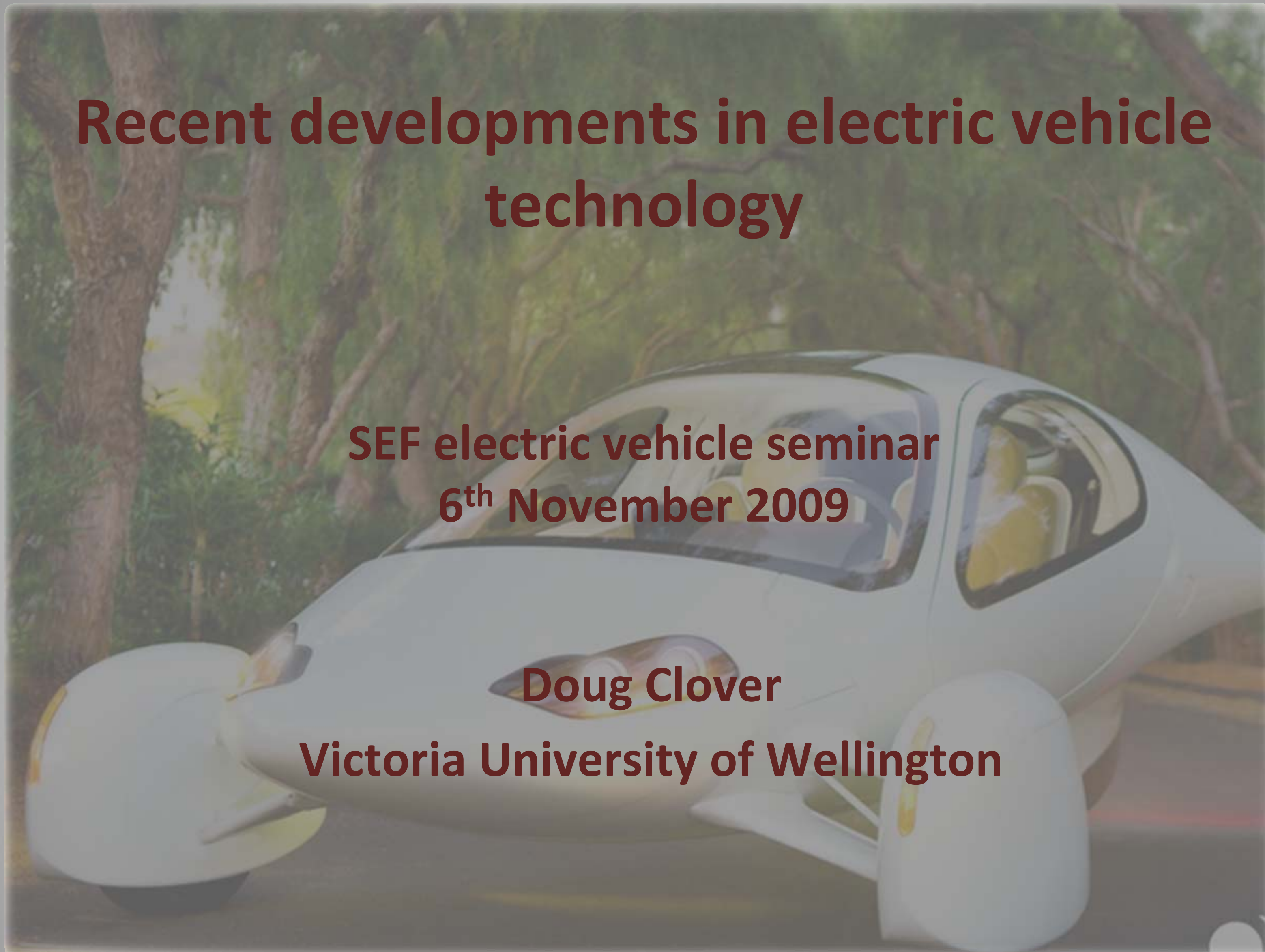


Recent developments in electric vehicle technology

SEF electric vehicle seminar

6th November 2009

Doug Clover

Victoria University of Wellington

Overview of presentation

1. Focus of this talk is light duty electric passenger vehicles (the electric car)
2. Types of electric cars
   – Performance, price, and production status
3. EV batteries
   – Current and potential technologies

Electric vehicles types

1. Quadra-cycles or Neighbourhood electric vehicles

e.g. Reva, YDEA, Megacity,, Maya 300

Seating: 2, 2+1, 4

Range: 80-160km

Top speed: 60-90 km (often speed limited to meet safety requirements),

Battery type: Lead Acid, Zebra sodium, Li-ion - 10-20 kWh

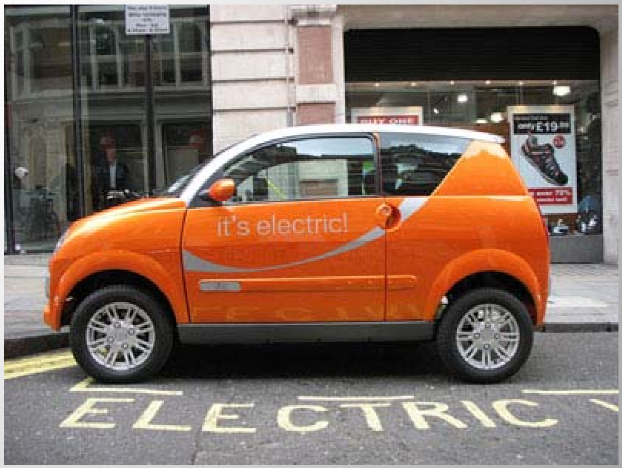
Peak power: 10 – 15 kW

Price: $20,000 - $40,000

Kerb weight: 650- 900 kg

Production status: in production, not available in NZ.

YDEA



NICE Mega city

Electric vehicles types II

2. City EV (Highway capable)

   e.g. Hyundai (GETZ) Blade Electron*, iMIEV, Smart EV*, Nissan NuVu, Th!NK City[?]

   Seating: 2 to 4

   Range: 120-160km

   Top speed: 110 - 130km

   Battery: Li-ion 12- 30 kWh,

   Peak power 40-80 kW

   Price: $50,000 +

   Kerb weight: 900 - 1100 kg

   Production status: Blade available in NZ. Smart EV available in Europe. More vehicles announced as concept vehicles.

TH!NK City

TH!NK City

Mitsubishi iMIEV

Electric vehicles types III

3. Plug-in hybrid electric vehicle (PHEV)

   e.g. BYD F6DM*, Chevy Volt, Prius (conversions)*, Fisker Karma, Ford Escape (PHEV)*

   Seating: 2 to 4

   Electric only range: 20-100km

   Top speed: 130+ km/hr

   Battery: Li-ion 10- 20 kWh,

   Peak power 100+ kW

   Price: $50,000(?) - $150,000 (Karma)

   Kerb weight: 1500+ kg

   Production status: Prius conversion, Ford Escape available in U.S. BYD in China. Can order the Karma.

BYD F6DM

Fisker karma

Electric vehicles types VI

4. General purpose EV

e.g. Tesla Model S, BYD 6e, Volvo C30 BEV, Nissan Leaf

- Seating: four – seven (with luggage space)
- Range: 150km – 350 km (mostly the lower end)
- Top speed: 130+ km/hr
- Battery: Li-ion 60 – 100+ kWh
- Peak power: 70 + kW
- Price: $80,000+ (?) **(increasing cost with range)**
- Kerb weight: 1500 -2,200 kg
- Production status: None in production (production status 2010+)

Nissan Leaf

Tesla Model S

EV Batteries

The main members of the Lithium-ion family

Table 1: Characteristics of lithium-ion batteries using various chemistries

Chemistry Anode/cathode	Cell voltage Max/nom.	Ah/gm Anode/cathode	Energy density Wh/kg	Cycle life (deep)	Thermal stability
Graphite/ $NiCoMnO_2$	4.2/3.6	.36/.18	100-170	2000-3000	fairly stable
Graphite/ Mn spinel	4.0/3.6	.36/.11	100-120	1000	fairly stable
Graphite/ $NiCoAlO_2$	4.2/3.6	.36/.18	100-150	2000-3000	least stable
Graphite/ iron phosphate	3.65/ 3.25	.36/.16	90-115	>3000	stable
Lithium titanate/ Mn spinel	2.8/2.4	.18/.11	60-75	>5000	most stable

Source: Burke and Miller, 2009

EV Batteries

The Lithium-ion family cont:

Table 5: Illustrative "Snapshot" of Li-Ion PHEV Battery Chemistries

Name	Description	Electrodes: Positive (Negative)	Companies	Automotive Status	Power	Energy	Safety	Life	Cost
LCO	Lithium cobalt oxide	$LiCoO_2$ (Graphite)	Various consumer applications (not automotive)	Limited auto applications (due to safety)	Good[4]	Good[4]	Low[2,4], Mod.[3]	Low[2,4]	Poor[2,3]
NCA	Lithium nickel, cobalt and aluminum	$Li(Ni_{0.85}Co_{0.1}Al_{0.05})O_2$ (Graphite)	JCI-Saft[3] GAIA[3] Matsuhita[3] Toyota[6]	Pilot[1]	Good[1,3]	Good[1,3]	Mod.[1]	Good[1]	Mod.[1,3]
LFP	Lithium iron phosphate	$LiFePO_4$ (Graphite)	A123[3] Valence[5] GAIA	Pilot[1]	Good[1]	Mod.[2,6]	Mod.[1,2,4]	Good[1,4]	Mod.[1], Good[2,3]
NCM	Lithium nickel, cobalt and manganese	$Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$ (Graphite)	Litcel (Mitsubishi)[3] Kokam[3] NEC Lamillion[3]	Pilot[3]	Mod.[3]	Mod.[3], Good[7]	Mod.[3]	Poor[3]	Mod.[3]
LMS	Lithium manganese spinel	$LiMnO_2$ or $LiMn_2O_4$ ($Li_4Ti_5O_{12}$)	GS Yuasa[3] Litcel (Mitsubishi)[3] NEC Lamillion[3] EnerDel	Devel.[1]	Mod.[2]	Poor[1,2,3]	Excel.[1], Good[2]	Excel.[1] Mod.[6]	Mod.[2]
LTO	Lithium titanium	$LiMnO_2$ ($LiTiO_2$)	Altairnano[3] EnerDel	Devel.[3]	Poor[3], Mod.[7]	Poor[3]	Good[3]	Good[3]	Poor[3]
MNS	Manganese titanium	$LiMn_{1.5}Ni_{0.5}O_4$ ($Li_4Ti_5O_{12}$)		Research[1]	Good[1]	Mod.[1]	Excel.[1]	Unkwn.	Mod.[1]
MN	Manganese titanium	$Li_{1.2}Mn_{0.6}Ni_{0.2}O_2$ (Graphite)		Research[1]	Excel.[1]	Excel.[1]	Excel.[1]	Unkwn.	Mod.[1]

Source : Axsen, Burke, Kurani, 2008

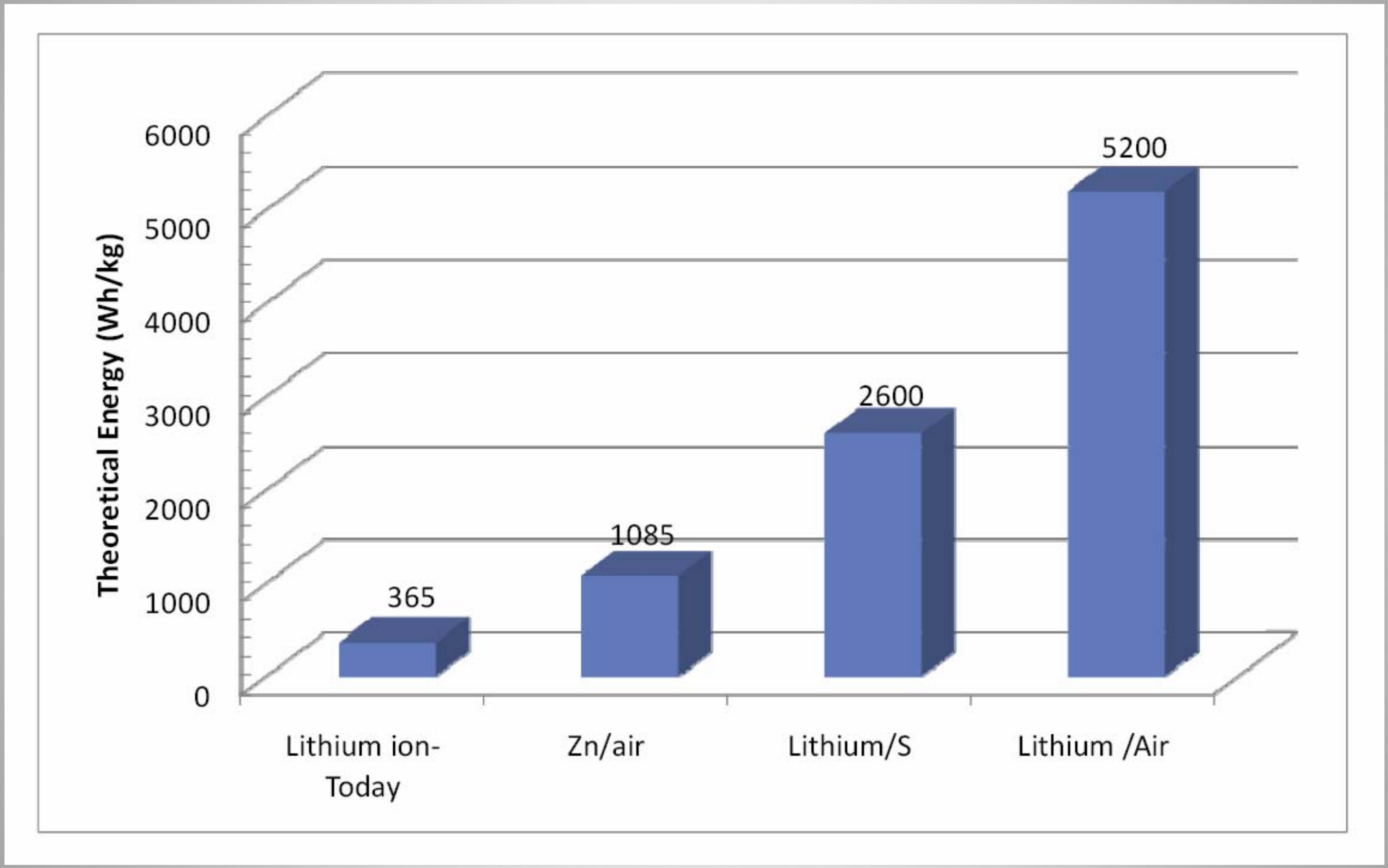
EV Batteries

Some recent announcements:

- Panasonic are releasing high specific energy (cathode $LiNiO_2$) battery (est. 150+ Wh/kg)
- Research efforts to increase charging and discharging rates (power) (e.g. Byoungwoo Kang and Gerbrand Ceder (2009))
- Research efforts to increase battery energy storage focusing on using silicon rather than carbon for anode material (25% increase in specific energy) (e.g. Fuchsbichler B., Stangl C., Kren H., Sternad M., Hohl R., Koller S. (2009)
- Reducing costs - currently cost about U.S. $600/kWh (lower in China around $3-500). The U.S. Govt goal is for U.S.200/kWh. Issue is mass production of EV batteries –

  American Recovery and Reinvestment Act - $1.5 billion to US-based manufacturers to produce batteries and their components and to expand battery recycling capacity

Future EV Batteries



Source : Srinivasan, 2008

Concluding comments

- ↓Price → Mass production →↑ demand → ↓Price

  Need a circuit breaker - sustained high oil prices and/or green transport policy initiatives.

- Significant improvements in battery technology are likely over next 10-20 years – significantly improving vehicle performance.
- But these improvements will not address the fundamental problem of trying to sustain the current personal mobility paradigm in an increasingly resource constrained world.

Thank you

doug.clover@xtra.co.nz