

Electric-Drive Vehicles - A Technology Update

(including recent experiences from North America)



Andrew Simpson PhD

2 March 2009

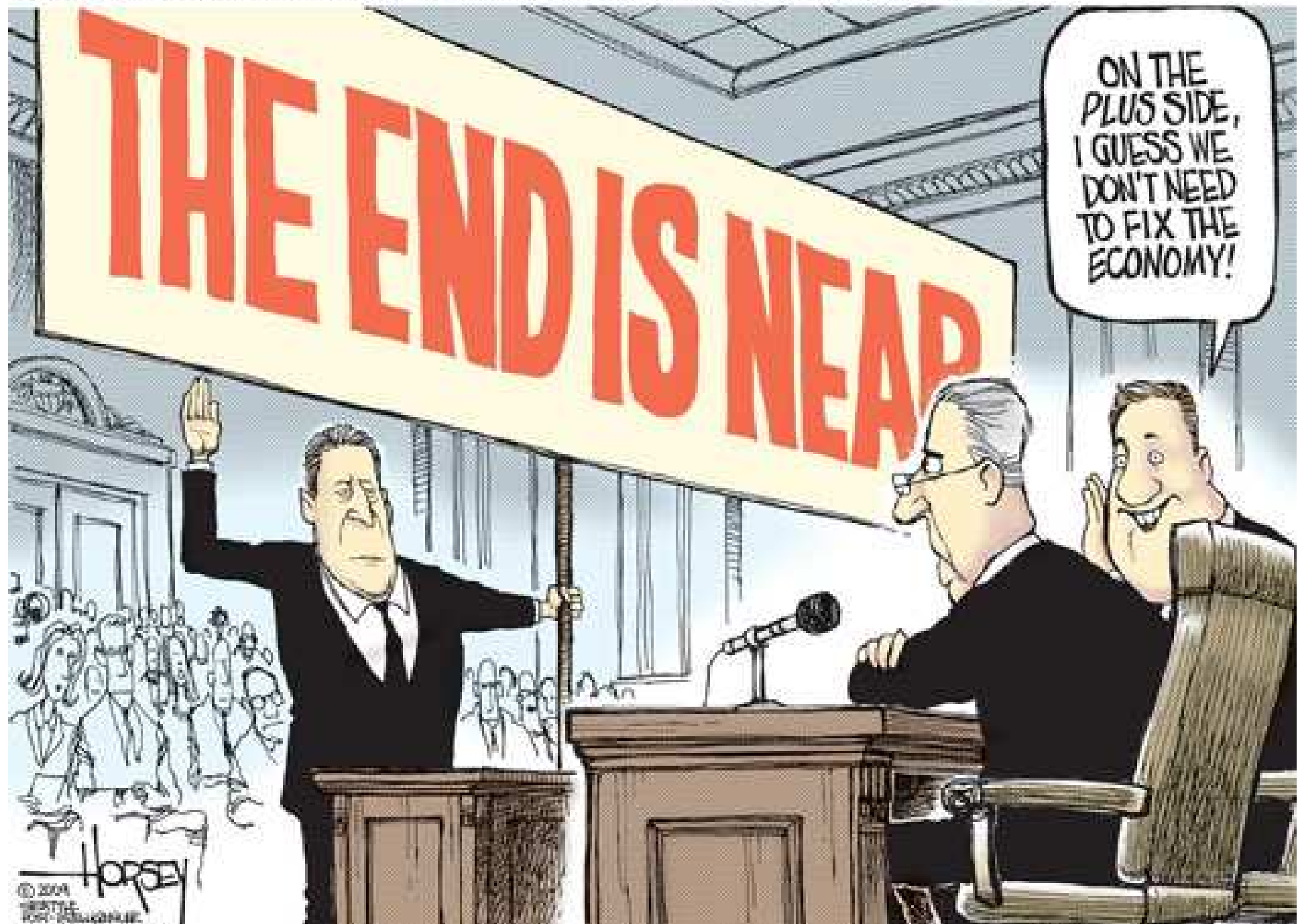
The University of Queensland / IEEE Queensland Section

Outline

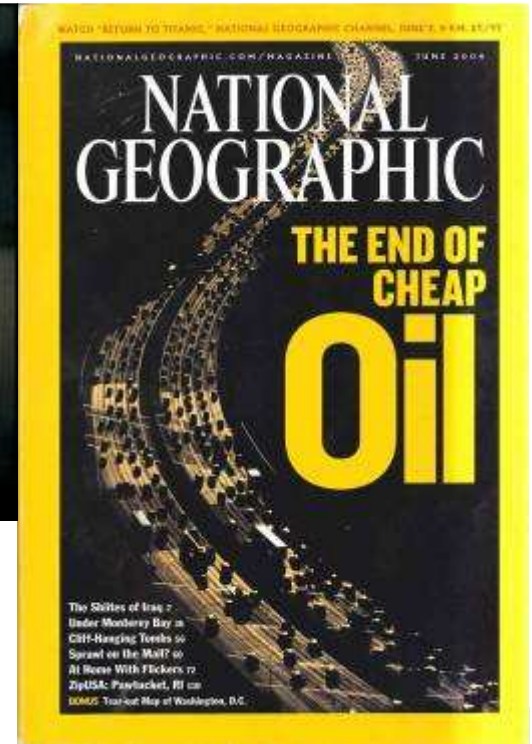
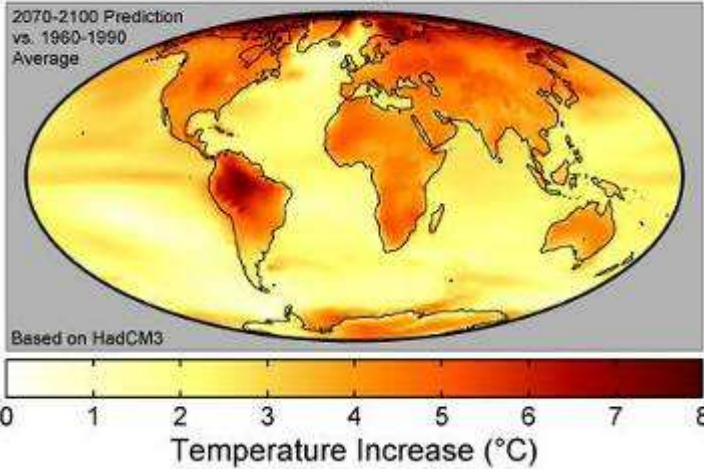
- Background
- Why electric-drive vehicles (EVs)?
- Enabling technology – batteries
- Automotive industry progress
- EVs and the grid
- Utility industry progress
- EVs and renewable cities



AL GORE GOES TO CAPITOL HILL TO TESTIFY ABOUT GLOBAL WARMING ...



Global Warming Predictions



What problems are we trying to solve?



Lesson #1: EVs don't deal with automobile dependence and traffic congestion.

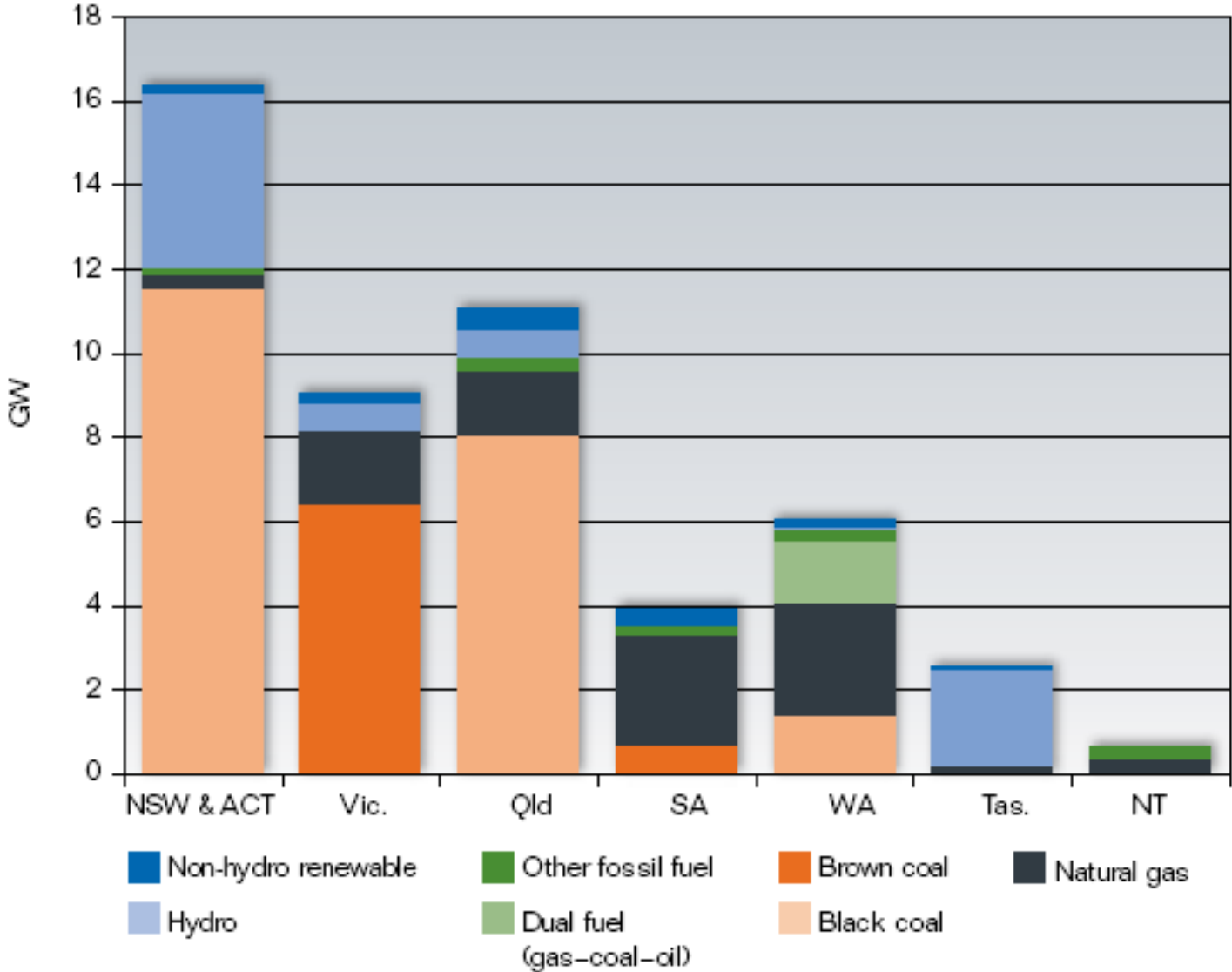


Why EVs?

- No tailpipe emissions, quiet operation
- Ubiquitous electricity infrastructure
- Near-equivalent functionality/performance
- No oil required
- Improved greenhouse gas emissions
- Lower cost of motoring
- Synergies with smart grids and renewable energy

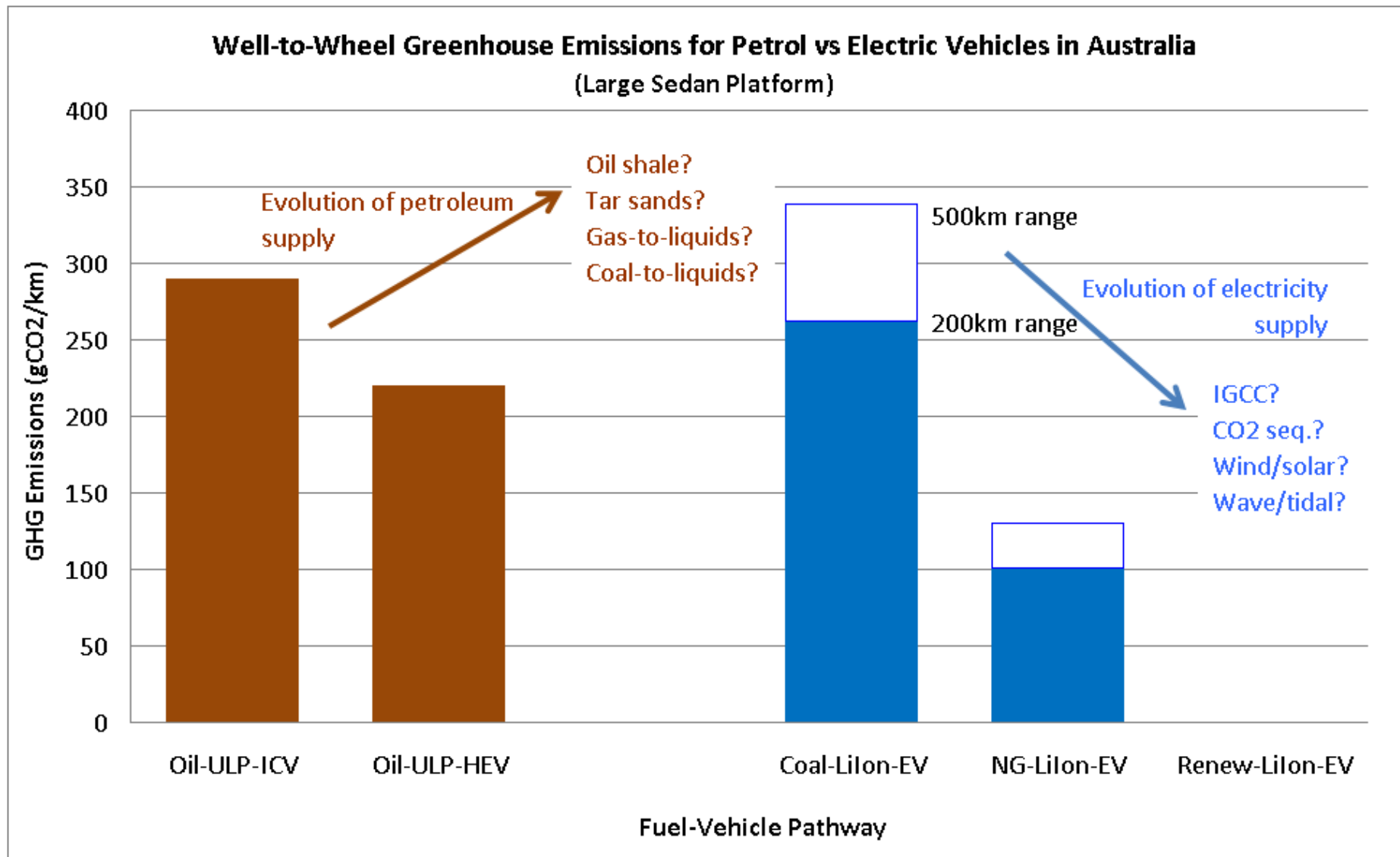
Figure 20.1 Installed electricity generation capacity, 2005–06

from Garnaut Review (2008)



Source: ESAA (2007).

Lesson #2: No oil required for EVs = energy independence



Simpson (2005) "Full-cycle assessment of alternative fuels for light-duty road vehicles in Australia"

Lesson #3: Cleaner electricity means cleaner EVs.

Lower Cost of Motoring

Operating Cost Comparison - Large Sedan Platform

Internal Combustion Vehicle (ICV)	
Fuel consumption (L/100km) ¹	10.1

Electric Vehicle (EV)	
DC Efficiency (Wh/km) ¹	230
AC Efficiency (Wh/km) ¹	250
Battery size (kWh) ²	40
Battery cost (AUD) ²	\$12,600
Cycle life @ 80% DOD ²	3200
Lifetime energy (kWh)	102400
Lifetime distance (km)	445217
Lifetime cost (\$/km)	0.028

Fuel price (\$/L)	\$ 1.00	\$ 1.25	\$ 1.50
ICV cost (\$/km)	\$ 0.101	\$ 0.126	\$ 0.152

Elec. price (\$/kWh)	EV cost (\$/km)
\$ 0.20	\$0.078
\$ 0.15	\$0.066
\$ 0.10	\$0.053
\$ 0.05	\$0.041

Net saving (\$/km)			
\$ 0.023	\$ 0.048	\$ 0.073	
\$ 0.035	\$ 0.060	\$ 0.086	
\$ 0.048	\$ 0.073	\$ 0.098	
\$ 0.060	\$ 0.085	\$ 0.111	

References:

1: PAMVEC model (Simpson, 2005)

2: CARB Expert Panel (2007) "Status and Prospects for Zero Emissions Vehicle Technology".

Lesson #4: Innovative business models can amortize EVs' higher upfront cost.

Why not EVs?

- Battery costs?
- Operating range?
- Recharge time?
- Charging locations?
- Load on grid?
- Competing technologies – hydrogen, etc?



Lesson #5: EVs offer a new concept for personal mobility – they are not meant as a substitute for the old way of getting around.

Enabling Technology: Li-Ion Batteries

CARB expert panel (2007): “High energy Li-Ion technology has good potential to meet all performance requirements of EVs with batteries of modest weight...cell and battery technology designed for these applications are likely to also meet cycle life goals.”



Table A: Specifications for Li-Ion FPBEV battery packs under development

Vehicle	Battery Supplier	Type	Energy (kWh)	Peak Power (kW)	Weight (kg)	Specific Energy (Wh/kg)	Specific Power (W/kg)
FPBEV	DOE goal ¹	n/a	25-40	50-100	250	100-160	200-400
Tesla Roadster	Tesla Motors	Li-Ion	53	230	450	118	511
THINK City	A123 Systems ²	Li-Ion	19	no data	260	73	no data
	EnerDel ²	Li-Ion	26	no data	260	100	no data
n/a	JCS ¹	Li-Ion	24	55	265	90	210
n/a	GAIA ¹	Li-Ion	22	50	200	115	250
n/a	LitCel ¹	Li-Ion	20	155	170	118	912
n/a	Lamilion ¹	Li-Ion	9.2	62	150	60	400
n/a	Kokam ¹	Li-Ion	30	130	265	110	490

¹ Data extracted from Tables 3-2 and 3-6 of the Expert Panel Report

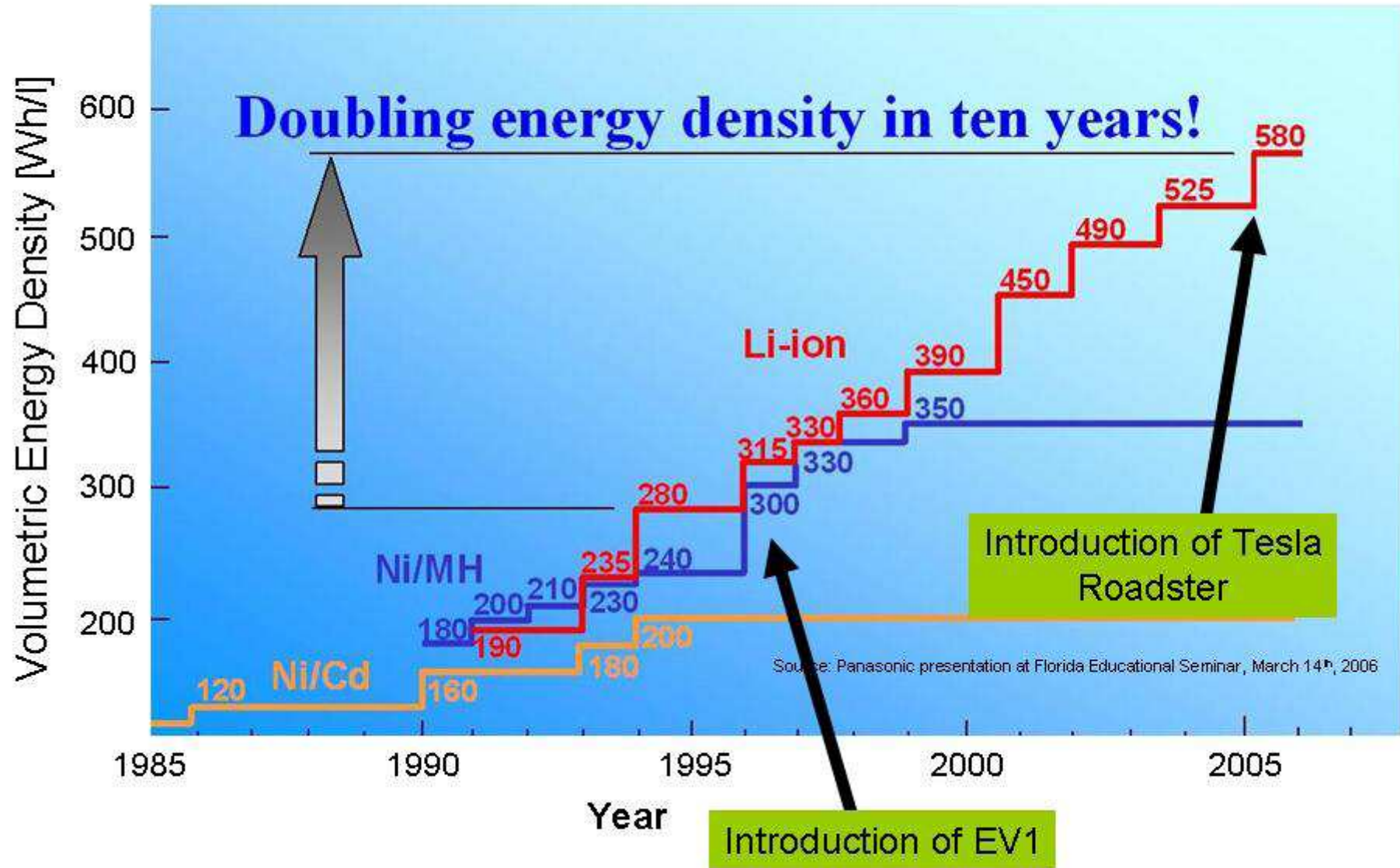
² Data reported by Green Car Congress [11]



Lesson #6: Not all Li-Ion batteries are created equal.

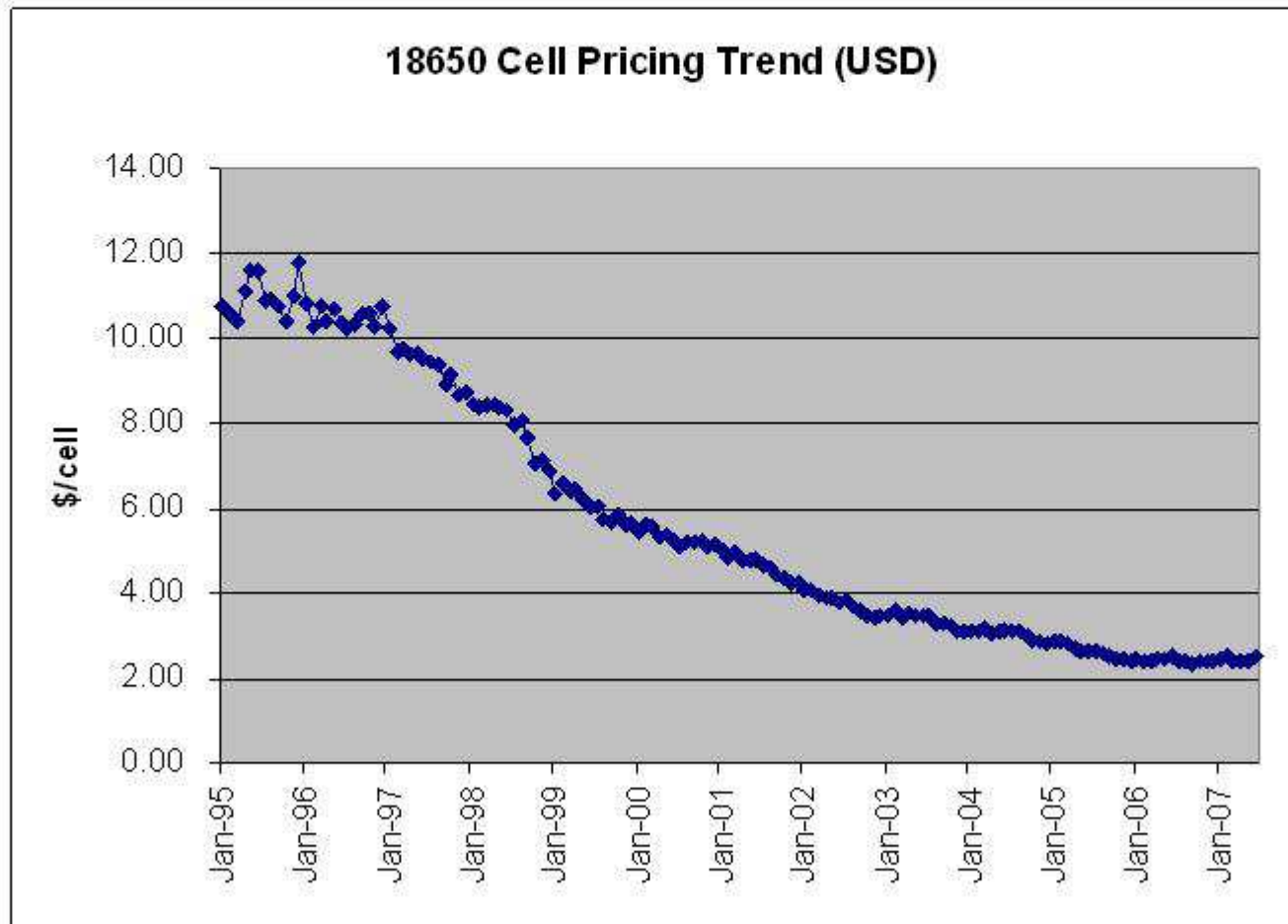
Battery Energy Density Trend

Lithium Ion vs. Ni-MH vs. Ni-Cd



Li-ion Battery Price Trend

- Ten years: twice the energy density at $\frac{1}{4}$ the price



Source: Institute of Information Technology, September, 2007

Li-Ion Battery Charging and Safety

Charging

- Li-ion battery charging rates depend on chemistry and anode/cathode engineering
- Most batteries can charge in <60min, some batteries can charge in <10min.
- Charging supply is usually the bottleneck



Safety?

- Li-ion battery safety also depends on chemistry and anode/cathode engineering
- The preferred automotive chemistry (Li-Ion phosphate) is inherently safer and cannot go into thermal runaway.
- Monitoring/management is critical for other Li-Ion chemistries



Automotive Industry: New Models



Chevy Volt PHEV – 40mi



Toyota FT-EV – 50mi



Mitsubishi MiEV – 120mi



Mercedes BlueZERO EV – 120mi



Mini EV – 150mi



Ford Focus EV – 100mi

Lesson #7: Established car companies don't always get it right.

Automotive Industry: New Companies



THINK City EV – 110mi



Aptera 2e EV – 100mi



Tesla Roadster EV – 240mi



BYD E6 EV – 180mi



Fisker Karma PHEV – 50mi



Reva EV – 50mi

Automotive Industry

Government investment:

- Obama stimulus package: \$2B for US domestic battery manufacturing
- US consumer tax credit of up to \$7,500 for EVs
- Australian \$1.3B Green Car Innovation Fund



Hymotion Prius PHEV kit – 30mi

Local business opportunities:

- Vehicle imports
- Retrofit solutions
- Powertrain components
- Niche market vehicle manufacture for local and export markets



Blade Electron EV – 75mi

Automotive Industry Barriers

For manufacturers:

- Battery supply

Lesson #8: Battery supply makes or breaks EV companies.

- Misguided industry directives/incentives

Lesson #9: The industry will go where the government money is.

- Barriers to entry for new companies

Lesson #10: It's incredibly hard to start a new car company.

- Lack of standards – battery packaging and safety, charging, testing

Lesson #11: Standards are essential for mass-market vehicles.

- Regulations, certification, registration

Lesson #12: Homologation is too often overlooked.

Automotive Industry Barriers

For consumers:

- Misperceptions about EVs

Lesson #13: Driving an EV puts a smile on your face.

- Lack of product

Lesson #14: You can't buy it if it's not for sale.

- Lack of consumer incentives

Lesson #15: Incentives sell cars.

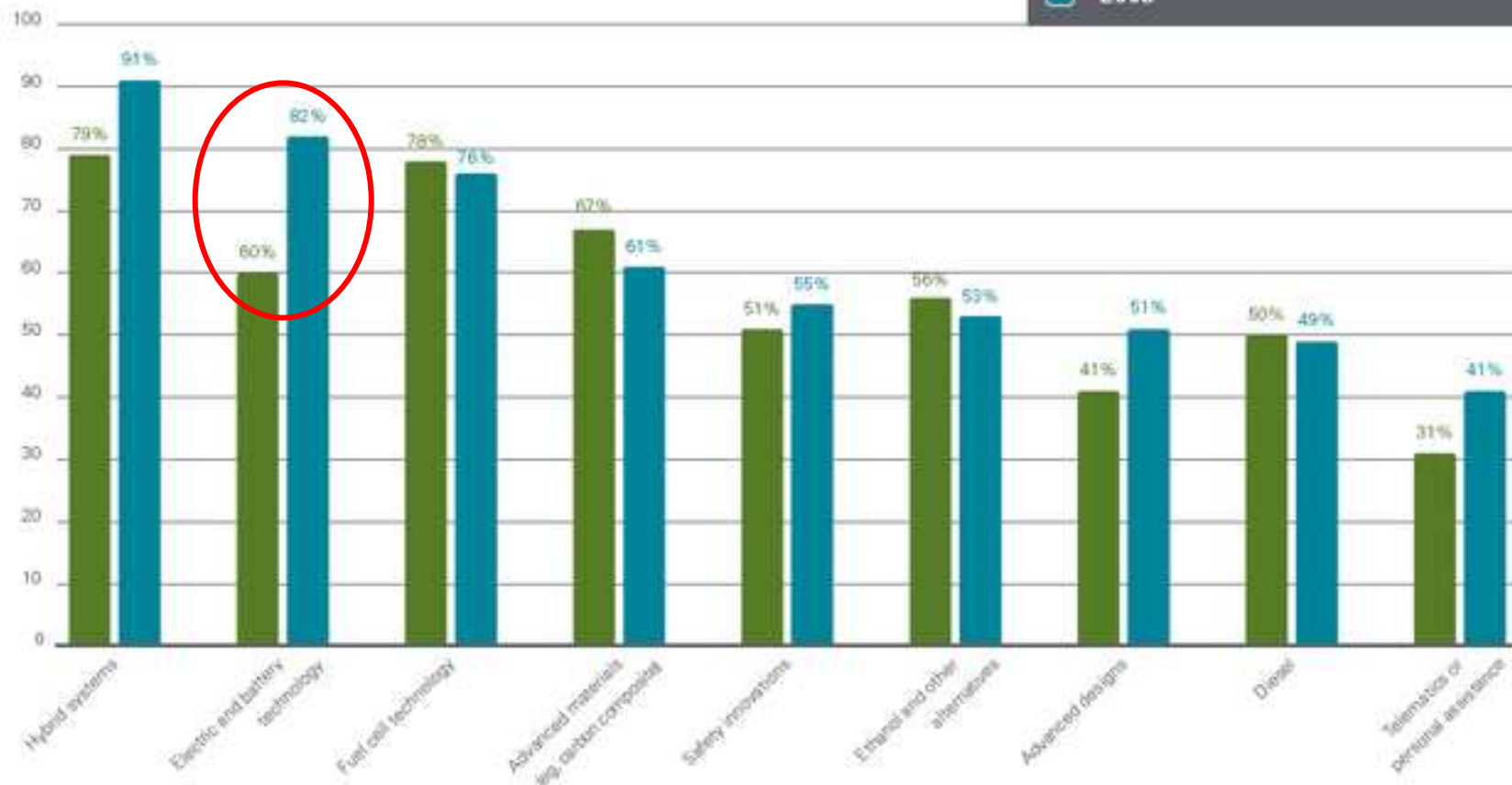
Automotive Industry Direction

For the following automotive product innovations, rate the importance to the industry over the next five years

Key

2007
2008

KPMG Global Auto Executive Survey (2009)



% citing important on a scale listing important, neutral, and unimportant for 2008

EVs and The Grid

“cars as appliances”

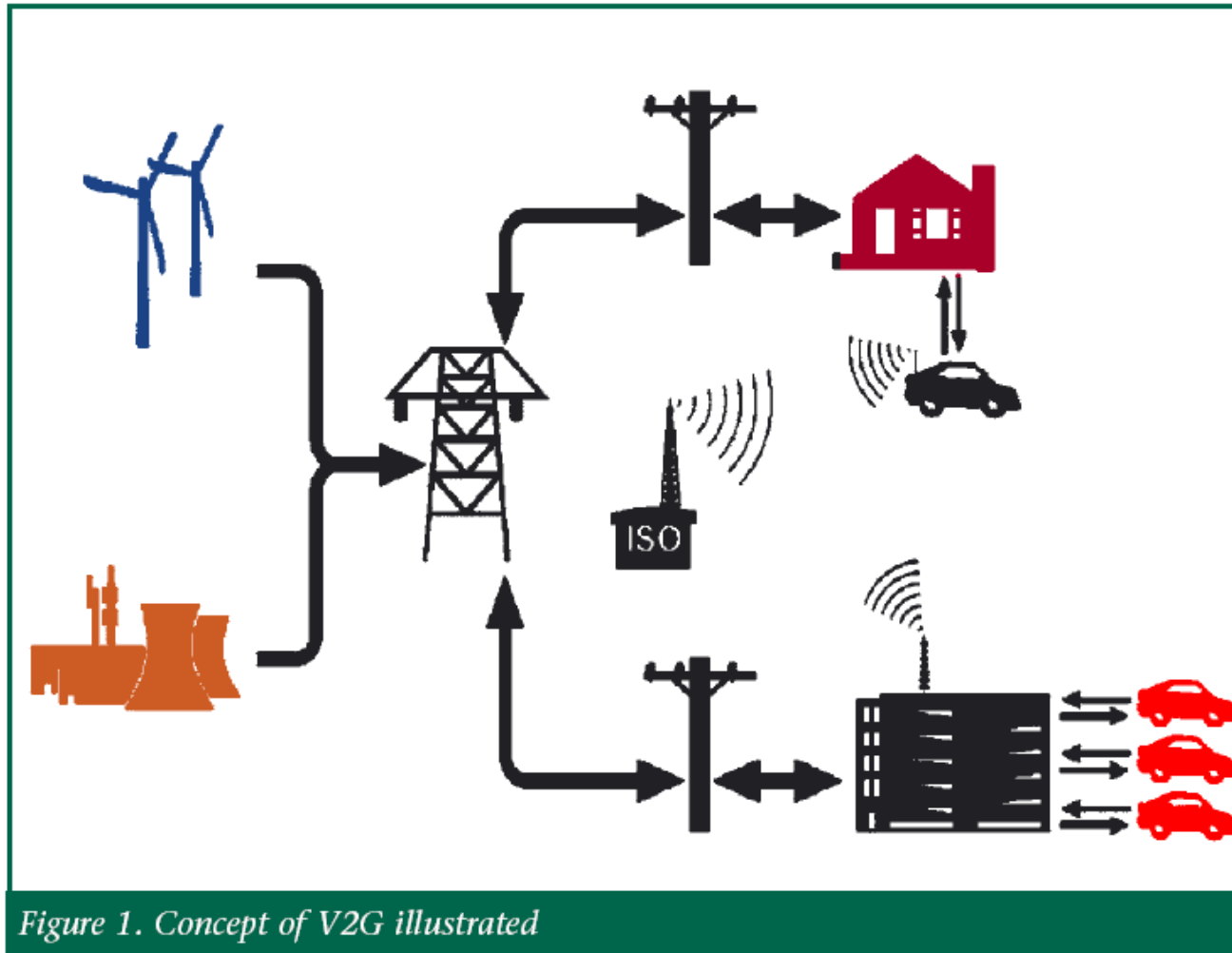


Figure 1. Concept of V2G illustrated

Kempton & Dhanju (2006) “Electric Vehicles with V2G”

EVs and The Grid: Capacity Expansion

- The existing US grid can support a light-duty vehicle fleet that is composed of 73% EVs (160 million).

*Pacific Northwest National Laboratory
(2007) "Impacts Assessment of Plug-In
Hybrid Vehicles on Electric Utilities
and Regional U.S. Power Grids"*

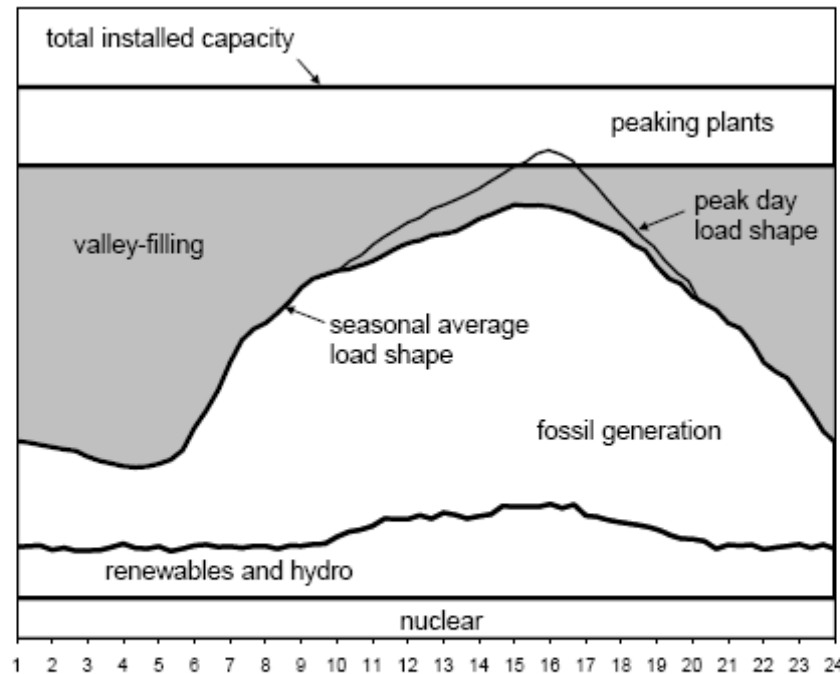
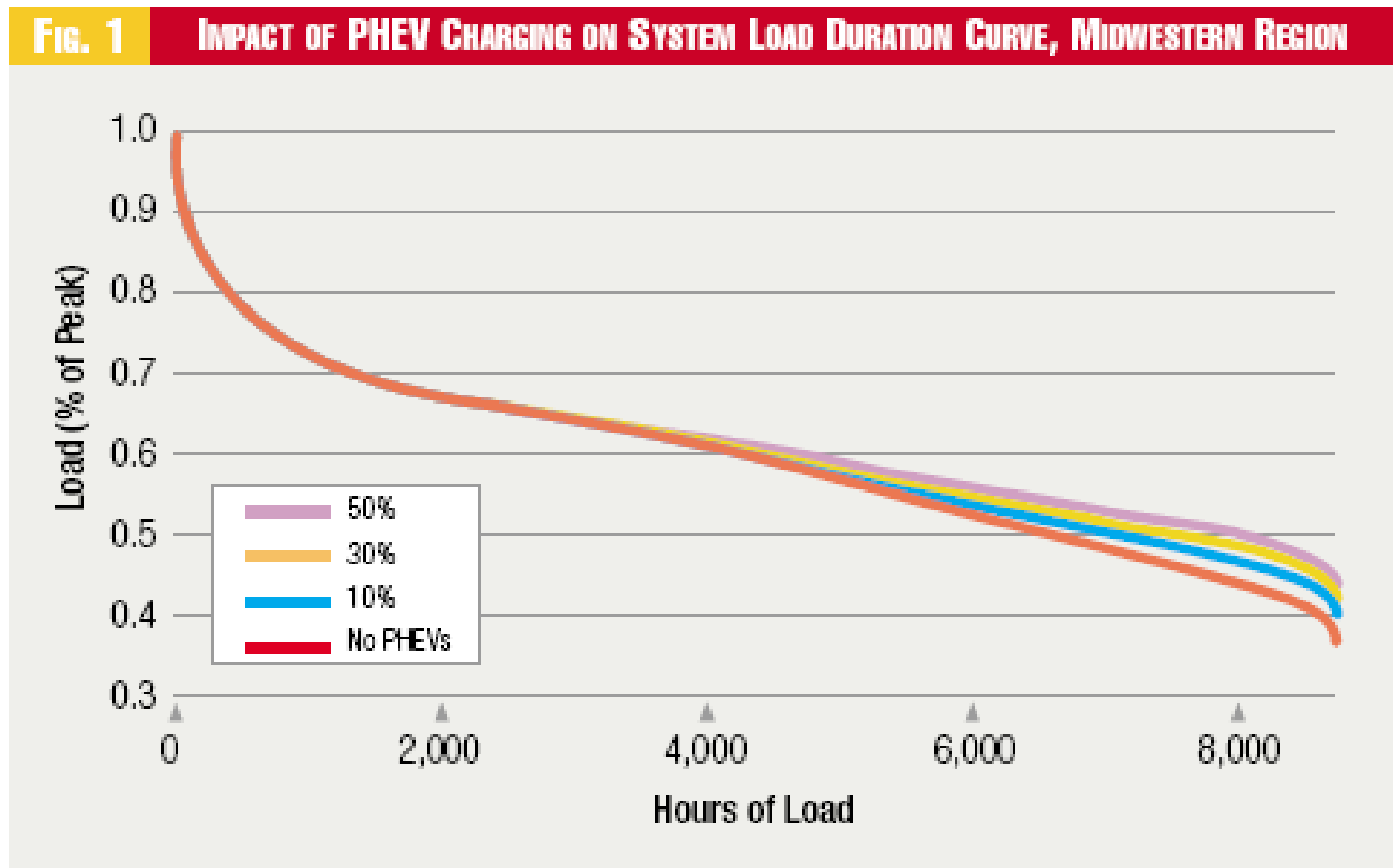


Figure 2: Stylized Load Shape for 1 Day During Peak Season, Generation Dispatch, and Installed Capacity

Lesson #16: No new capacity required to support mass-market EVs, but utility-optimized charging is preferred.

EVs and The Grid: Capacity Factors

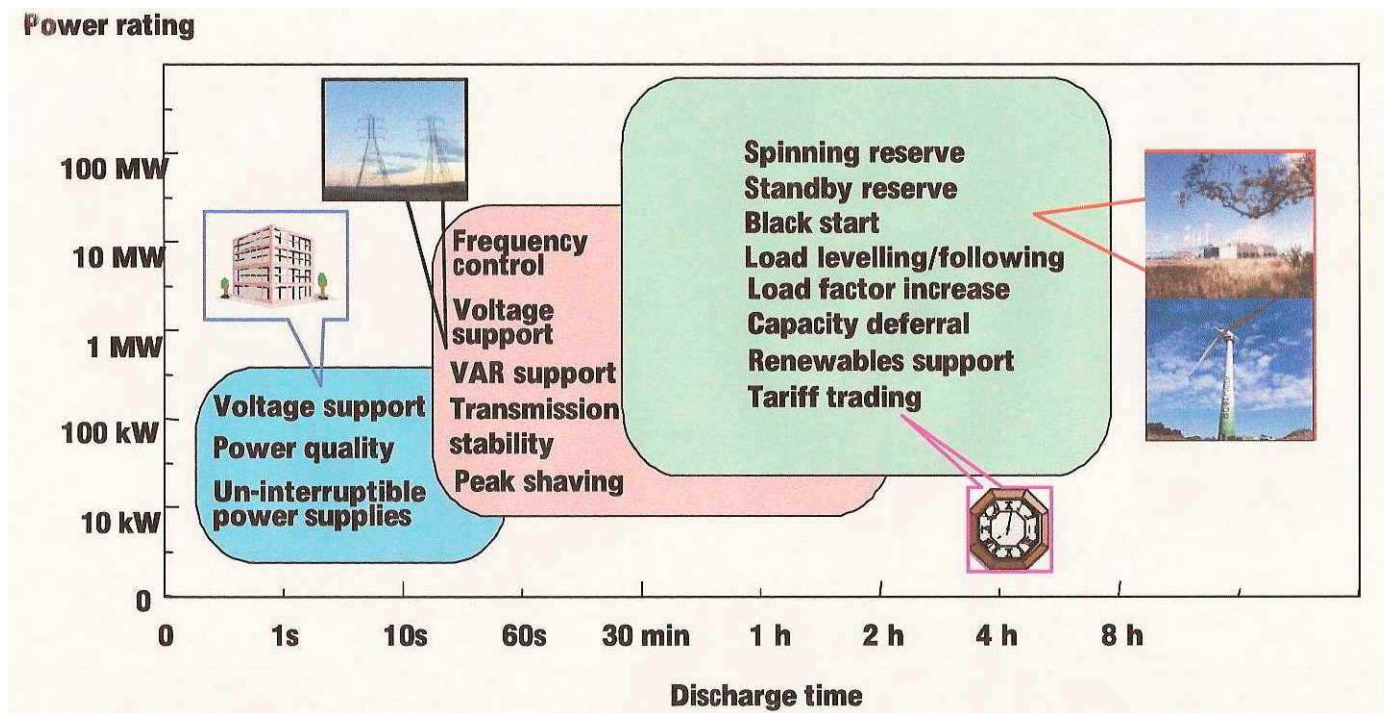
- EVs can increase capacity factors with low marginal cost of electricity supplied.



Letendre et al (2006) "Electric & Hybrid Cars – New Load, or New Resource?"

EVs and The Grid: Ancillary Services

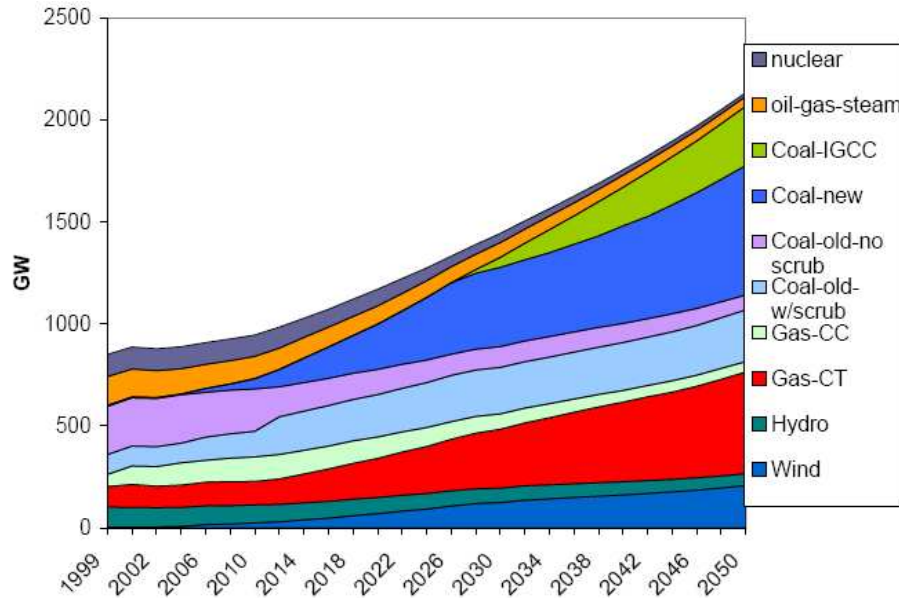
- Ancillary services are a multi-billion-dollar market, and are also the most promising application of vehicle-to-grid (V2G) technology.



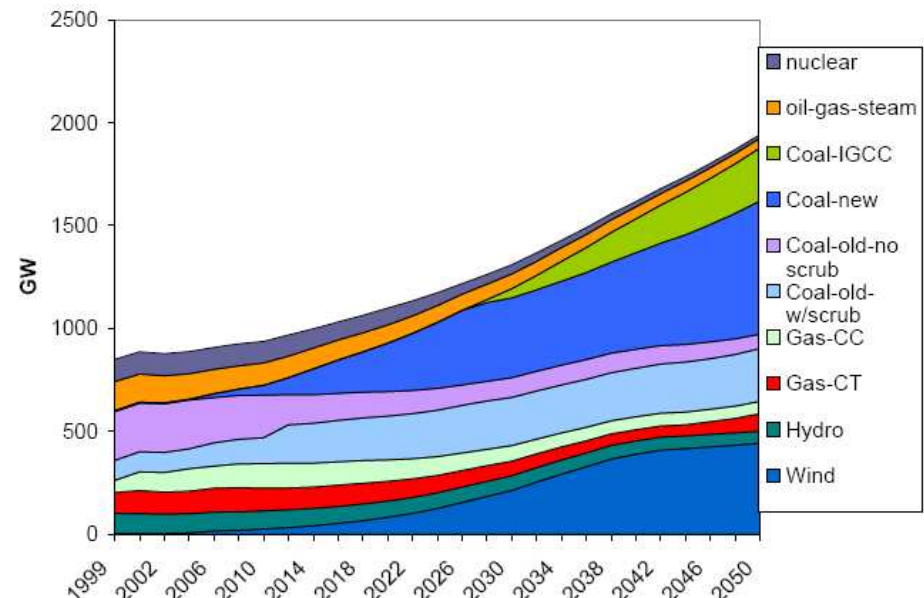
Lesson #17: “Back-feeding” is not essential to utilize V2G.

EVs and The Grid: Enabling Renewables

Grid mix without EVs



Grid mix with EVs



———— Doubling of installed wind capacity. —————>

Short & Denholm (2006) "A Preliminary Assessment of Plug-In Hybrid Electric Vehicles on Wind Energy Markets"



EVs and the Utility Industry

- Utilities that 'get it' are incredibly supportive of EVs: SCE, PG&E, Xcel Energy, Austin Energy, Delaware, EDF, TEPCO, AGL



**Southern California Edison's
Electric Vehicle Technical Center**



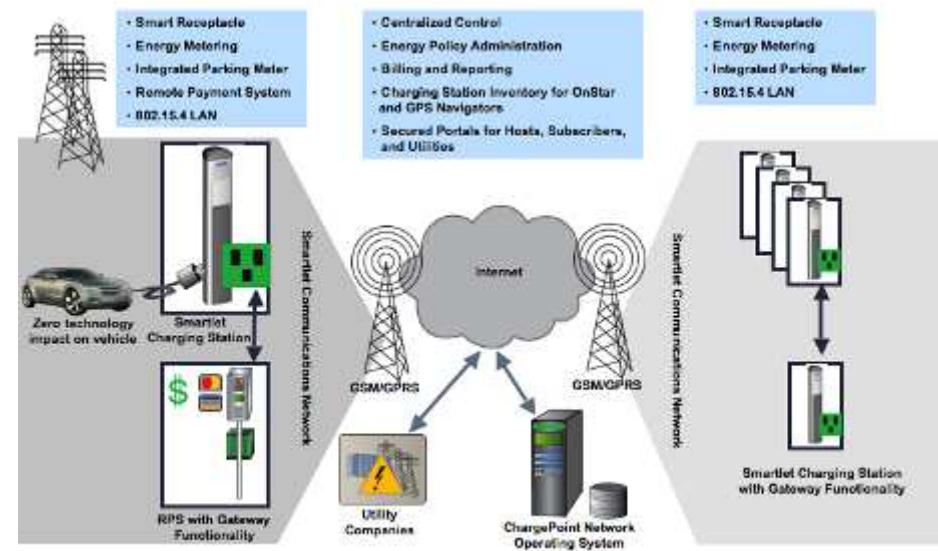
Lesson #18: Many utilities are still unfamiliar with EVs.

EVs and Smart Grids

- Enormous demand for smart-grid technologies to support EV networks
- \$11B in Obama stimulus package for smart grids
- Emerging business opportunities for EV “aggregators”



Project Better Place



Coulomb Technologies

Lesson #19: Standardized EV infrastructure is essential.

EVs and Renewable Communities



EVs in Toyota's Dream House, Japan



MASDAR City, United Arab Emirates



EVs and Renewable Communities



North Port Quay, Fremantle WA



Lesson #20: From this...



...to this...





...or we'll be stuck with this.