Vehicle to Grid (V2G): Technologies, Applications, and Economics

Travis Bradford, Prometheus Institute

Solar 2007 (ASES)

Emerging Transportation Panel

July 11, 2007

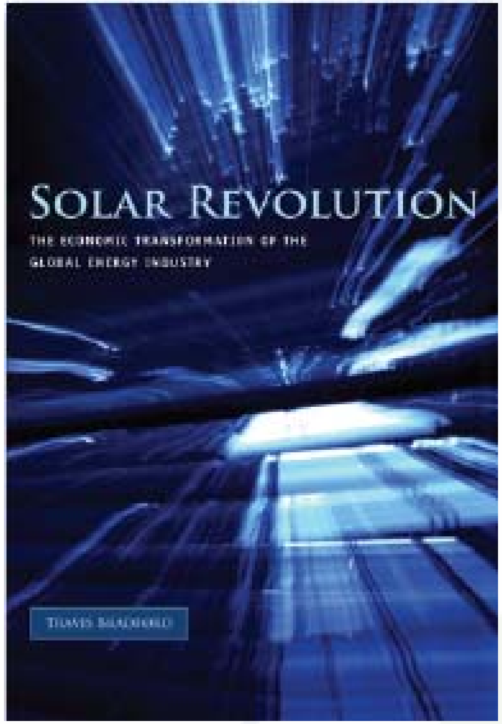
Meeting the Need for Information

The Prometheus Institute for Sustainable Development

Institute Research Products

Solar Revolution

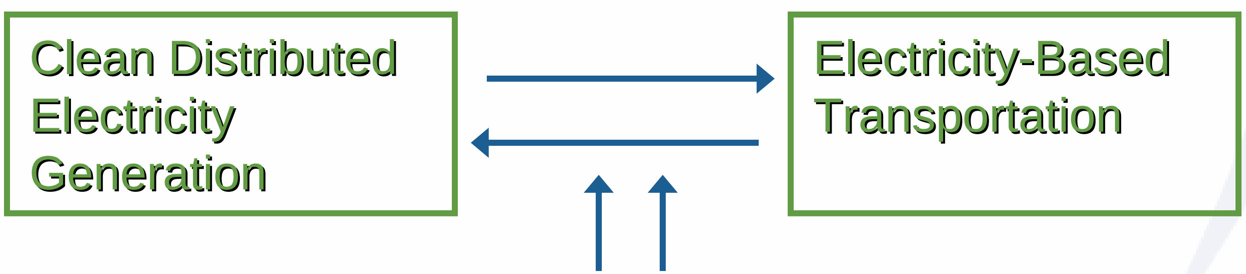
- From MIT Press – *September 2006*
- Based on Economic-only Projection Models
- Not only will we reach grid-parity, but permanently exceed it
- Disruptive Technological Transformation = HUGE BUSINESS OPPORTUNITY



V2G Technology and Mechanics

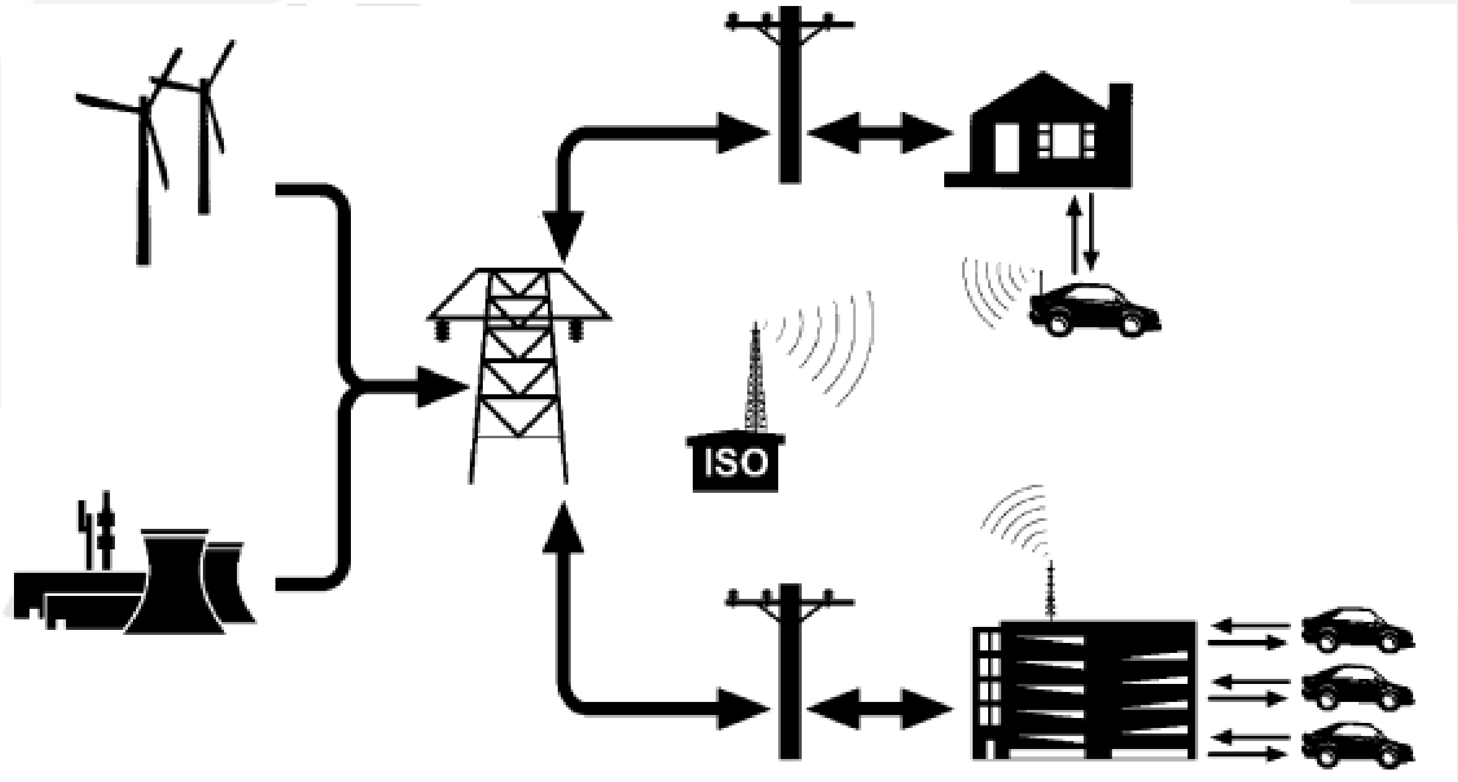
Why PHEVs and EVs?

- ***Electricity-Based Transportation***
  - Needs Clean Source of Fuel
- ***Distributed Renewables***
  - Needs Storage Solution for Intermittency



- **Can Solve Simultaneously with Plug-in Hybrid Electric Vehicles (PHEVs)**

Mechanics of Renewable V2G



Source: Tomic Kempton, Journal of Power Sources

Why V2G? - The Vision

- Grid-connected cars seamlessly integrated into the electric power system as both new load and new distributed energy resources.

- Renewables (beyond biofuels) can now serve as a source of energy for transportation enabling sustainable mobility.

- Hundreds of GWh of distributed storage serves to allow greater penetration of intermittent resources such as wind and solar onto the grid.

Prices and Economic Drivers

Solar/ Wind as a Fuel for Transportation

- Solar @ $0.20/ kWh is cost competitive at $3.00/gallon of gasoline even when using a conventional hybrid vehicle getting 50 miles/gallon for comparison purposes

- ***For 25 MPG Vehicle***

Electricity Cost		Fuel Equivalent
20 cents	➔	$1.45
10 cents	➔	$0.73
5 cents	➔	$0.36

- ***For 50 MPG Hybrid***

Electricity Cost		Fuel Equivalent
20 cents	➔	$2.90
10 cents	➔	$1.45
5 cents	➔	$0.73

Other Value Streams of V2G

- Grid Storage
  - Day/ Night Arbitrage
  - Ancillary Services
    - Frequency Regulation
    - Spinning Reserves

- Grid Peak Shaving

- Buffer Storage for PV Dispatchability

Frequency Regulation Economics

Calculation of revenue from a RAV4 EV providing regulation

Revenue parameters	Value	Comments
P (kW)	15	Use P_{line} because $P_{line} < P_{vehicle}$ (Table 1)
p_{cap} (\$/kW-h)	0.04	CAISO 2003 market prices [28]: \$ 0.02/kW-h for regulation up capacity plus the same for regulation down
p_{el} (\$/kWh)	0.10	Retail electricity price[a]
t_{plug} (h/year)	6570	Assume vehicle plugged in 18 h daily, so $t_{plug} = 18$ h/day × 365 day/year
R_{d-c}	0.10	See text with Eq. (1)
r (\$)	4928	Revenue, result by Eq. (8)

[a] Retail electric rates are used on the RAV4 for revenue and subsequently for cost, so the net effect is paying retail for round-trip electrical losses.

Calculation of cost of RAV4 EV providing regulation

Cost parameters	Value	Comments
c_{pe} (\$/kWh)	0.10	Assume purchase at retail electric cost
η_{sys} (%)	73	Round-trip electrical efficiency, grid–battery–grid
c_{bat} (\$)	9890	350 (\$/kWh)[a] × 27.4 \$/kWh + 10 h replacement labor × 30 (\$/h)
c_d (\$/kWh)	0.075	By Eq. (13)
c_{en} (\$/kWh)	0.21	Result by Eq. (11)
L_{ET} (kWh)	131520	This NiMH battery achieves 2000 cycles under deep cycle testing (EPRI 2003). By Eq. (11), $L_{ET} = 43840$ kWh; for shallow DoD, we assume 3 × L_{ET} (see text).
c_c (\$)	1900	On-board incremental costs \$ 400 [29]; wiring upgrade \$ 1500[b]
c_{ac} (\$/year)	304	Result by Eq. (16), assuming $d = 10\%$; $n = 10$ years, thus CRF = 0.16
c (\$)	2374	Cost, result by Eq. (10), assuming as before $P = 15$ kW and $t_{plug} = 6570$ h

[a] Assuming annual production of 100,000 batteries per year, EPRI estimates \$ 350/kWh [30].

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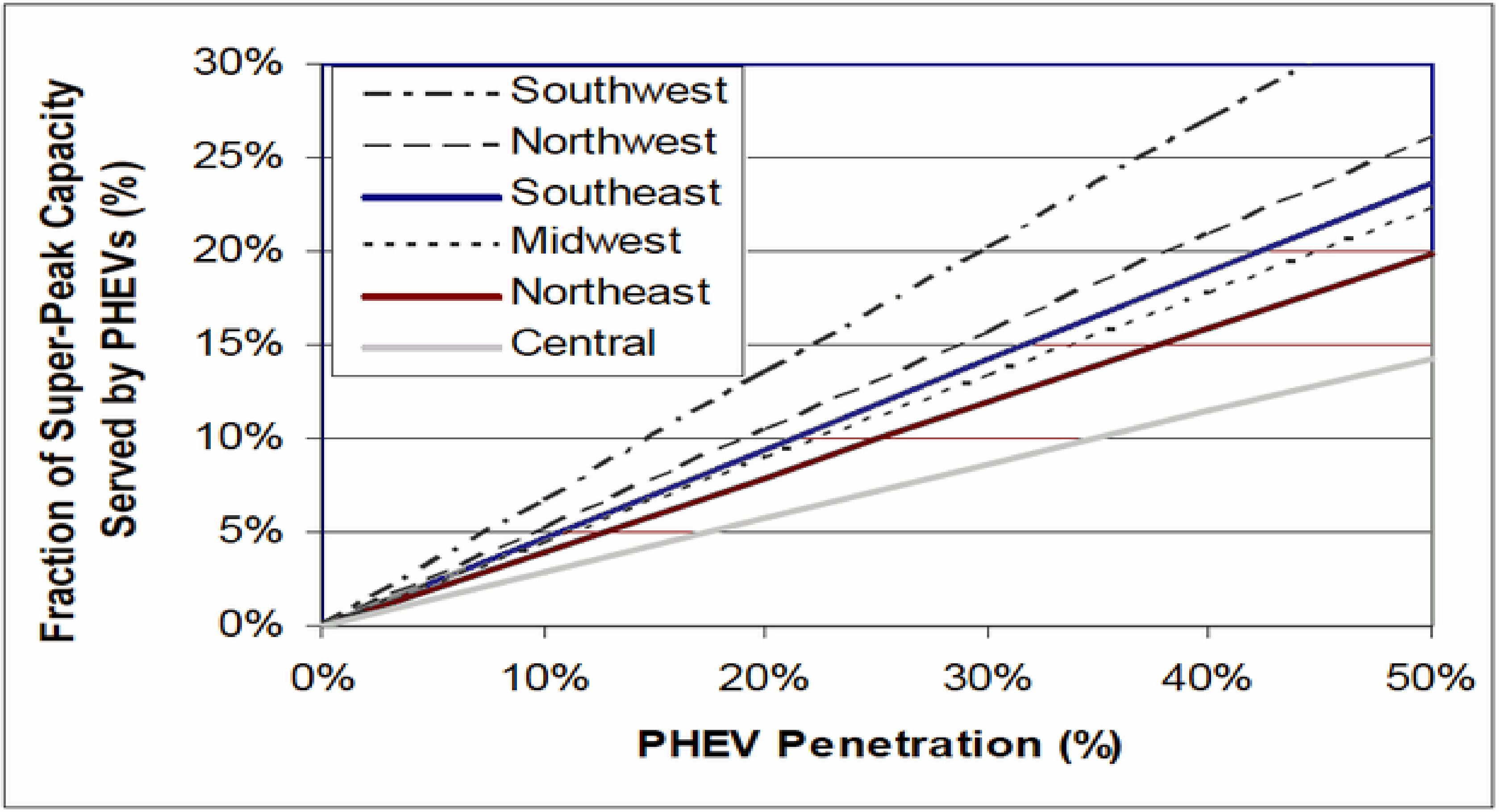
Peak Shaving through V2G



PHEV Storage Potential

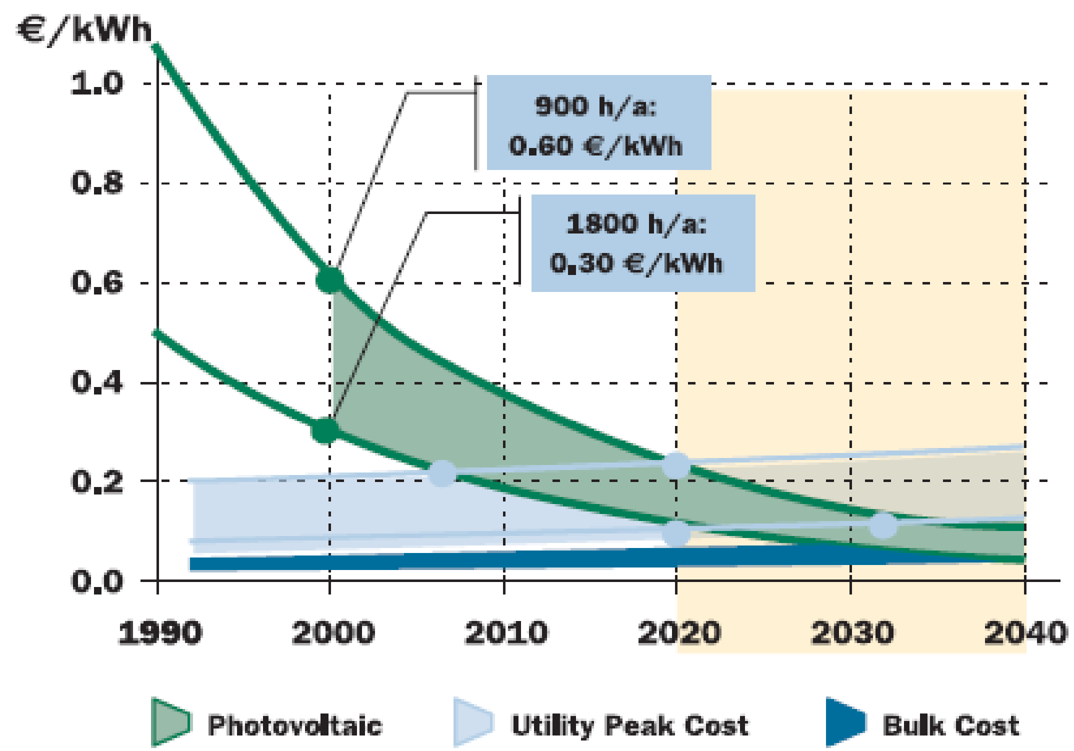
- Even with a small penetration of PHEVs - GWh of potential energy storage emerges.
- V2G value dictated by power rating of plug connection, also dictates recharge times
- Real time communication between vehicles and grid operators essential.
- Better performance data on emerging lithium ion battery technology (e.g., A123Systems, Altair Nano etc.)
  - Discharge cycles dictate economics

V2G Landscape in 2010

2010 Expectations

- DG System prices cut in half by 2010
  - Delivered PV electricity prices
    - < 10 cents/ kWh in best locations
    - < 5 cents/ kWh after subsidy
- Traditional Fuel Prices?? Electricity Rates??
  - Most important are those for ancillary services (spinning reserves and frequency regulation)
- Policy changes are wildcard
  - Direct subsidies will have largest price impact

EPIA Scenario - Europe



__Source:__
European Commission/ EPIA

- **By 2020, 20-30% of European energy could be met cost-effectively with solar energy.**
  - **Versus forecast market penetration of 1.1%**

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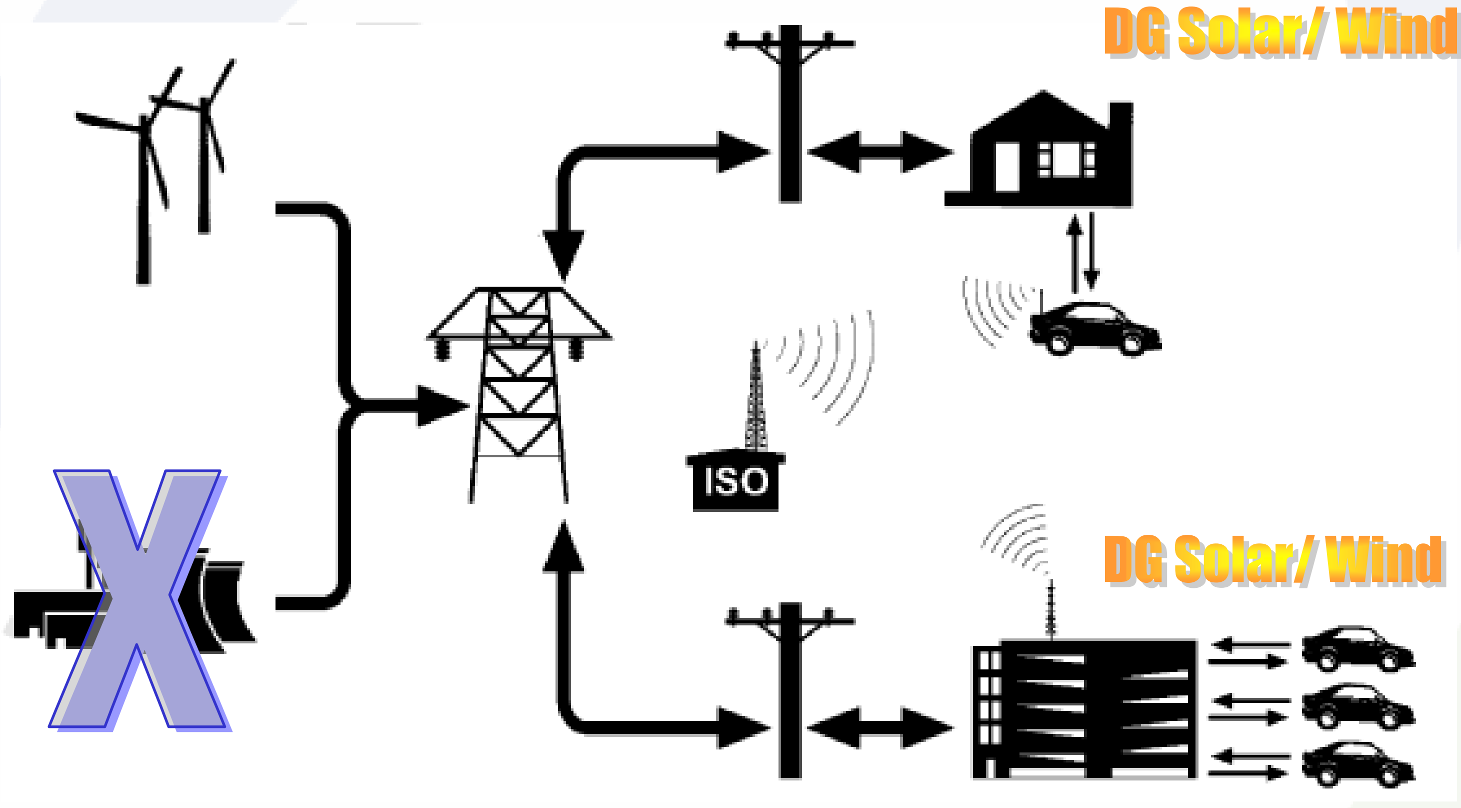

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Thank You and Good Luck