Vehicle to Grid Power as Wind Storage

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University of Delaware
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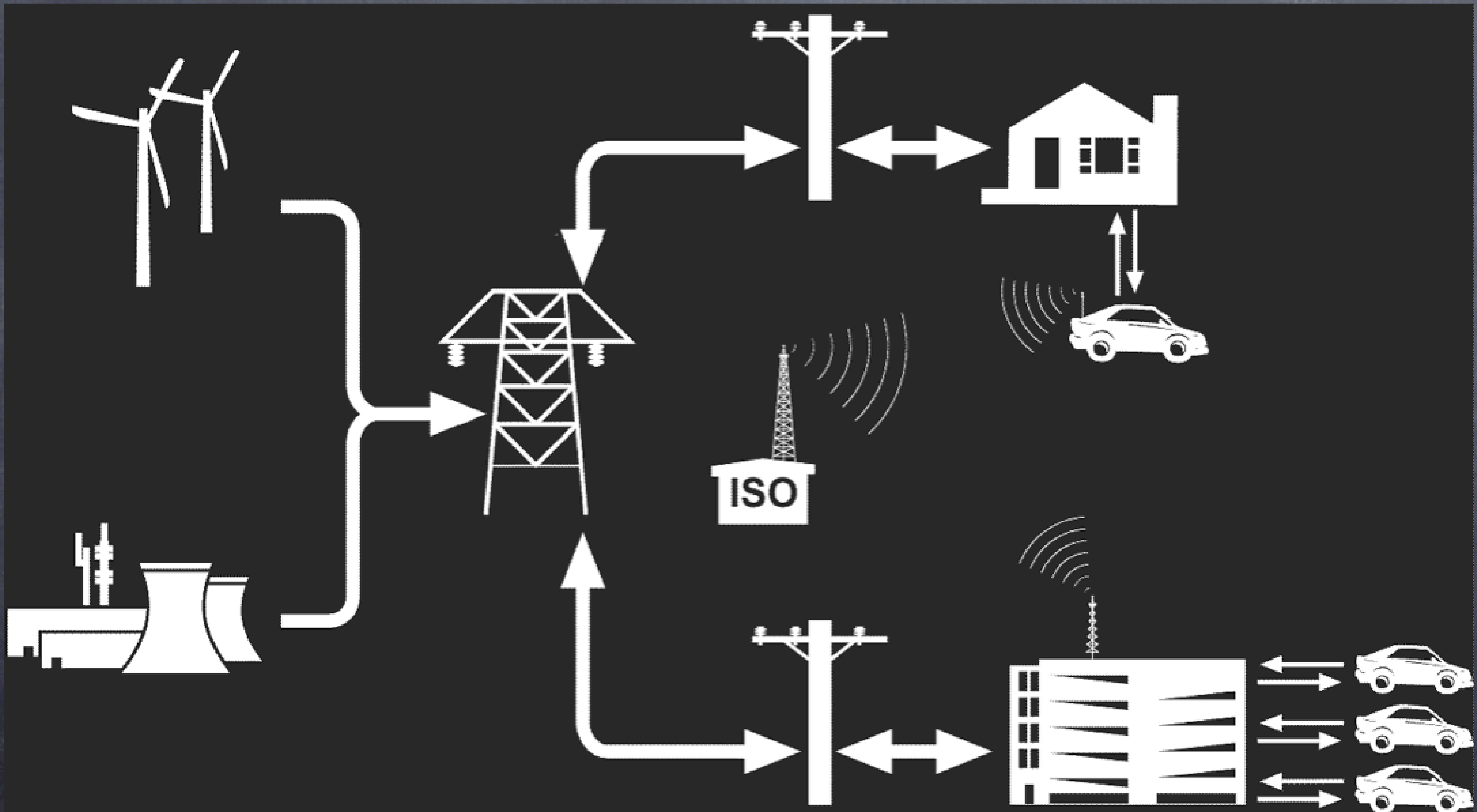
Outline

- V2G terms and concept
- Three types of vehicles for V2G
- Selling to existing electric markets (now)
- Backing up 50% wind power
- A transition strategy
- Possible policies and a vision ...

Terminology

- V2G: Flow of power from Vehicle to Grid
- Electric Drive Vehicle for V2G, one of:
  - Battery (e.g. 30 kWh Li-Ion)
  - Fuel Cell (e.g. 3 kg H_2)
  - Plug-in Hybrid (e.g. 50 km local range on batteries, long distance on fuel)
- Ancillary services: Short-term power needed to balance generation and load

Vehicle to Grid



Arrows indicate direction of power flow

How Much Power?

	Australia	UK	USA
Electric Capacity (GW)	45	80	811
Light vehicles (10^6)	13	22	176
Vehicle GW (if electric drive @ 15 kW each)	195	330	2,640

... 4x more power in cars

Revolution in Battery Technology

- Today's automotive starter batteries: Lead-acid
- RAV4 EV (and Toyota Prius hybrid battery): Nickel Metal-hydride
- New batteries based on Lithium, Li-ion or Li-polymer: 5x lighter for same energy!
- These advances make possible large battery storage for vehicles.

Which atom would you schlep?

PERIODIC TABLE OF THE ELEMENTS

Columbia Analytical Services INC.

An Employee - Owned Company

800-695-7222
www.caslab.com

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H 1.0																	2 He 4.0
3 Li 6.9	4 Be 9.0											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
11 Na 23.0	12 Mg 24.3											13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9
19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.8	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.7	32 Ge 72.6	33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8
37 Rb 85.5	38 Sr 87.6	39 Y 88.9	40 Zr 91.2	41 Nb 92.9	42 Mo 95.9	43 Tc (97.9)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209.0)	85 At (210.0)	86 Rn (222.0)
87 Fr (223.0)	88 Ra (226.0)	89 Ac (227.0)															

58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (144.9)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.2	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
90 Th 232.0	91 Pa (231.0)	92 U (238.0)	93 Np (237.0)	94 Pu (244.1)	95 Am (243.1)	96 Cm (247.1)	97 Bk (247.1)	98 Cf (251.1)	99 Es (252.1)	100 Fm (257.1)	101 Md (258.1)	102 No (259.1)	103 Lr (262.1)

Priority Pollutant   TCLP Metals   Appendix II and IX

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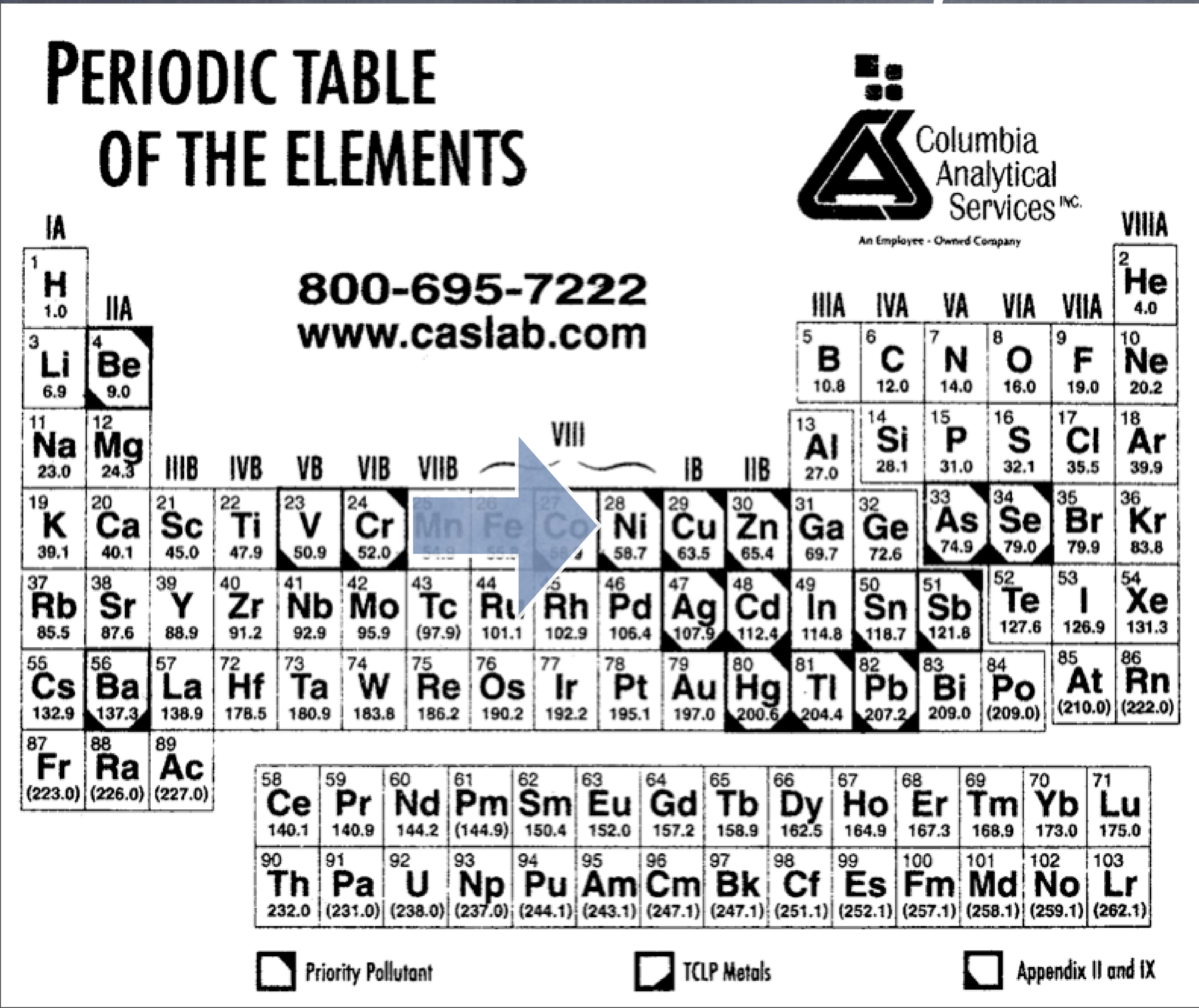
Priority Pollutant · TCLP Metals · Appendix II and IX

Pb=207.2

Which atom would you schlep?



Pb=207.2

Ni=58.9

Which atom would you schlep?

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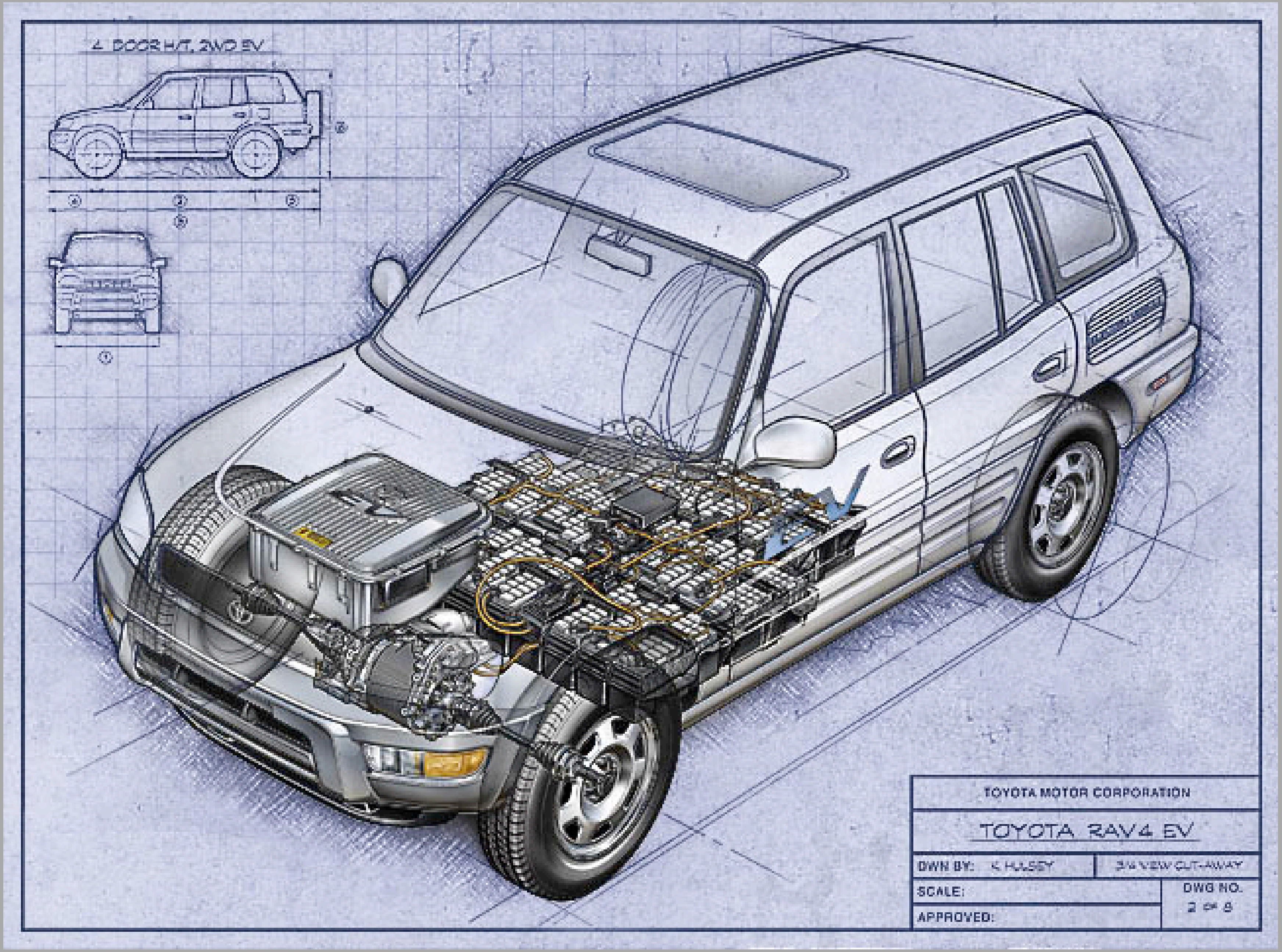
Priority Pollutant · TCLP Metals · Appendix II and IX

Pb=207.2
Ni=58.9
Li=6.9

So, what can you do with these batteries?

Electric-drive vehicles, from global car companies (OEMs) and smaller shops

Battery Vehicle: Toyota RAV4 EV



Toyota Scion conversion by AC Propulsion

	Base	Premium
AC Induction Motor	75 kW	130 kW
Vehicle Weight	2570 lb	2850 lb
Range	80-110 mi	150-210 mi
Acceleration 0-60	< 9 sec	< 7 sec
Top Speed	82 mph	90 mph
Battery Type	Li Ion	
Battery capacity	20 kWh	35 kWh
Charging	Plug-in-anywhere Fast charge in 2 hrs V2G capable	
Features	A/C, full power	

AC PROPULSION

"We plan to manufacture safety-certified electric vehicle conversions and sell them to retail and fleet customers. The conversions will be based on the Scion xA and xB, the new sport compact vehicles built by Toyota...

The base model will outperform the RAV4 EV and is expected to sell for about the same price. Currently in production at about 1/month.
www.acpropulsion.com

Scion xB

Compact Utility Vehicle

Spacious, comfortable, unique, sporty, versatile

Scion xA

Compact Sport Wagon

Fun, useful, nimble, roomy, efficient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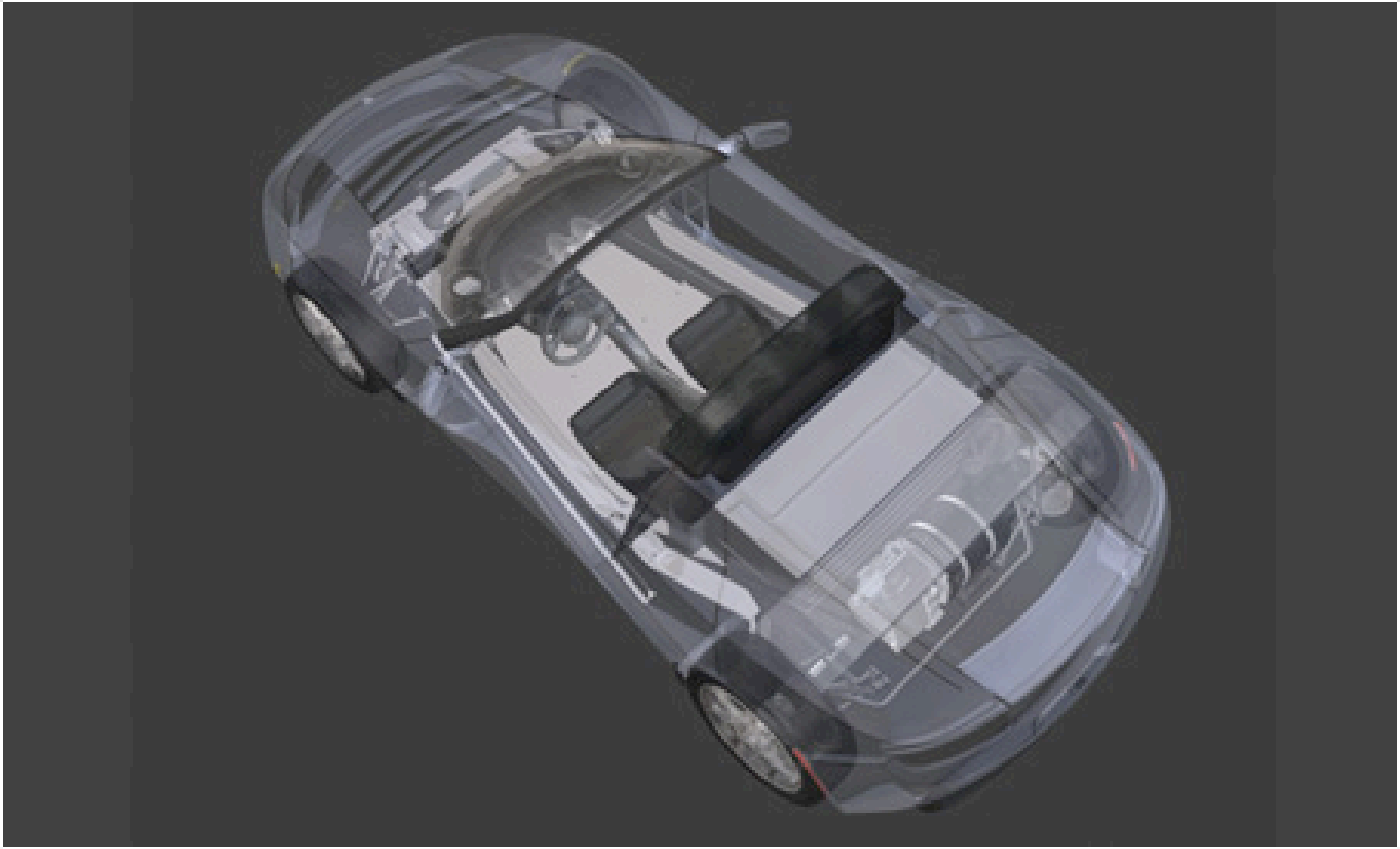
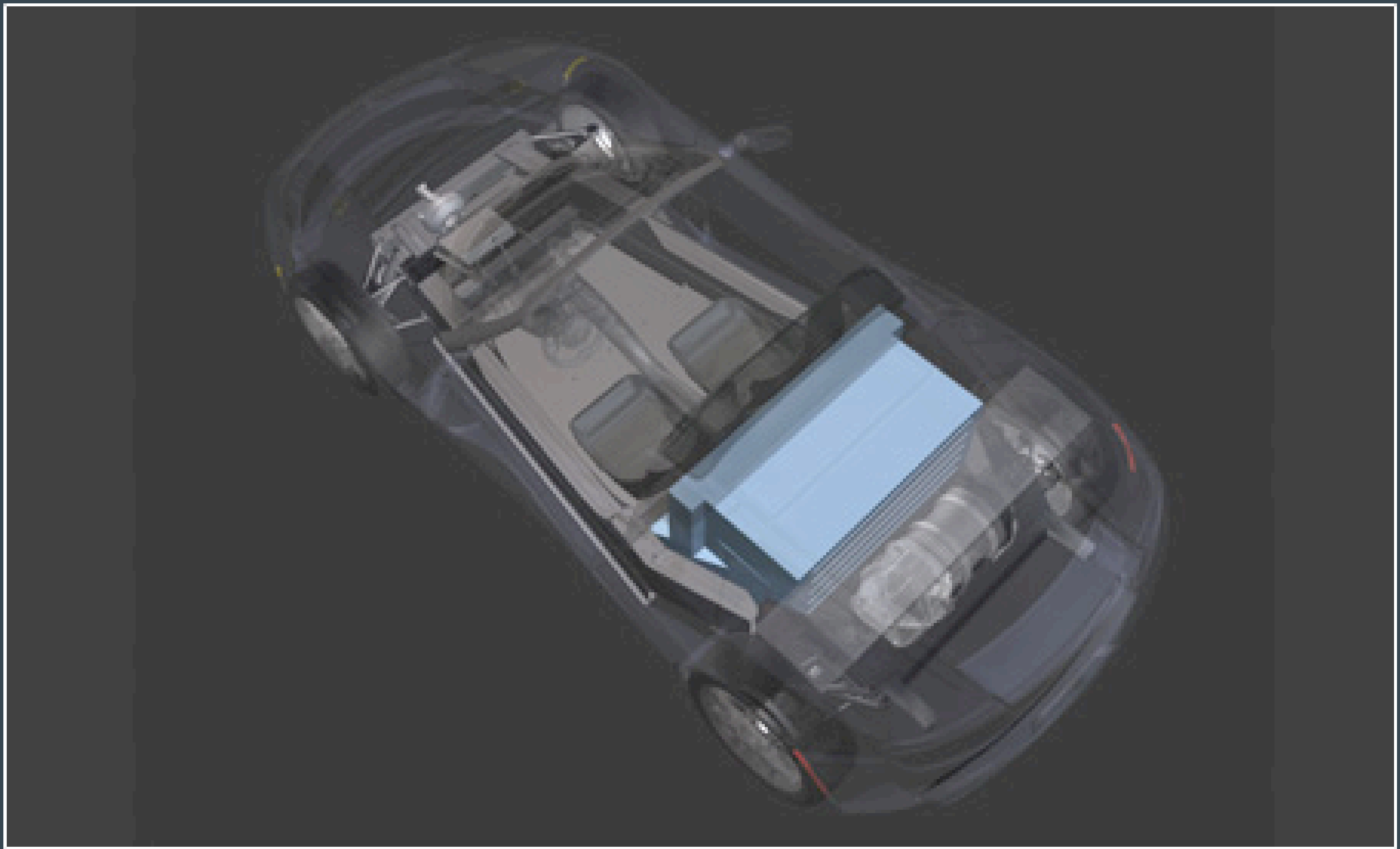
MORE
BUY
Burn rubber, not gasoline.
Introducing the Tesla Roadster:
• 100% electric
• 0 to 60 in about 4 seconds
• 135 mpg equivalent
• 250 miles per charge
• about 1¢ per mile*
see more images & colors

■ Overview ■ ESS ■ Chassis ■ Motor ■ PEM

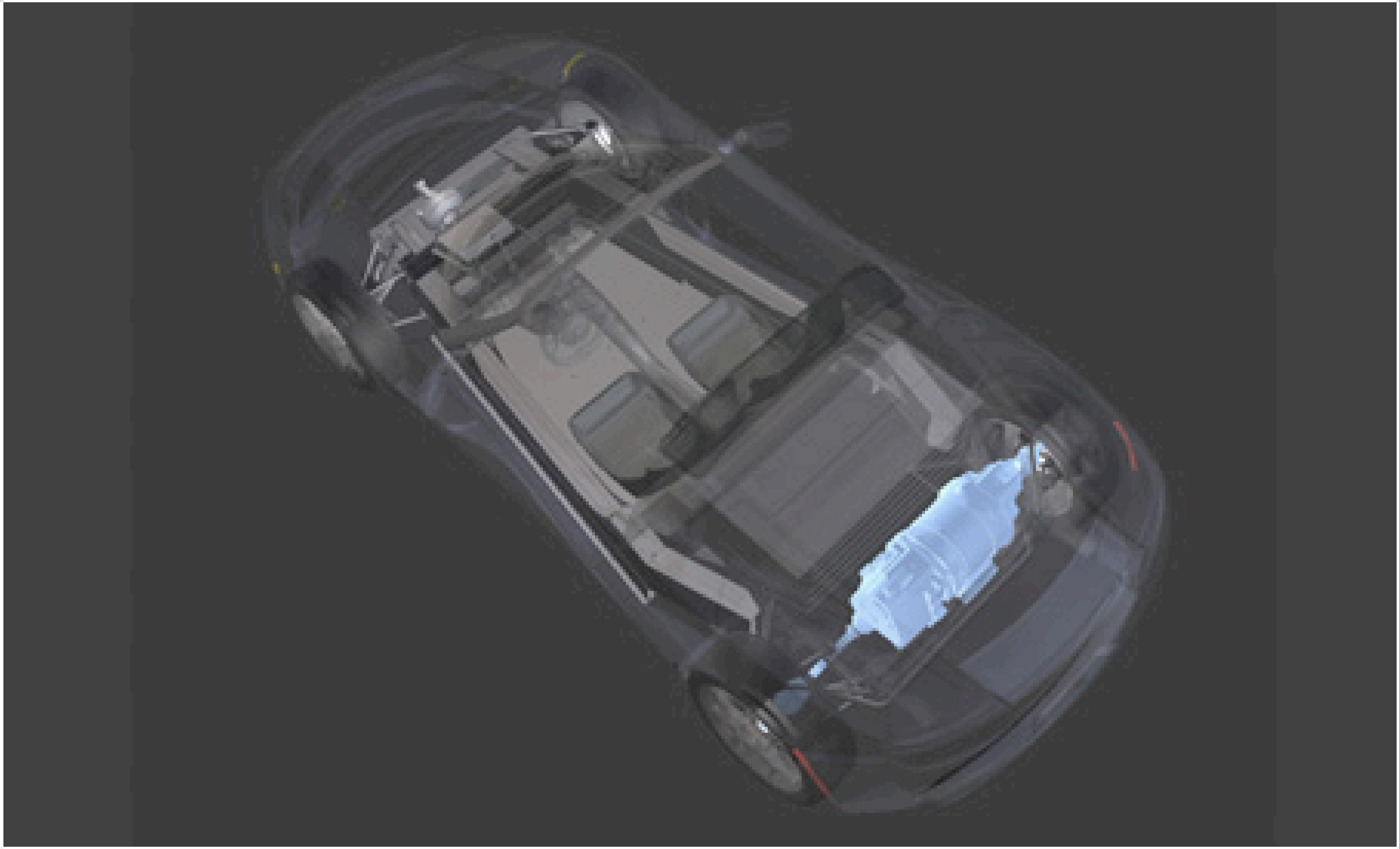


Our minimalist design philosophy encourages multiple uses for each component and fanatical attention to weight, which helps to maximize energy use, efficiency, and performance.

■ Overview ■ ESS ■ Chassis ■ Motor ■ PEM



The Energy Storage System (ESS) – comprised of several thousand consumer-grade lithium-ion cells – is the heart of the Tesla Roadster. Battery conditions are continuously monitored and fed to the Vehicle Management System (VMS), allowing for precise tracking of battery history, performance, and available energy.



The Tesla motor weighs less than 70 pounds yet produces horsepower equivalent to a much heavier internal combustion engine. And unlike a gasoline engine, Tesla's electric motor doesn't sacrifice mileage for performance.

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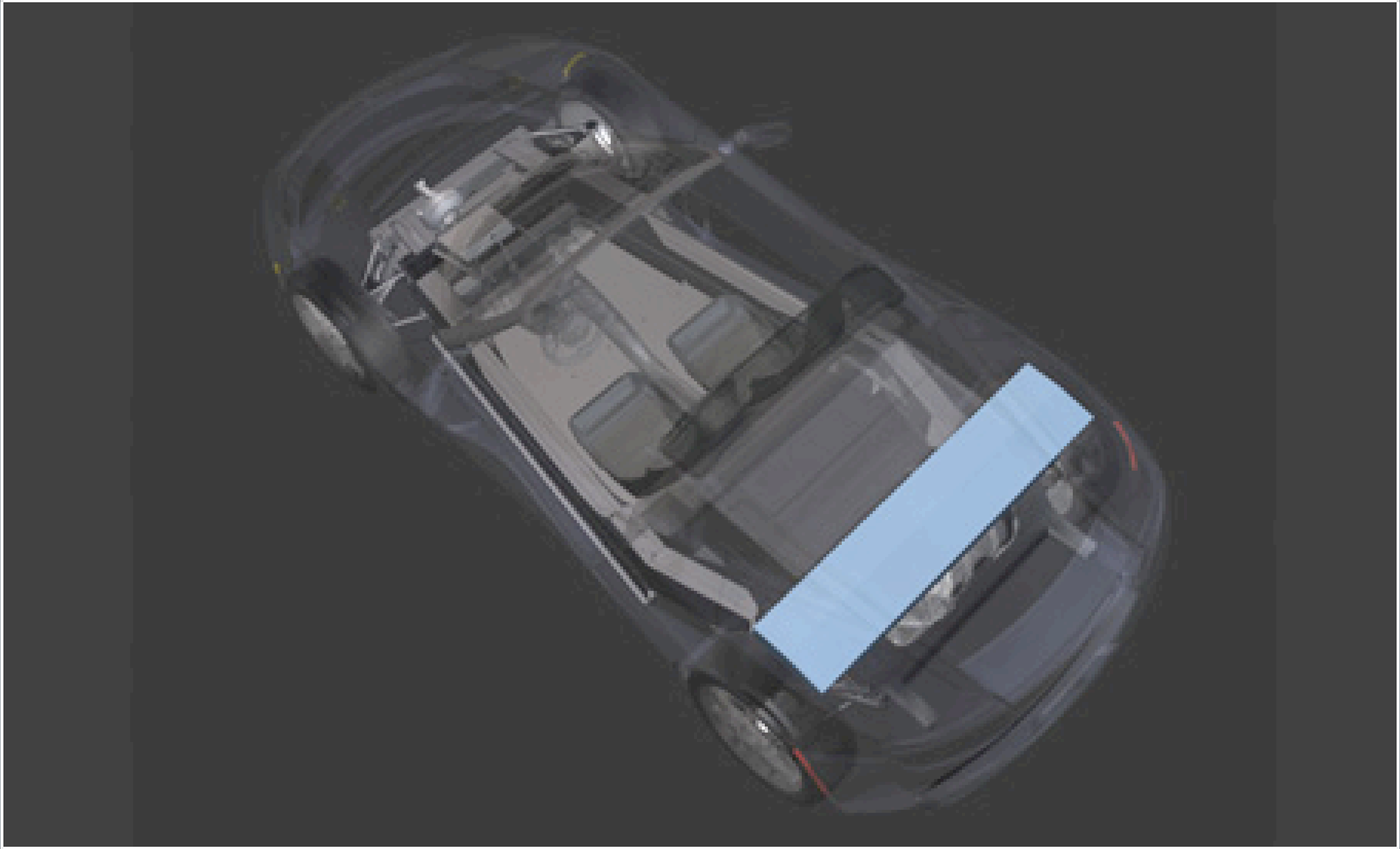
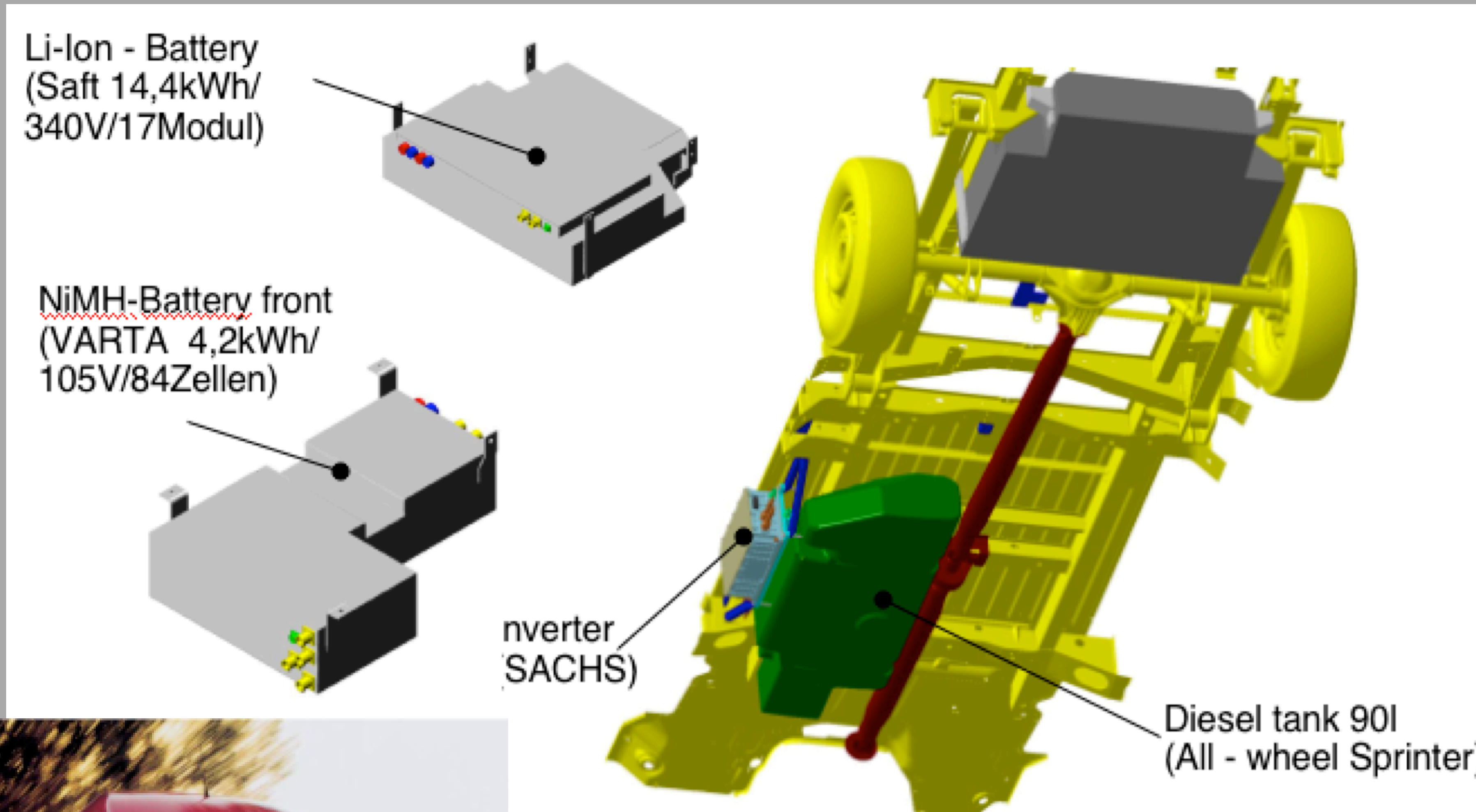


The Power Electronics Module (PEM) contains high voltage electronics that control the motor and allow for integrated battery charging. The motor and PEM have been designed as a tightly integrated system that delivers up to 185 kW of motor output.

Plug-in Hybrid Vehicle: DaimlerChrysler Sprinter



4th vehicle

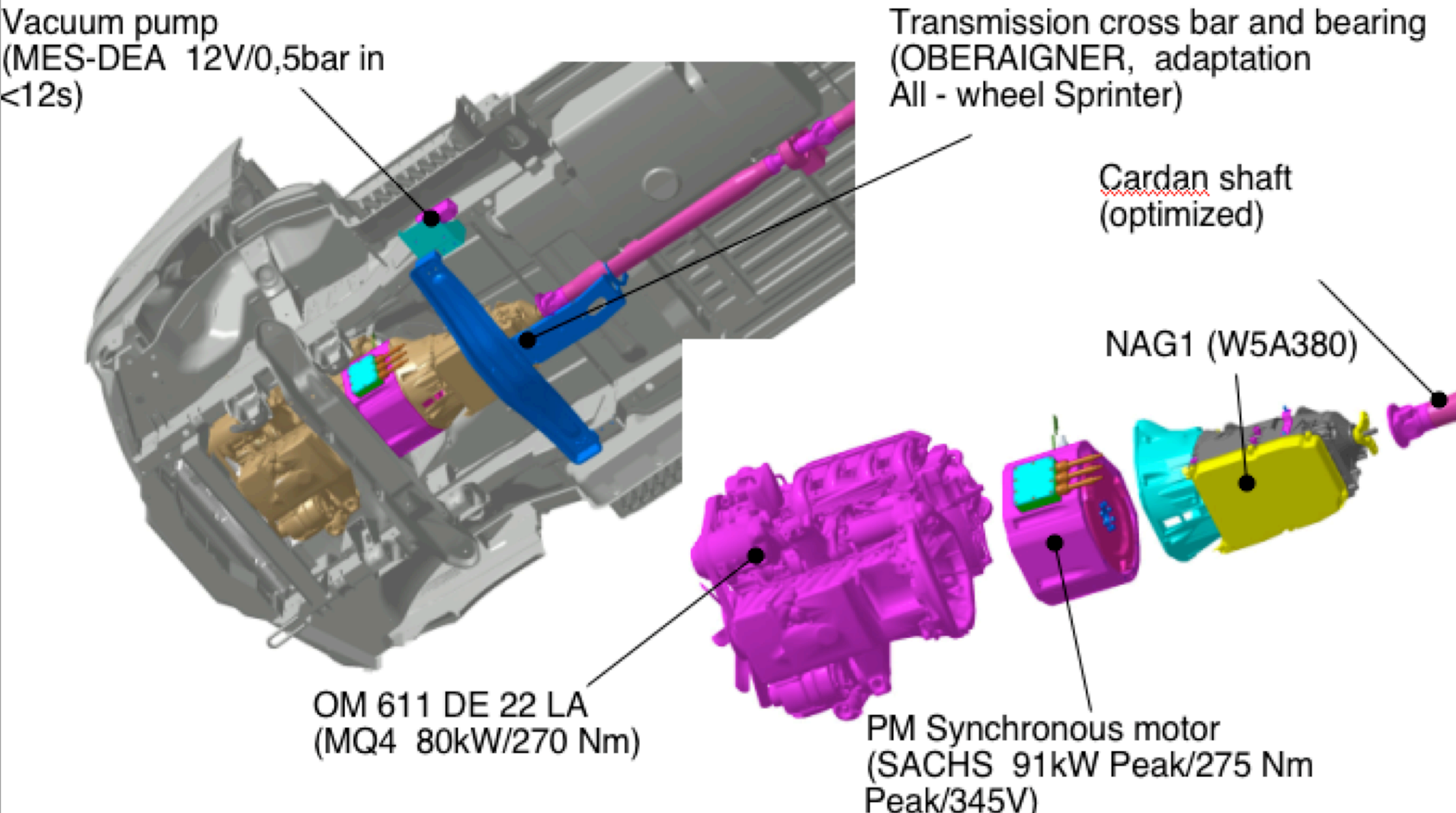
- Gas PHEV
- 3,88t/3550 mm
- Li Ion battery

Plug-in Hybrid Vehicle: DaimlerChrysler Sprinter (cont.)

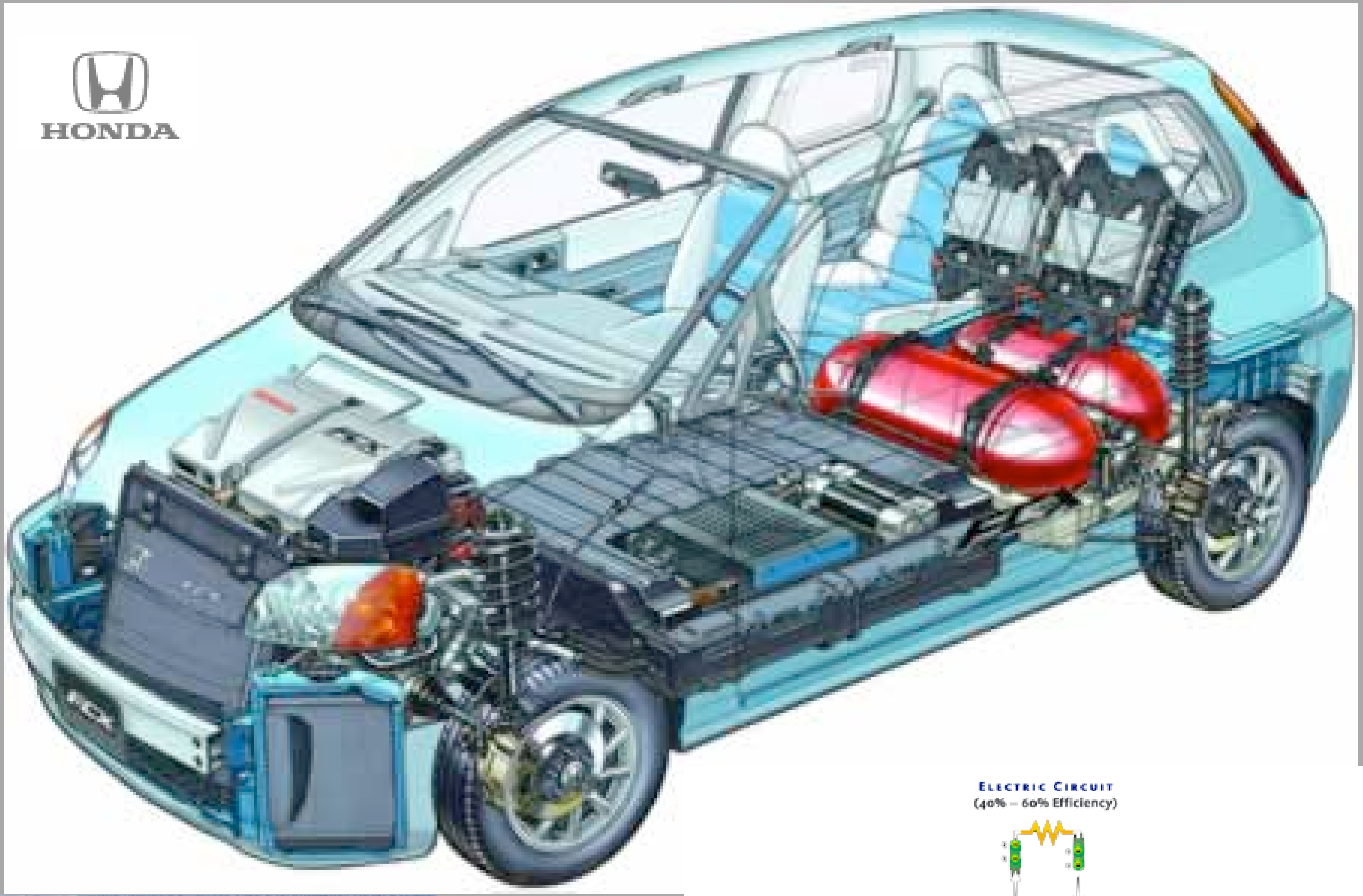
Hybrid Sprinter Phase II

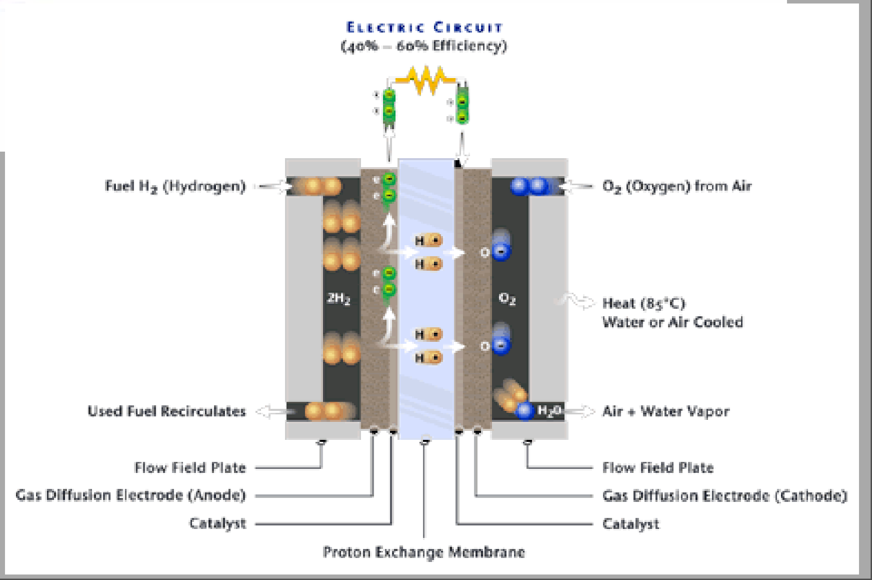
DAIMLERCHRYSLER

- Traction system (engine, clutch, transmission) –



Fuel Cell Vehicle: Honda FCX





But... no OEMs currently offer inexpensive EDVs, and only smaller companies have V2G built in.

What markets could introduce V2G, and push down production cost for later use as wind backup?

Power markets

- Baseload: Steady, round-the clock supply.
- Peak load: 2-5 hours per day, on extreme weather days (sold on "energy market").
- Ancillary services, "regulation", "operating reserves", "contingency" etc.
- Backup for wind/solar (not a separate market, but important re: policy).

Ancillary Service -- Regulation

- Very fast response, short duration
- Batteries can serve this market better (faster response) than current electric generators
- About \$10 - \$15 B/year US market
- Markets in most OECD countries

Available vehicle power

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

$P_{vehicle}$ available power from V2G (kW)

E_s stored energy (kWh)

d_d distance driven since fill up (km or mi)

d_{rb} range buffer required by driver (km or mi)

n_{veh} vehicle efficiency (km/kWh or mi/kWh)

n_{inv} efficiency of DC to AC inverter (dimensionless)

t_{disp} time the energy is dispatched (hours)

Cost

$$c_{en} = \frac{c_{pe}}{\eta_{conv}} + c_d$$

c_{en} $/kWh to produce electricity (or £, € etc)

c_{pe} purchased energy cost ($/fuel unit)

n_{conv} conversion efficiency (kWh/fuel unit)

c_d cost of equipment degradation (wear) due to the extra use for V2G, in $/kWh of delivered electricity

Annual net revenue

(Net per car†, based on CA elec. markets)

	AU$*	£*	$US
Battery/regulation	3350	1360	2554
FC/Contingency	286	116	218
FC/Peak	380	154	290

* Currency change from $US, 1/05.

† Net after all V2G costs; based on mass production vehicle cost.

Saturating high-value markets

	Australia	USA
Electric Capacity (GW)	45	811
V2G vehicles for A/S (10^3)	40 (0.3%)*	2640 (1.5%)
Annual revenue (10^6)	AU$ 28*	US$ 2600

* FCAS only, reactive power may be 2x more.

Conclusions on (current) markets

- Opportunity for revenue to V2G battery or hybrid/battery vehicles
- This revenue could help start the V2G industry
- High-value FCAS markets saturated by 0.3% of fleet, 40,000 vehicles
- What about wind backup?

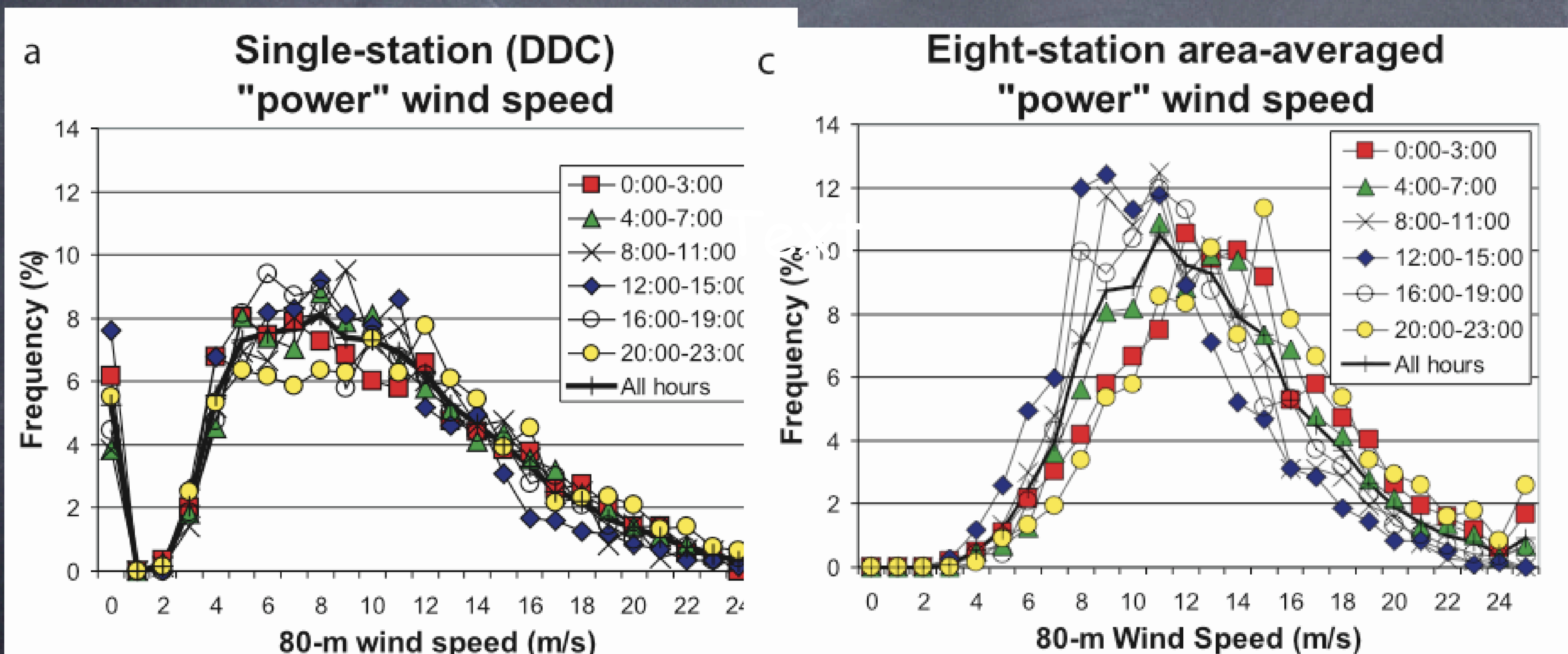
Wind power

- Cheap and abundant
- Large fluctuations, uncorrelated with load, many zero hours
- Conventional view: Wind limited to 20% of generation mix
- Our evidence: With V2G and dispersed windfarms, >50% can be met at low cost

Solving the wind-stability problem

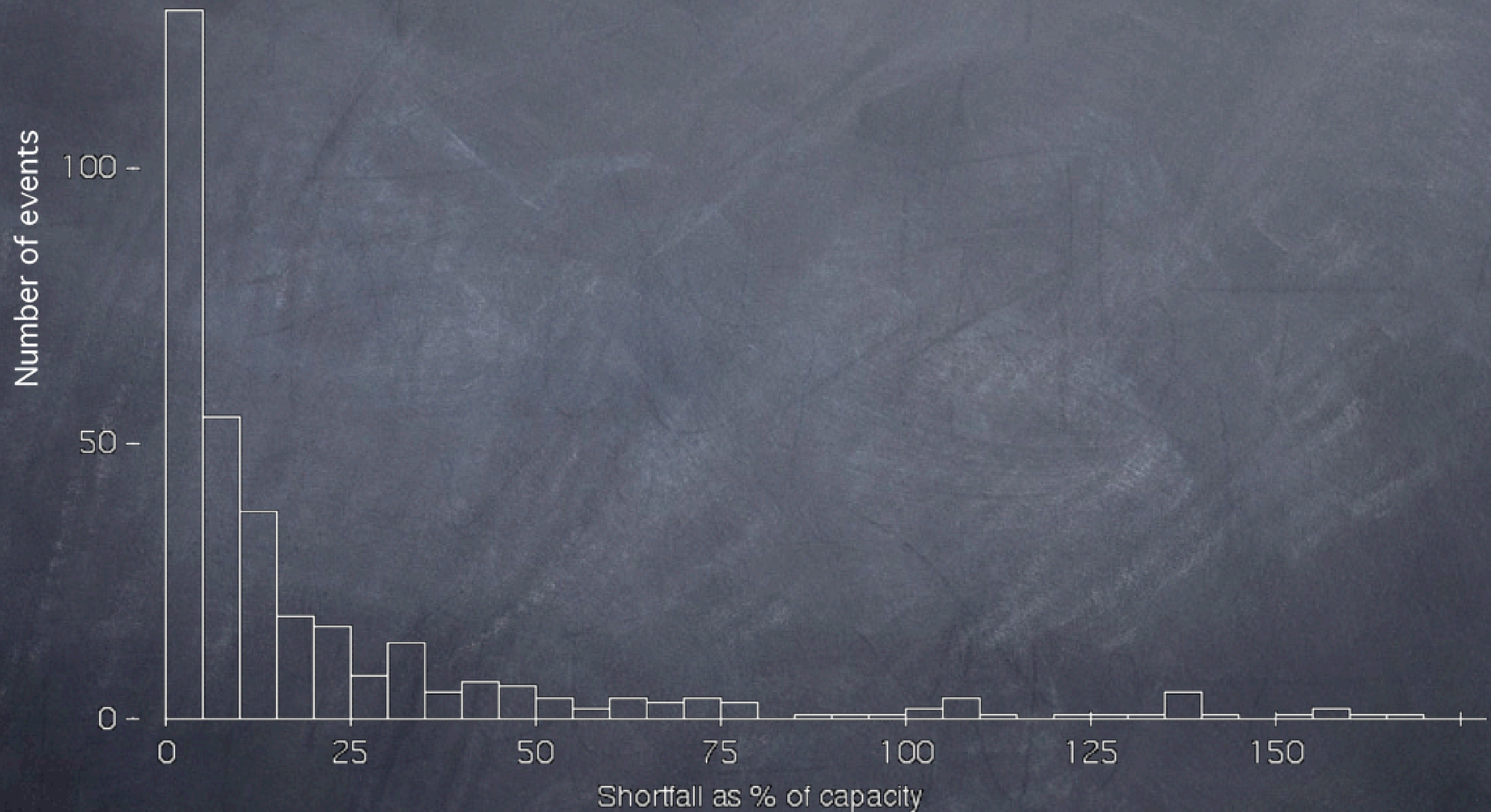
- Interconnected arrays 600-1000 km distant yield normal, not Rayleigh, distribution, thus, less storage needed (Archer and Jacobson 2003)
- V2G at 5 - 40% of the fleet covers remaining gaps, yielding firm wind capacity (Kempton and Tomic, 2005)

Distributed & Connected Wind Sites Reduce Storage Need



from: Archer and Jacobson, 2003

V2G meets remaining storage needs of wind



from: Kempton and Tomic, 2005 (preprint)

Incremental costs

- Approx $500 on-board for 50 Amp @ 240, 12 kW, 7 kWh spin, OR
- Approx $500 on-board + $1500 home re-wiring for 15 kW, and 7 kWh for spin
- Power cost $500/12 kW = $42/kW
- Storage cost $500/7 kWh = $71/kWh

Transition path

1. Build and test prototypes (done)
2. Strategically picked demonstration sites
3. First 3, then 10, then 300 vehicles, selling A/S regulation to PJM
4. OEMs commitment; production 100,000+ per year, LC cost parity with petrol
5. Replace large fractions (e.g. half) of ICE fleet and of fossil electric generation

Possible Policies

Example policies

- Early: Subsidize demonstration projects
- Create markets for ZEVs and/or V2G
- Fleet of state or department specified to be V2G-capable

Example Policies (cont.)

- Incentives for investment for in-country manufacturing
- Local policies, e.g.: Parking in prime areas limited to, or incentivised for, V2G.
- Announce purchase incentives/requirements for V2G-capable vehicles
- For wind, upgrade transmission between sites

Vision

- One-half of electric energy from wind
- One-half vehicle fleet is electric drive: battery plus hybrid (less likely fuel cell)
- Electricity supply is steady and highly reliable; vehicles without petrol
- CO2-free electricity with CO2-free transportation: an unexpected and dramatic synergy