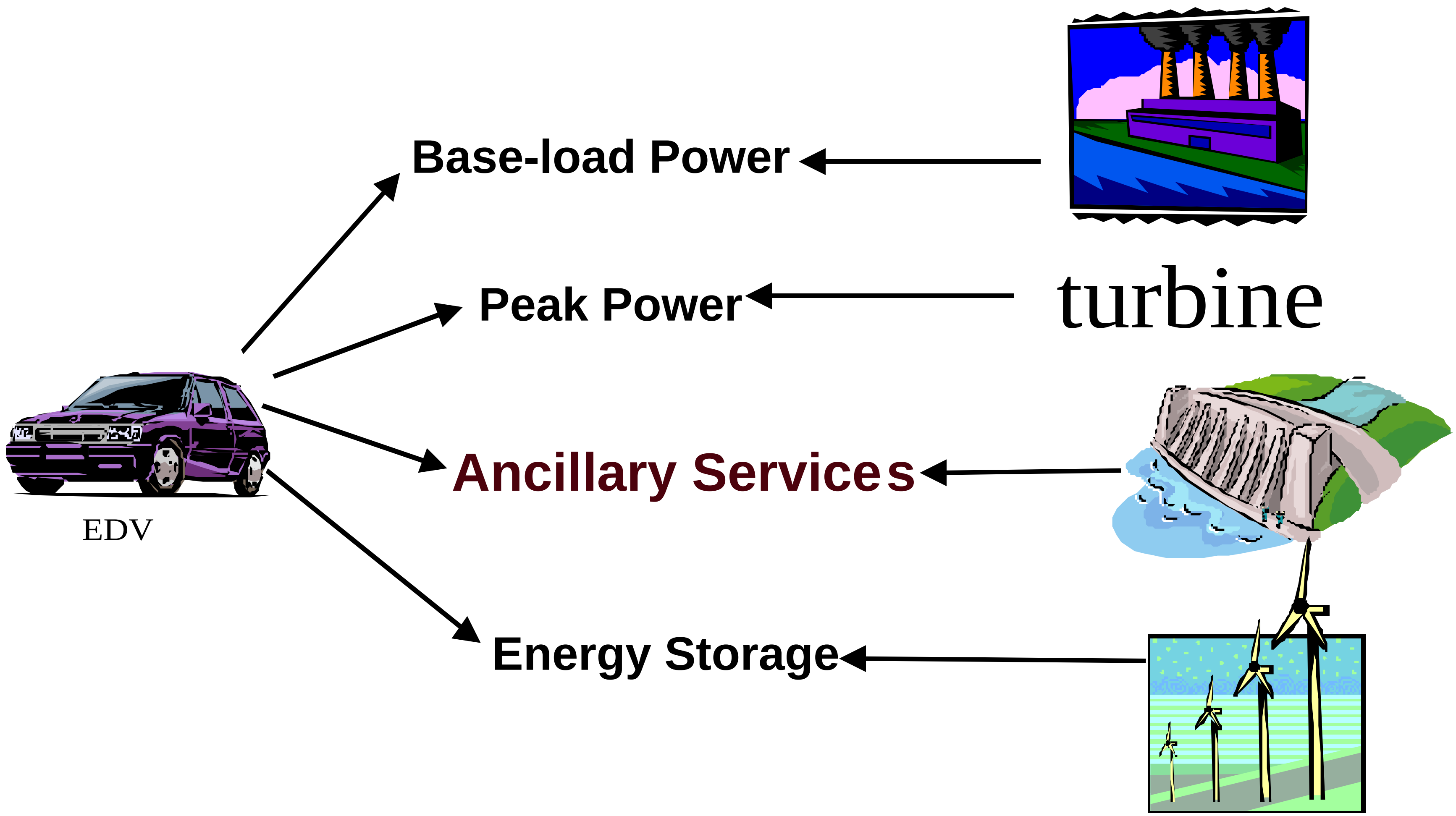
Jasna Tomic

Consultant, WestStart-Calstart
and
Fellow, University of Delaware

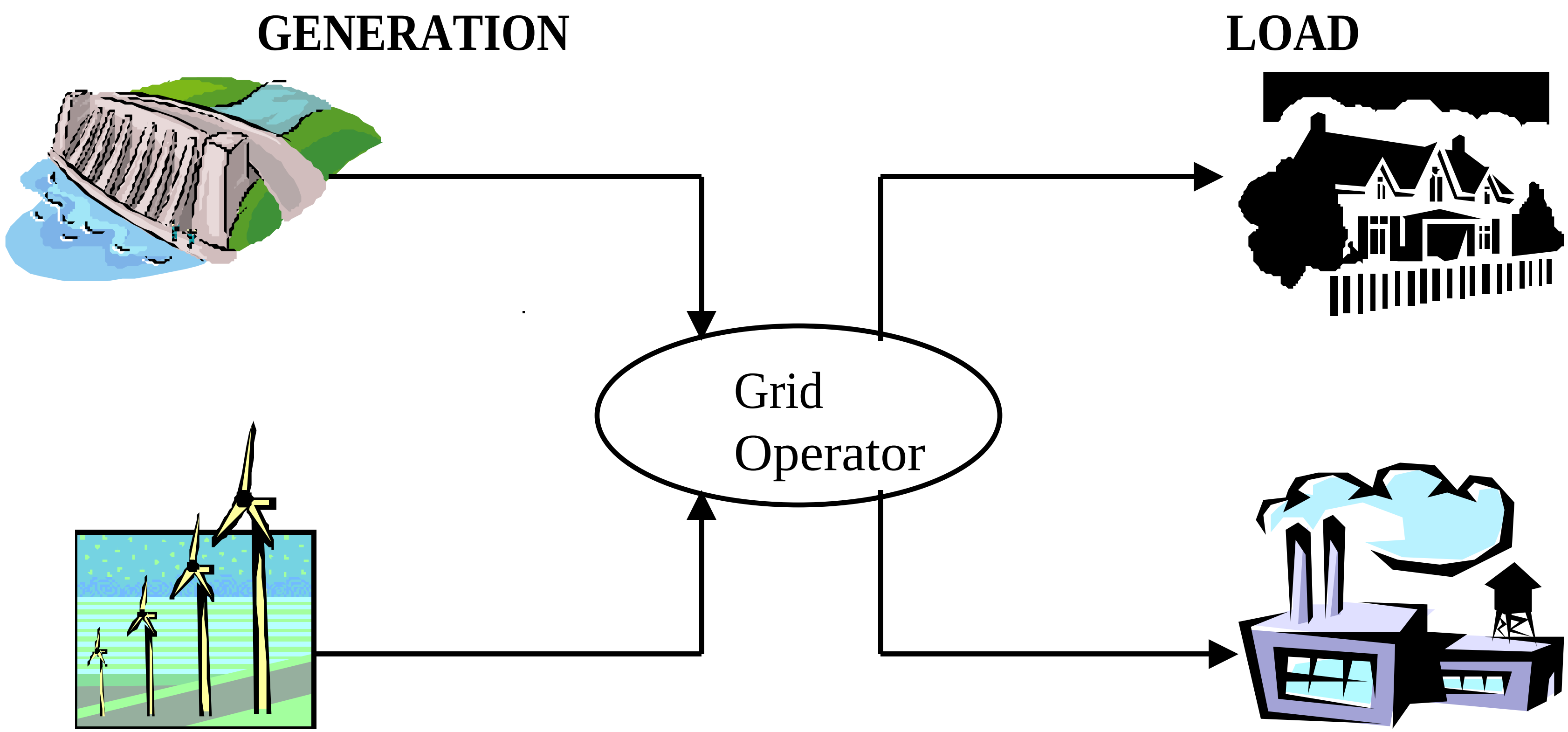
Outline

- V2G power for Ancillary Services
- What are Ancillary Services
- Cost and Revenue Calculations
- Sample results of 2 actual EDV fleet cases
- Potential for Seattle City Light Fleet
- Summary and Conclusions

USES FOR V2G POWER



Ancillary Services



- Maintain grid reliability
- Balance Supply and Demand
- Support transmission of electric power
- AS requirements 5-10% of the system load

Providing Ancillary Services

- Grid Operators require utilities to self-provide A/S
- Competitive A/S markets (ISO regions)
- In Pacific NW — Case 1
- Will draw from other market experiences

Ancillary Services

- Regulation: On-line generation synchronized to the grid to keep frequency and voltage steady. Energy is increased/decreased instantly (~ 2-3 min) via automatic generation control (AGC)

- Spinning Reserves: Additional generating capacity synchronized with system to respond ~10 min in case of failures.

- Payments consist of:

  Capacity price ($/MW-h) + Energy price ($/MWh)

Utility EDV Fleets for Regulation

UTILITY EDV FLEETS

- Utility EDV fleets already exist (battery EDV)
- Have a predictable schedule
- Utilities are familiar with A/S

REGULATION and SPINNING RESERVES

- High value energy markets
- Compatible with battery EDVs

Cost and Revenue Regulation

$$r_{Reg} = (p_{cont} \bullet P \bullet t_{plug}) + (p_{el} \bullet P \bullet t_{plug} \bullet R_{d\text{-}c})$$

$$c_{Reg} = (c_{en} \bullet P \bullet t_{plug} \bullet R_{d\text{-}c}) + c_{ac}$$

p_{cont}	contract price for regulation ($/kW-h)
P	power capacity (kW)
t_{plug}	availability of vehicles as fraction of day
$R_{d\text{-}c}$	energy dispatched as proportion of contracted power
p_{el}	market selling price of electricity ($/kWh)
c_{en}	cost to produce energy ($/kWh)
c_{ac}	annualized capital cost for V2G ($)

Cost and Revenue Spinning Reserves

$$r_{Spin} = (p_{cont} \bullet P \bullet t_{plug}) + (p_{el} \bullet P \bullet t_{plug})$$

$$c_{Spin} = (c_{en} \bullet P \bullet t_{plug}) + c_{ac}$$

p_{cont}	contract price for regulation ($/kW-h)
P	power capacity (kW)
t_{plug}	availability of vehicles as fraction of day
R_{d-c}	energy dispatched as proportion of contracted power
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Power Capacity

Spinning Reserves

$$P_{vehicle} = \frac{\left(E_s - \frac{d_d + d_{rb}}{\eta_{veh}} \right) \bullet \eta_{inv}}{t_{disp}}$$

Regulation

P_{line}= 15 kW
240 V, 50 amp

P_{line}— power capacity line (kW)
$P_{vehicle}$— power capacity vehicles (kW)
d_d – distance driven (mi)
d_{rb} – range buffer (mi)
η_{veh} — efficiency vehicle (mi/kWh)
η_{inv} — efficiency inverter
t_{disp} — time dispatched (h)

Energy Cost

$$c_{en} = \frac{c_{el}}{\eta_{GBG}} + c_d \qquad c_d = \frac{c_{bat}}{E_{LT}} = \frac{(E_s \bullet c_b) + (c_l \bullet t_l)}{L_C \bullet E_s \bullet DoD}$$

E_S – energy stored on-board (kWh)
c_b – cost of battery replacement ($/kWh)
c_l – cost of labor ($/h)
t_l – labor for battery replacement (h)
DoD – depth of discharge allowed
L_C – battery life in cycles
η_{GBG} — efficiency grid-battery-grid

Three Fleet Cases

- **New York Station Cars — 100 Th!nk City**

- **CA Utility Fleet — 252 RAV4 EDV**

- **Seattle City Light — 250 Toyota Scion EDV**

Fleet Case A

New York Station Cars

100

- For regulation services
- Upgrade cost for V2G included
- P_{line} = 6.2 kW
- t_{plug} = 23 h
- c_{el} = 0.05 $/kWh, c_{en} = 0.16 $/kWh

- NY ISO Regulation Capacity price

  p_{contr} = 27.5 $/MW-h (2003)

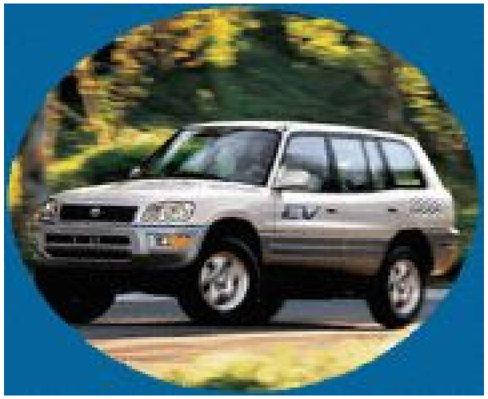
Calculated Profits

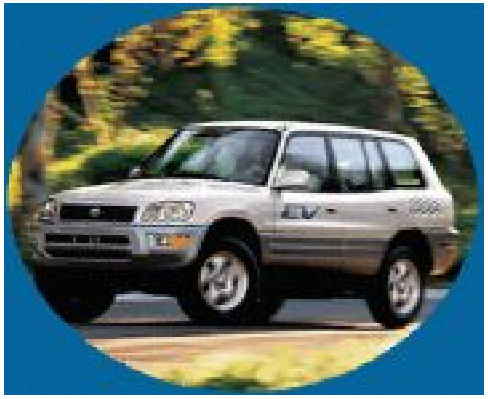
Case A

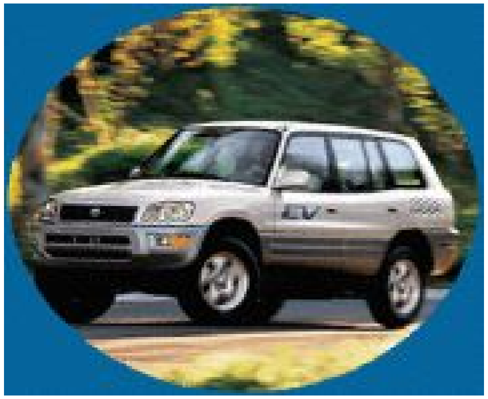
	In 2003		
FLEET POWER kW	Cost	Revenue	Net Profit
620	$ 99,500	$ 311,700	$ 212,200

Fleet Case B

Utility EDV Fleet







- For regulation services
- Upgrade costs for V2G included
- P_{line} = 15 kW
- t_{plug} = 17 h
- c_{el} = 0.05 $/kWh, c_{en} = 0.15 $/kWh

- CAISO Regulation Capacity price (2003)

  Reg_{up} p_{contr} = 19.5 $/MW-h

  Reg_{down} p_{contr} = 20.3 $/MW-h

Calculated Profits

Case B

	In 2003		
FLEET POWER kW	Cost	Revenue	Net Profit
@15 kW 3,780	$380,000	$1,039,000	$659,000

Seattle City Light Potential Fleet

250

- For spinning reserves
- V2G ready !
- $P_{veh/line}$ = 15 kW
- t_{plug} = 16 h
- c_{el} = 0.05 $/kWh, c_{en} = 0.22 $/kWh
- Spinning Reserves Capacity price

  p_{contr} = 7.39 $/MW-h (2005)

Spinning Reserves Potential Profits
Seattle City Light Fleet

	In 2003		
FLEET POWER kW	Cost	Revenue	Net Profit
@ 15 kW 3,750	$ 17,000	$ 165,500	$ 148,500

Regulation Profits Could be Higher

Markets	Spinning Reserves ($/MW-h)	Regulation ($/MW-h)
NY ISO	5.3	27.5
CA ISO	7.1	19.5
Pacific NW (Seattle)	7.4	?

Summary

3 fleet case analyses in different markets show significant economic potential for V2G providing A/S

- Fleet of 100 small EDVs in NY
  Revenue of $200,000
- Fleet of 250 EDVs in CA
- Revenue of $660,000
- Fleet of 250 EDVs in Seattle
  Revenue of $150,000

Important parameters:

- market value of A/S
- kW capacity of vehicles and electrical connections
- kWh capacity of vehicle battery

Conclusions for Fleets

- EDVs are promising sources of grid power
- V2G has high market value for regulation services and spinning reserves
- Utility fleets can be early adopters of V2G technology

Conclusions for V2G

- V2G provides a link between the electric power system and vehicle fleets
- V2G introduces the dual use of vehicles — for transportation and power generation
- Benefits — clean transportation (no CO_2) and clean source of electric power

Acknowledgments

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