



Cenex

Centre of excellence for low carbon and fuel cell technologies

EV range testing

November 2010

EV range testing

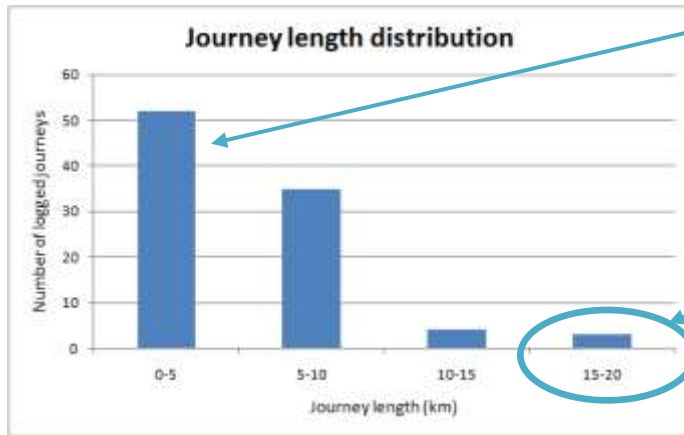


Introduction

- Study of EV range under different test scenarios
 - Laboratory range testing
 - Regulated cycle R101 over NEDC
 - Real world drive cycles, artemis urban, rural and motorway
 - Millbrook EV track cycle
 - High speed circuit
 - City course
 - Hill course
 - Urban circuit
 - Cenex drive event
 - Drive event range variation
 - Ancillary use effect
 - Effect of vehicle heating and cooling

EV range testing

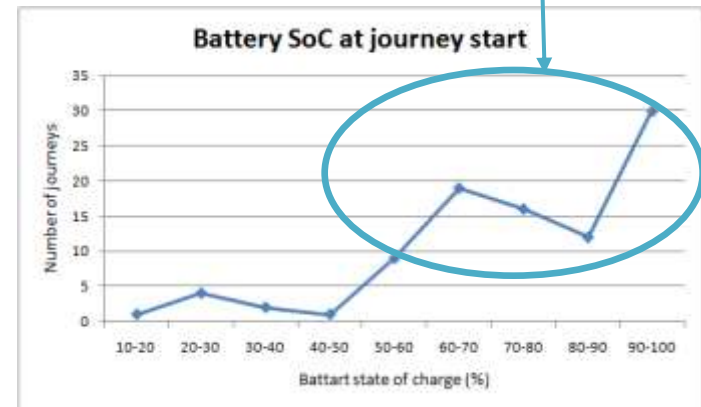
introduction - why range?



55 % of journeys were less than 5 km. The average journey length was 4.8 km

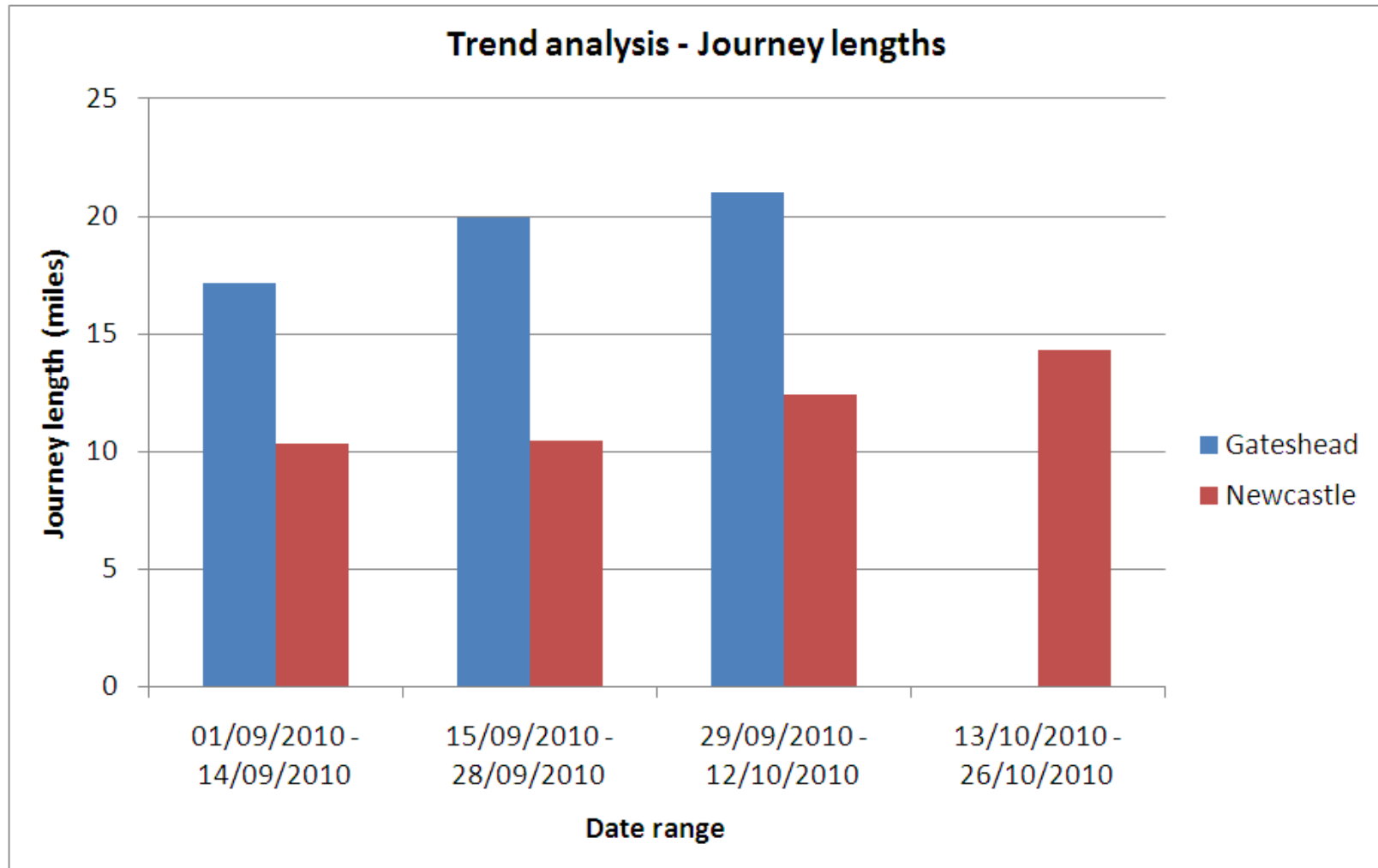
The maximum journey length is 17.8 km. This represents only 46% of the minimum extrapolated range observed during the trial, or 25% of the average range

93 percent of journeys are started with above 50% SoC



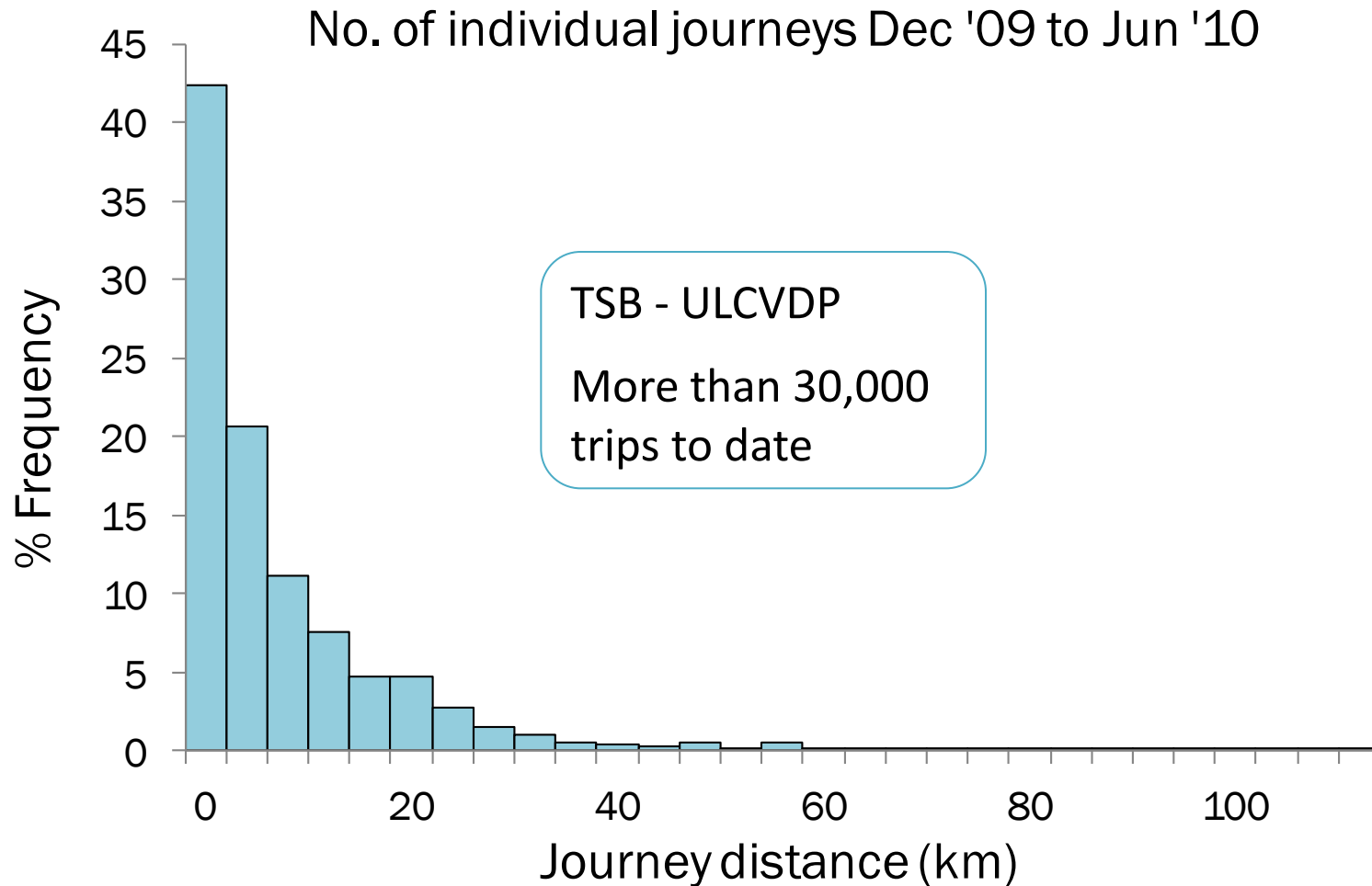
EV range testing

introduction - why range?



EV range testing

introduction - why range?



EV range testing

Introduction – vehicles



- Vehicle specifications and drive economy features



- **smart ED**, 30 kW
- range 84 miles (135 km) (NEDC)
- 16.5 kWh Li-on battery
- Top speed 62 mph
- Charge time : 8 hours @ 240 v
- Seating capacity : 2, Unladen weight 965 kg
- Drive economy features :
 - 20 kW continuous + 10 kW Kick-down
 - Remote control cab temperature conditioning



- **i_MiEV**, 47 kW, AC PM motor
- Range 80 miles (129 km) (EU combined)
- 16 kWh Li-ion battery
- Top speed 81 mph
- Charge time 6 hours @ 240v, 30 minutes @ 3-phase 200V-50kW
- Seating capacity : 4 , Unladen weight (?)
- Drive economy features :
 - D mode – for normal driving
 - Eco mode - ~75% power and more effective regenerative braking on coast down
 - B mode – 100% power, severe regenerative braking on coast down

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EV laboratory range testing

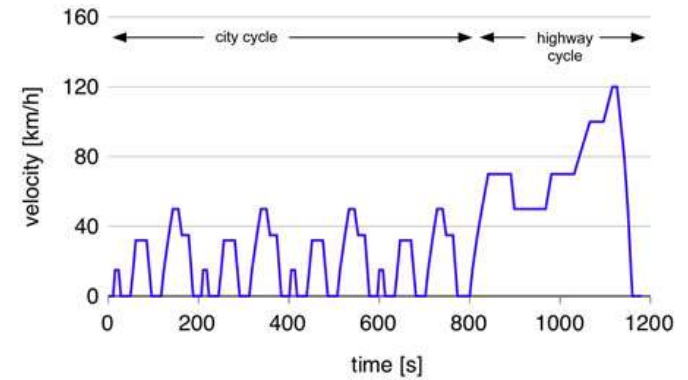
Regulatory range testing to R101



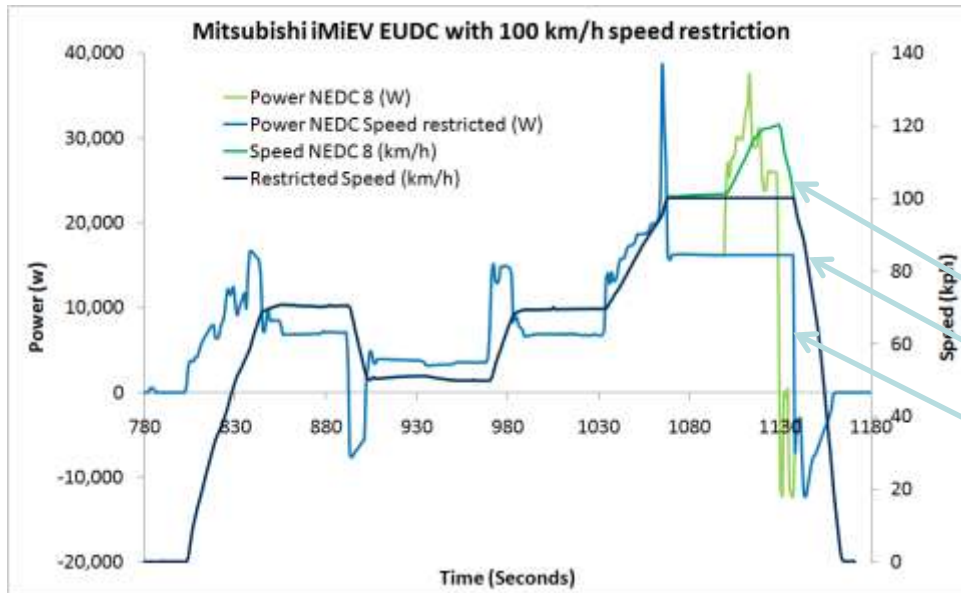
	smart	i_MiEV	i_MiEV (100 km/h)
Range	142 km	116 km	120 km

smart R101 + 10%
i_MiEV R101 - 10%

NEDC drive cycle



- Distance = 11.022 km
- Average speed 33.6 kph
- Gentle rates of acceleration and deceleration



- EUDC required speed
- Restricted speed (100km)
- Restricted power

EV laboratory range testing

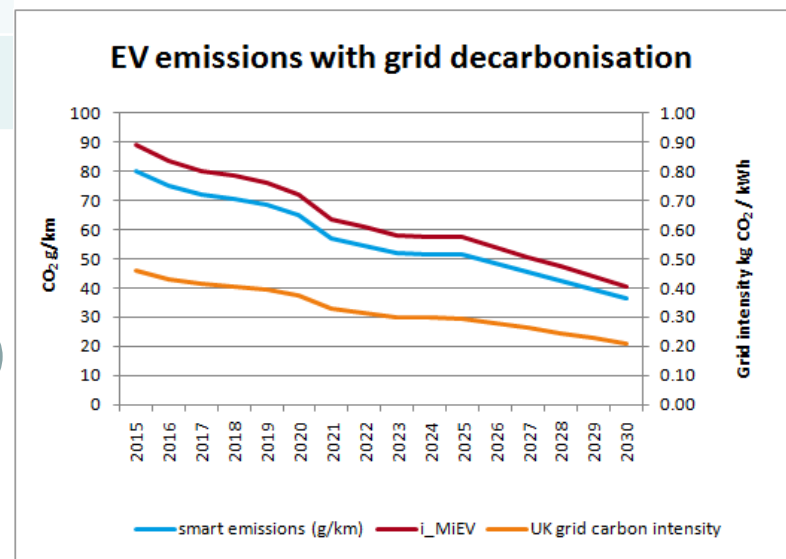
Regulatory range testing CO₂ analysis



	smart 450 Zebra battery	smart 451 Li-ion	smart cdi	i_MiEV
Range (km)	114	142	-	116
Energy consumption (Wh/km)	290	174	-	194
TTW CO ₂ (g/km)	0	0	86	0
WTW CO ₂ e (g/km) [1]	178	107	103	123
WTW CO ₂ (g/km) [2]	113	68	90	76

WTW analysis includes plug to battery charging efficiency of 78 %

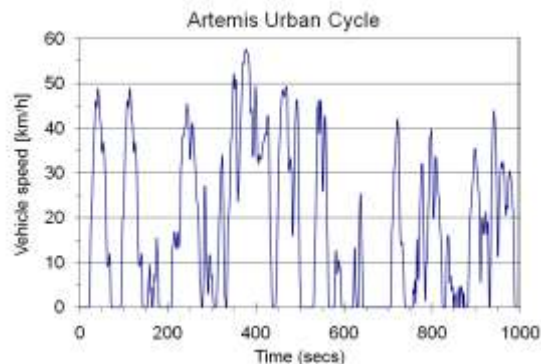
[1] – DEFRA guidance for company emission reporting 2010
 [2] – DECC Marginal emission factor used for energy policy appraisals



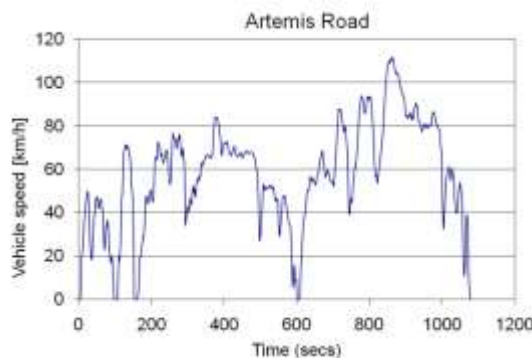
[1] Ref. 2010 DECC/Defra emission factors for company reporting, 617.07g CO₂e/kWh
 [2] DECC Inter-department analysis guidance on valuation of energy use and greenhouse gas emissions

EV laboratory range testing

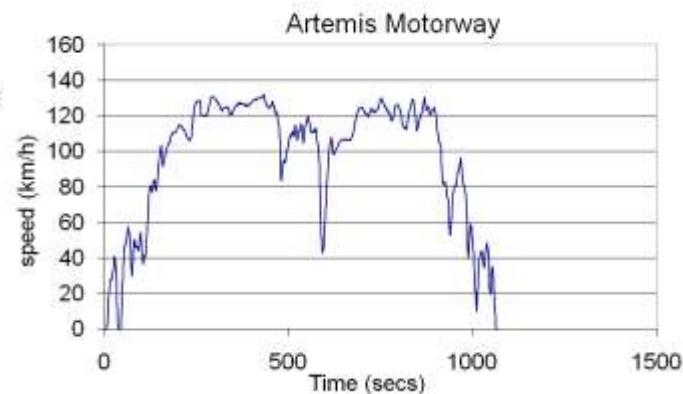
Extrapolated real world drive cycles



Distance: 4.9 km
 Average speed: 18 km/h
 Max speed: 57 km/h



Distance: 17.3 km
 Average speed: 57.5 km/h
 Max speed: 112 km/h



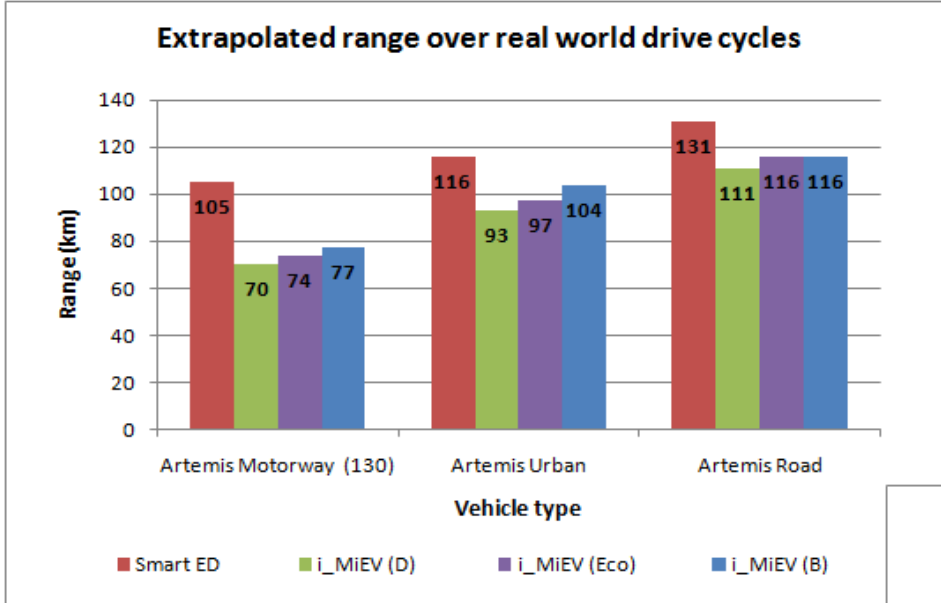
Distance: 28.7 km
 Average speed: 97 km/h
 Max speed: 131.8 km/h

- Extrapolated range calculated from energy consumption over one cycle and extrapolated to full battery capacity using energy consumed during during Regulation R101 range test

Measurement method	Smart	i_MiEV
Reg 101	142	116
Extrapolated	142	117

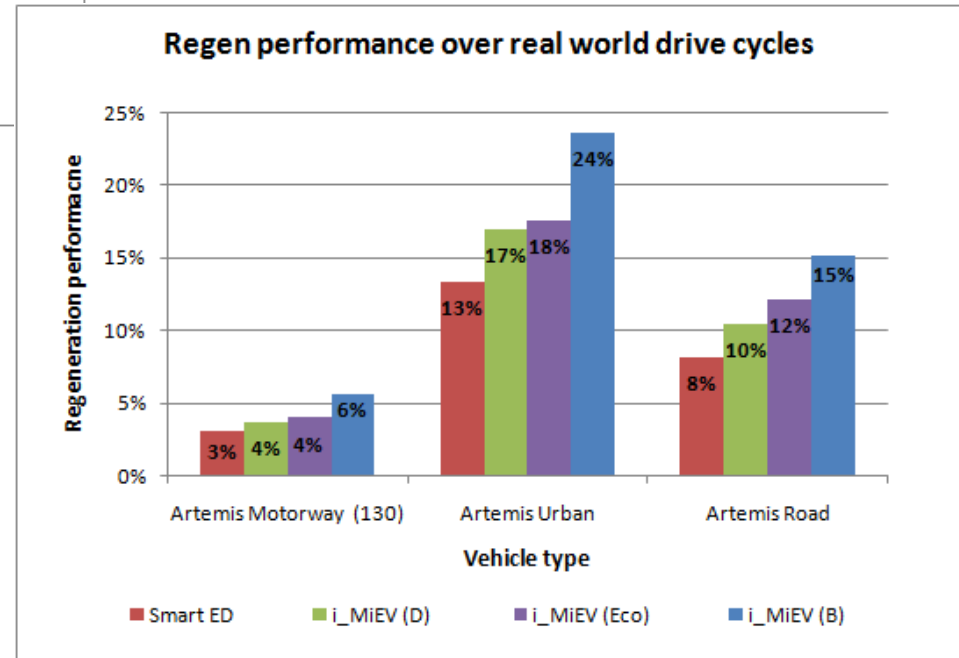
EV laboratory range testing

Range and regen performance



- i_MiEV Maximum range and regeneration available through using B mode
- Smart maintains highest range in all cycles
- Consistently higher regen from the i_MiEV

Mode	Power	Re-gen
Drive (D)	Max	Low
Eco (E)	Restricted	Medium
Brake (B)	Max	High



EV laboratory range testing

i_MiEV drive mode focus

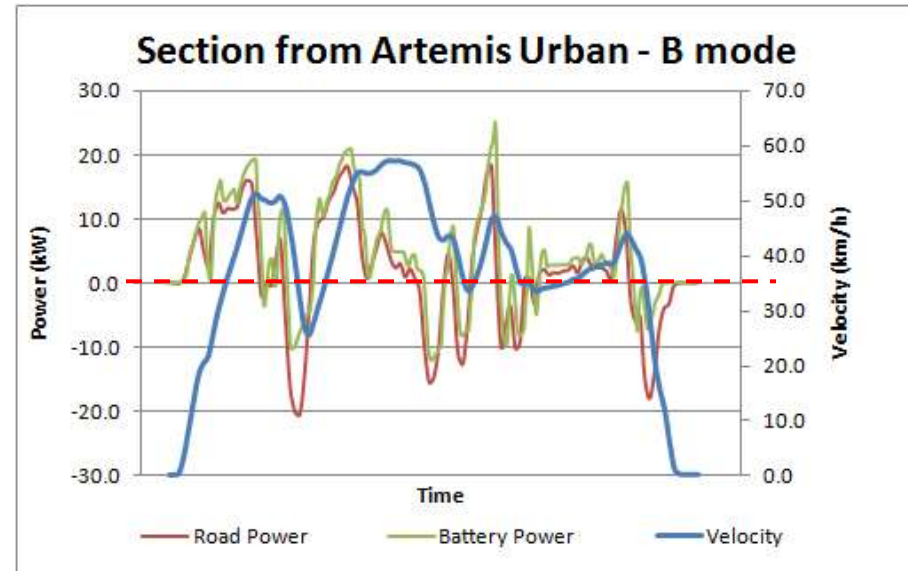
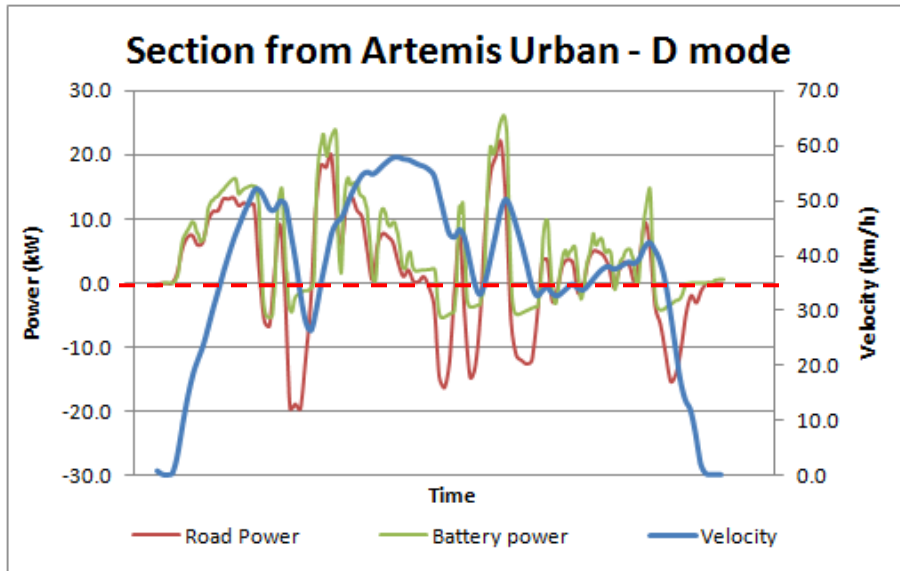


i_MiEV range differential by drive mode

Drive cycle	Drive to Eco	Drive to B mode
Artemis motorway	+ 5.7 %	+ 10.6 %
Artemis urban	+ 4.3 %	+ 11.8 %
Artemis road	+ 4.5 %	+ 4.5 %
Average	+ 4.8 %	+ 9.0 %

Mode	Power	Re-gen
Drive (D)	Max	Low
Eco (E)	Restricted	Medium
Brake (B)	Max	High

- Use of friction brakes minimised on B-mode drive cycles



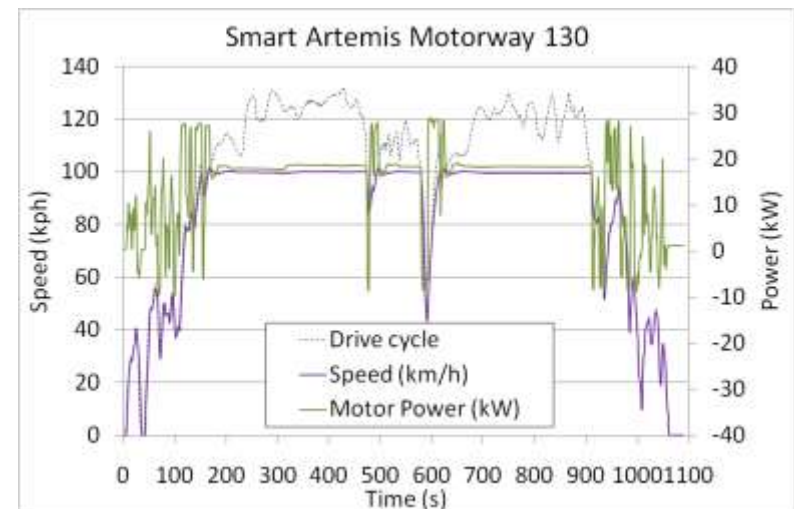
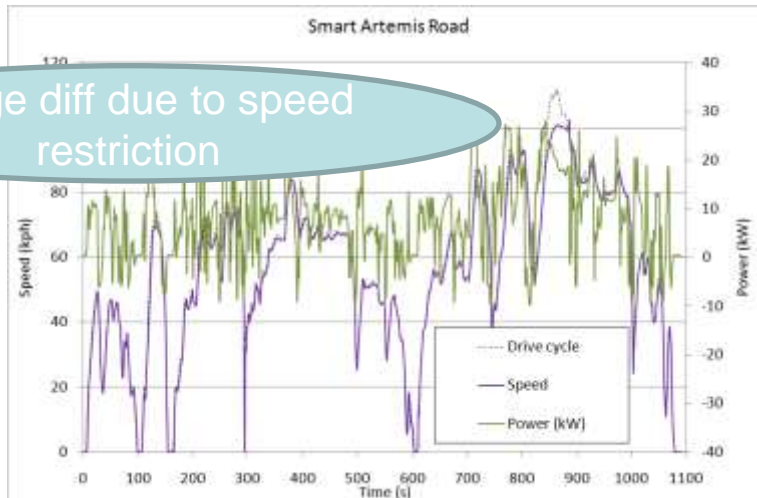
EV laboratory range testing

Laboratory range testing



EV range difference drive cycle

Drive cycle	smart ED	i_MiEV
NEDC	0 %	0 %
Artemis motorway	- 26 %	- 40 %
Artemis urban	- 18 %	- 20 %
Artemis road	- 8 %	- 5 %



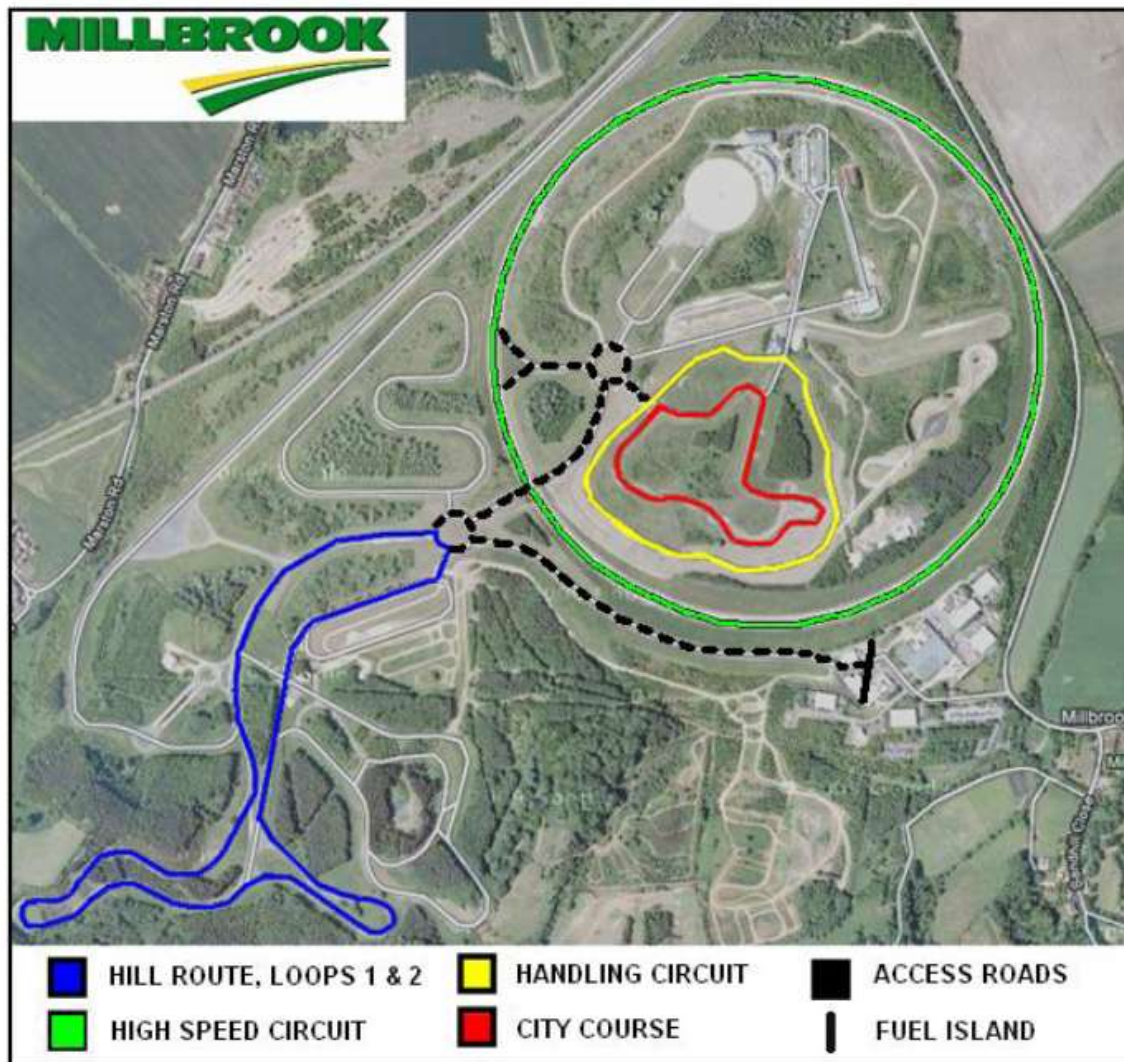
EV range testing



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EV track cycle range testing

Millbrook EV track cycle



- **High speed circuit (HSC)**

- 3.2 km
- Enter 30 mph
- Accelerate to 112 kph in between four predefined rest points
- Exit 30 mph

- **City course (City)**

- 1.4 km
- Urban city course (max speed 48 kph) with numerous stops
- Reverse park
- Posted speed limits

- **Hill route (Hill)**

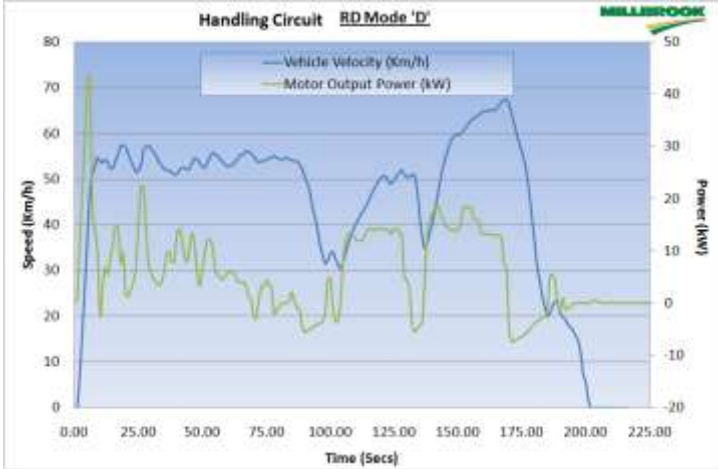
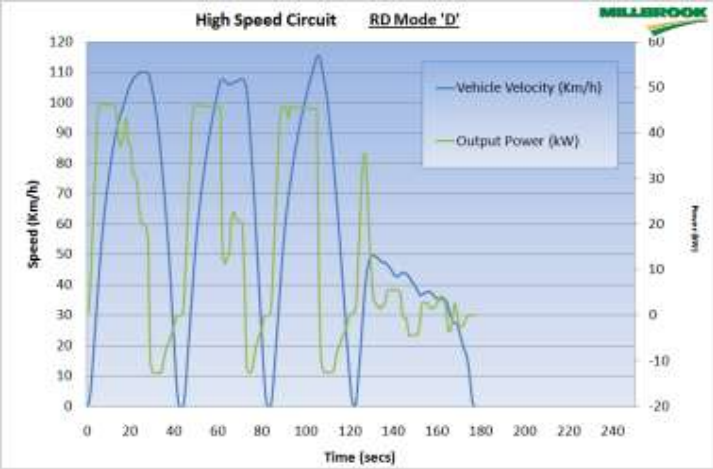
- 4.5 km
- Maintain 30-35 mph over various gradients (max gradient 11.6%)

- **Handling circuit (HC)**

- 2.7 km
- Representative of UK B road
- Speed limit 35 mph

EV track cycle range testing

Millbrook EV track cycle

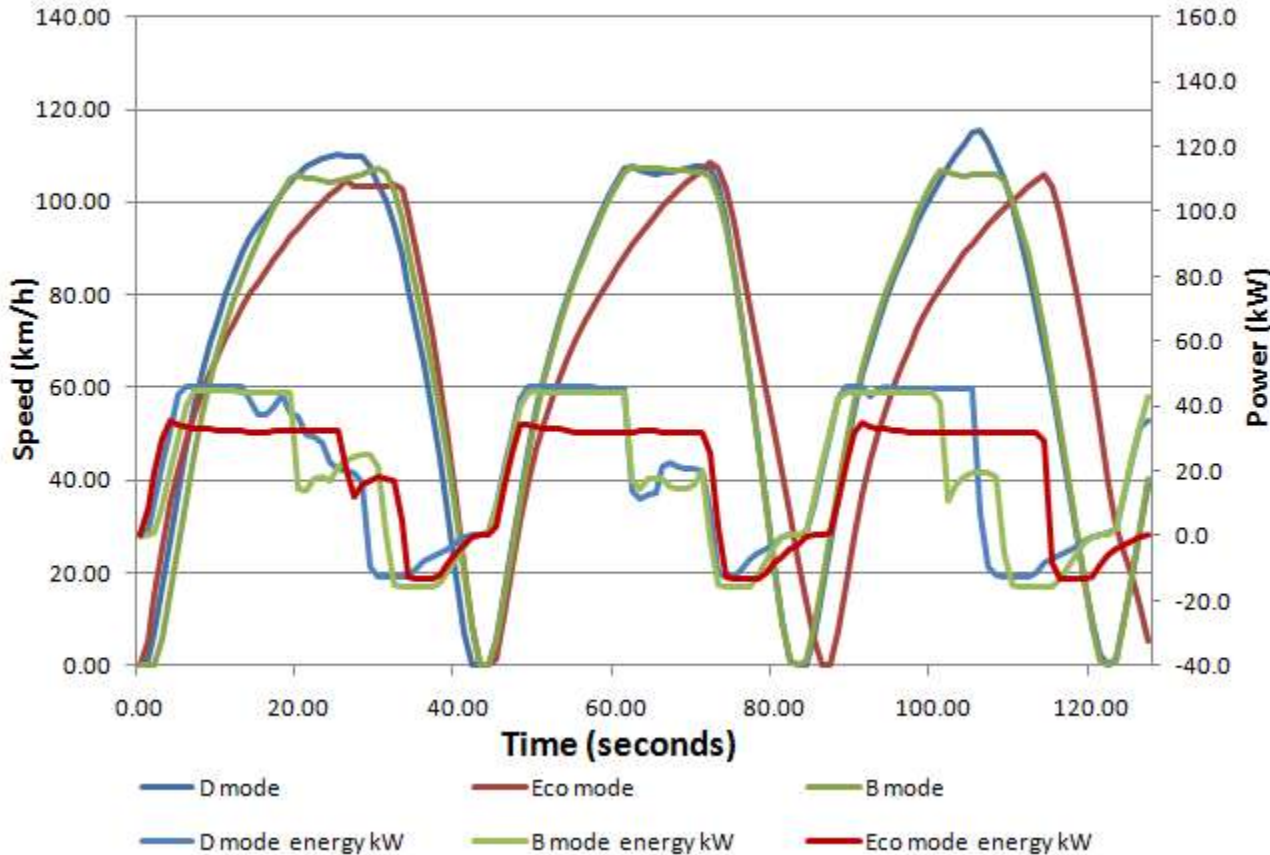


EV track cycle range testing

i_MiEV drive mode analysis

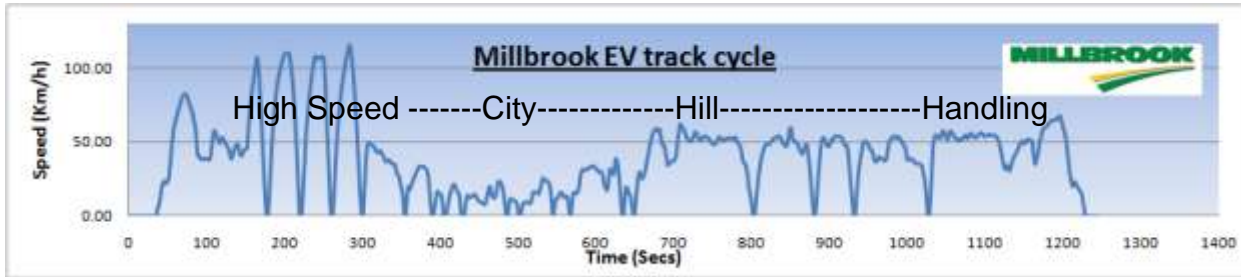


HSC MiEV performance analysis



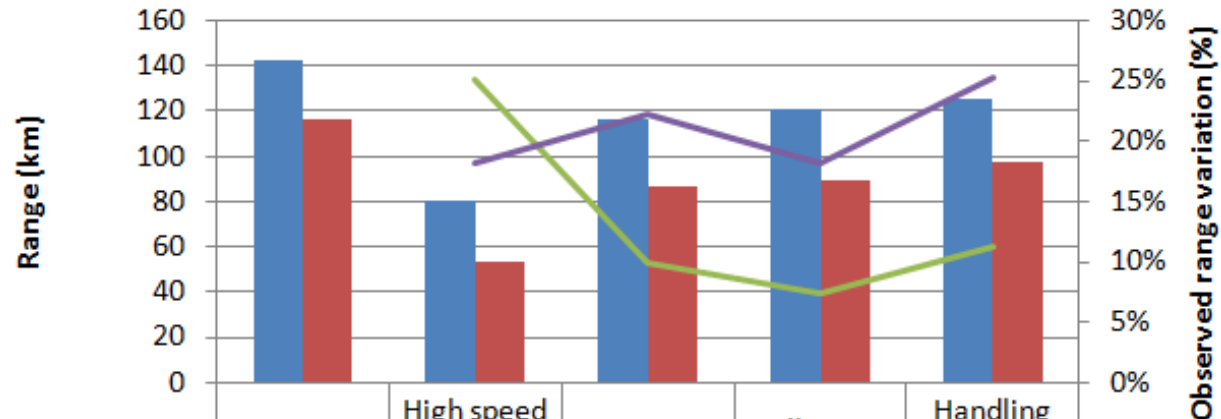
EV track cycle range testing

Range performance and variation



- High speed circuit has severe impact due to large accelerations and high speeds
- Hill route has little impact

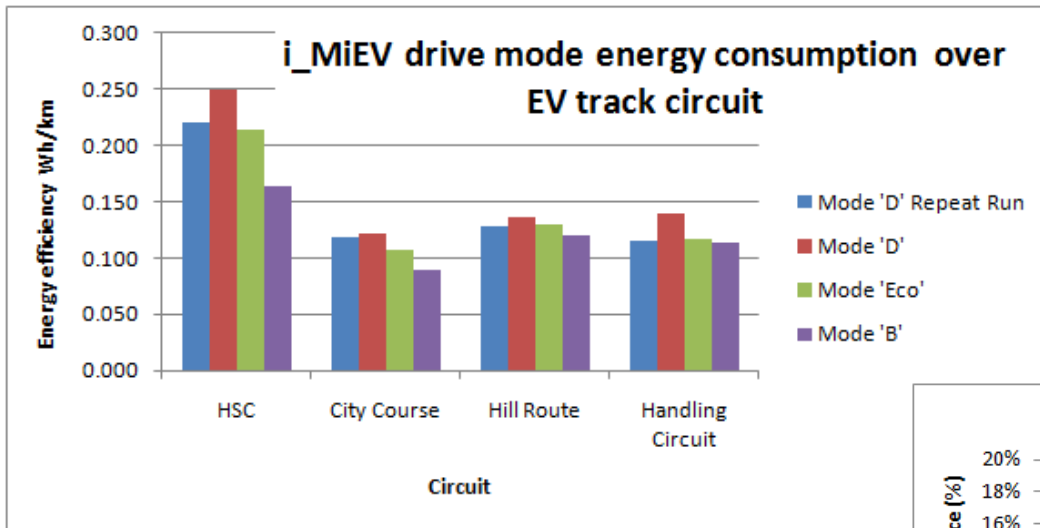
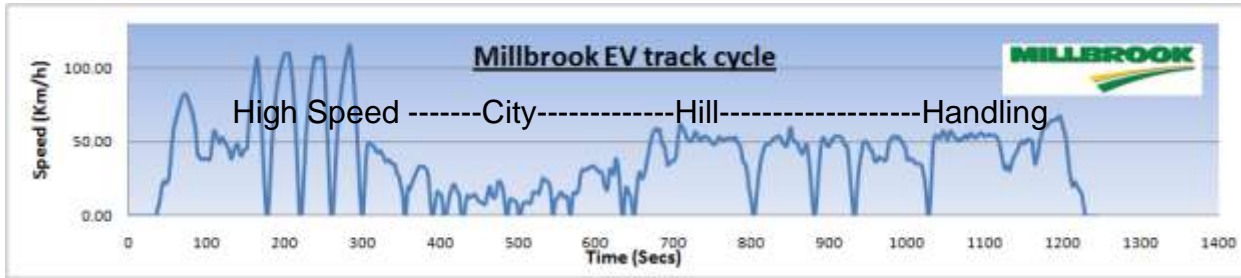
EV track cycle extrapolated range performance and variation



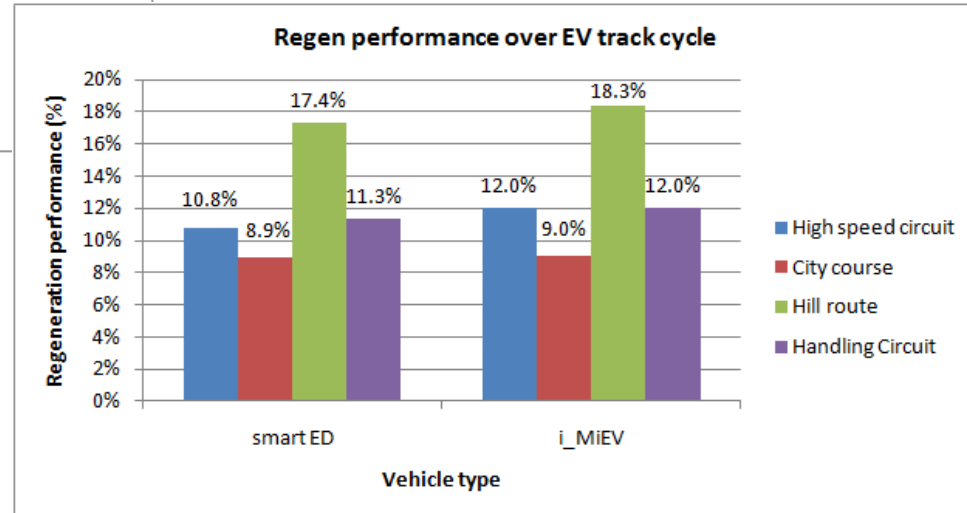
Smart ED	142	80.8	116.5	121.2	125.5
i_MiEV (D)	117	53.1	86.3	89.4	97.0
Smart ED variation (+/- %)		25.1%	9.9%	7.3%	11.3%
i_MiEV variation (+/- %)		18.2%	22.3%	18.2%	25.2%

EV track cycle range testing

Range performance and variation



- Limited impact of hill route, due to regeneration levels?
- i MiEV shows - increasing regeneration rate is more effective limiting power consumption



Mode	Power	Re-gen
Drive (D)	Max	Low
Eco (E)	Restricted	Medium
Brake (B)	Max	High

EV track cycle range testing

i_MiEV drive mode analysis



i_MiEV range differential by drive mode

Track cycle	Drive to Eco	Drive to B mode
High speed circuit	+ 3.6 %	+ 9.6 %
City course	+ 0.6 %	+ 8.7 %
Hill route	+ 2.6 %	+ 7.4 %
Handling circuit	+ 3.6 %	+ 3.0 %
Average	+ 2.6 %	+ 7.2 %

Mode	Power	Re-gen
Drive (D)	Max	Low
Eco (E)	Restricted	Medium
Brake (B)	Max	High

i_MiEV regen performance differential by drive mode

Track cycle	Drive to Eco	Drive to B mode
High speed circuit	+ 1.9 %	+ 32.2 %
City course	-1.6 %	+ 32.3 %
Hill route	+ 0.3 %	+ 9.6 %
Handling circuit	+ 31.8 %	+ 55.9 %
Average	+ 8.1 %	+ 32.5 %

EV range testing

Introduction



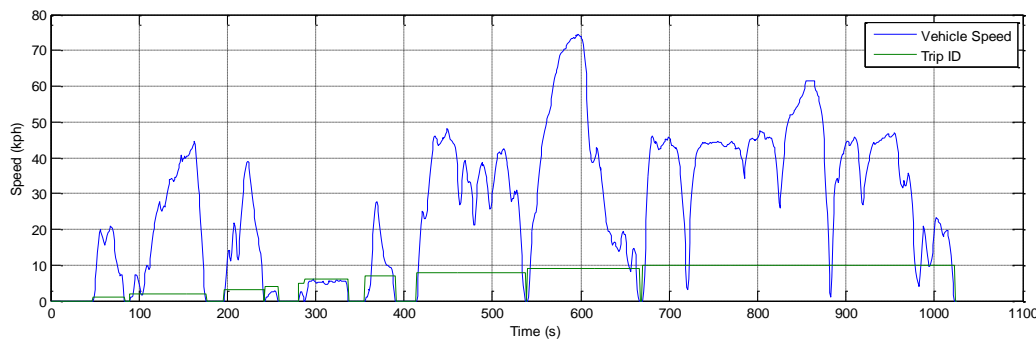
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EV drive event range testing

Cobalt business park – drive event

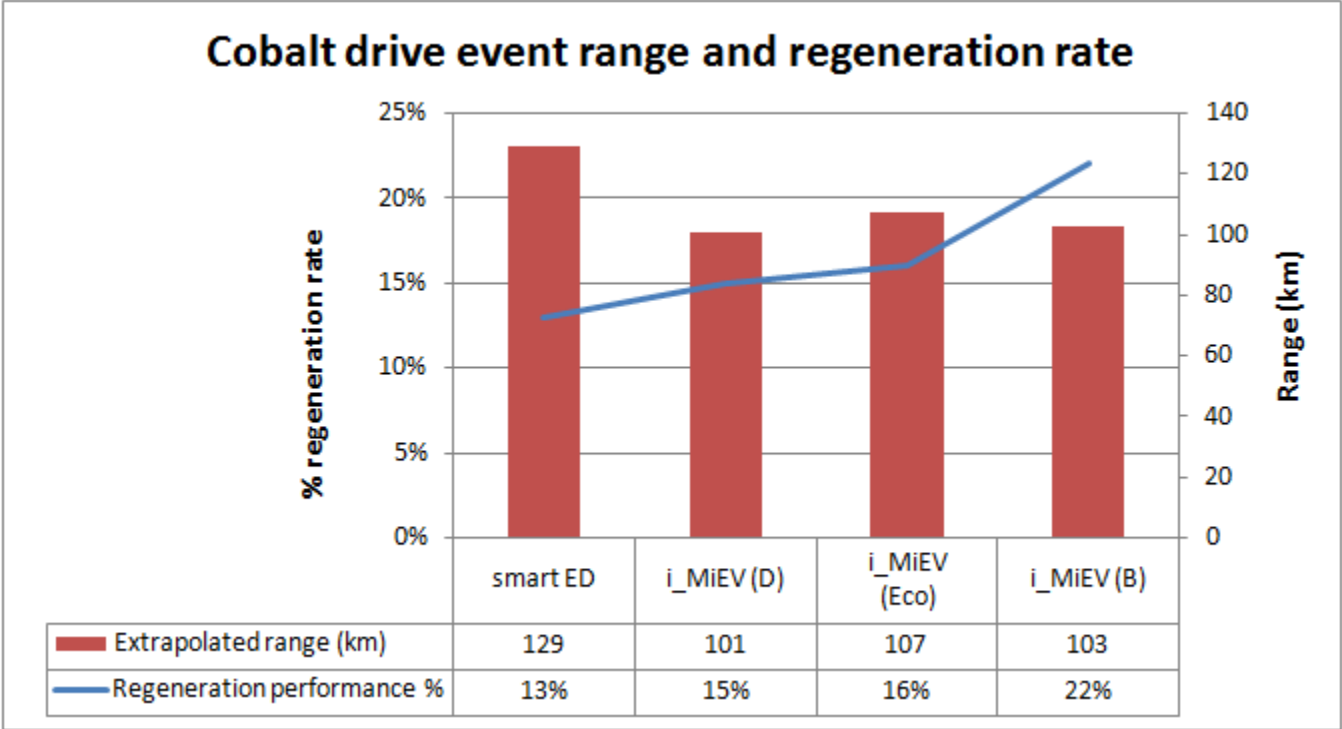


- Cobalt business park test drive
 - 33 logged test drives over two days
 - 7.5 km circuit encompassing urban, A road and B road duties



EV drive event range testing

Cobalt business park drive event

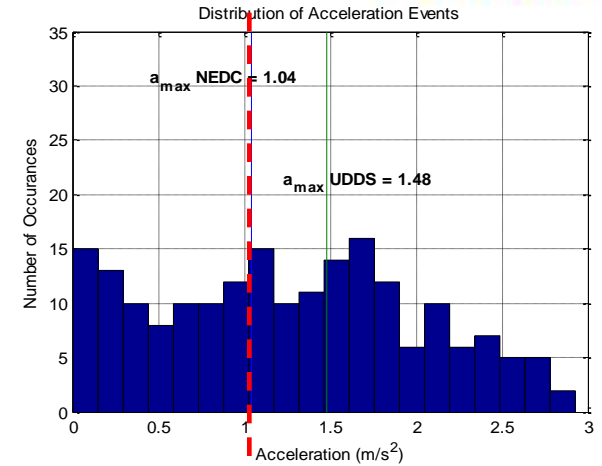
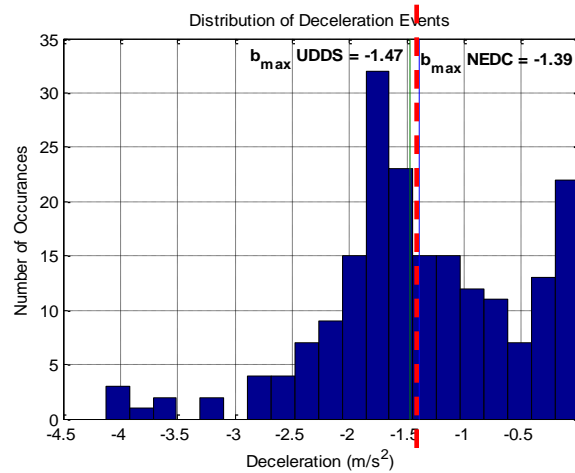


- Real world ranges reflect well to other tests, artemis road/urban and HC track values
- Regeneration performance follows similar pattern in drive event
- B Mode shows decrease range to lab and track work due to first time drivers not driving modifying driving style for increased regen rates

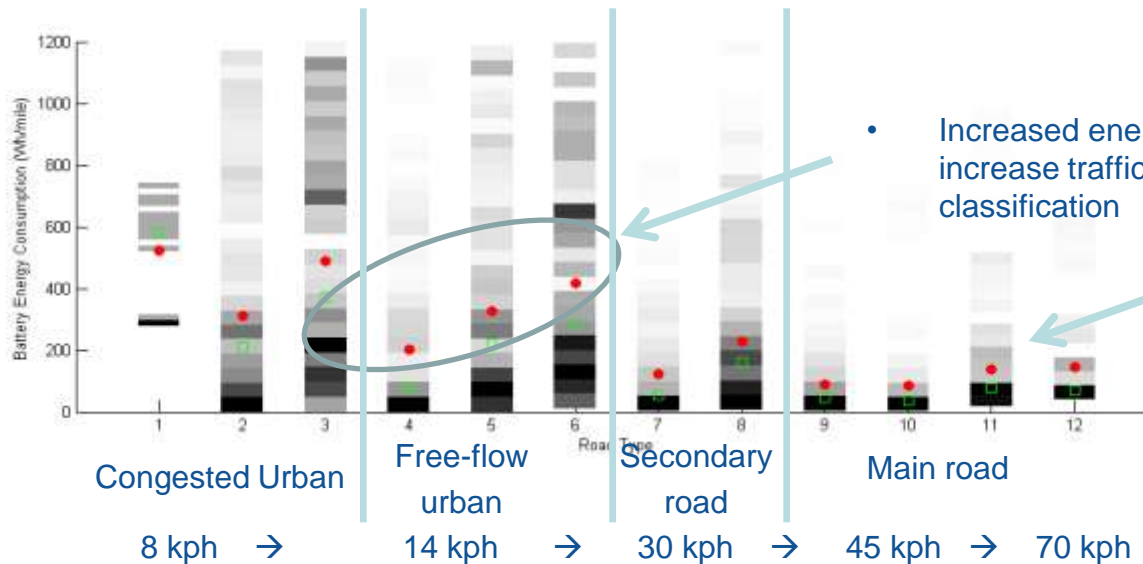
EV drive event range testing

Cobalt business park drive event

- Acceleration and decelerations rates high compared to test cycle



Power consumption by road condition



- Increased energy consumption with increase traffic flow within each road classification

- Energy consumption begins to increase with higher speed operation

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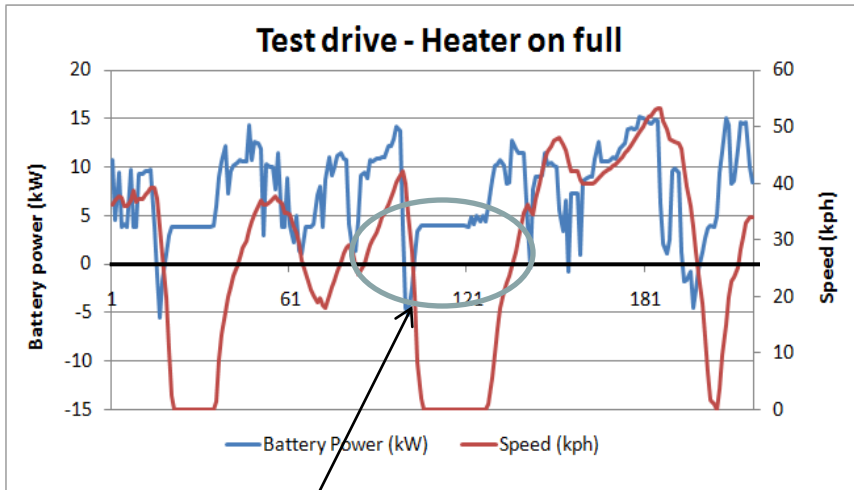
EV ancillary load range testing



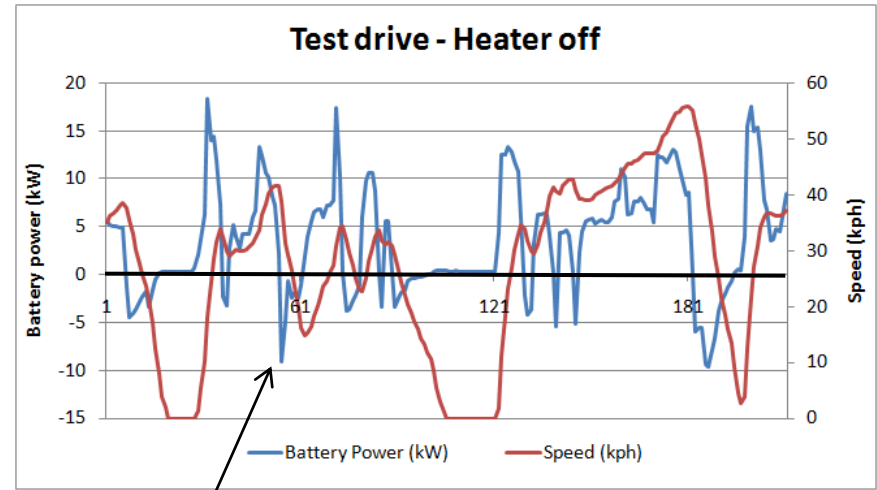
Vehicle heating demand range analysis

- Simultaneous testing of three heater settings using three smart cars
- 16 km route, average speed 40 kph
- Ambient temp 10 deg C
- On full condition - worst case scenario

Heater setting	Extrapolated range (km)	Range diff	Aux power consumption
Off	128 km	0	11.5 Wh/km
On - warm	115 km	- 10 %	33.7 Wh/km
On - full	85.5 km	- 33 %	98.4 Wh/km



High battery output at zero speed



Increased regeneration into battery

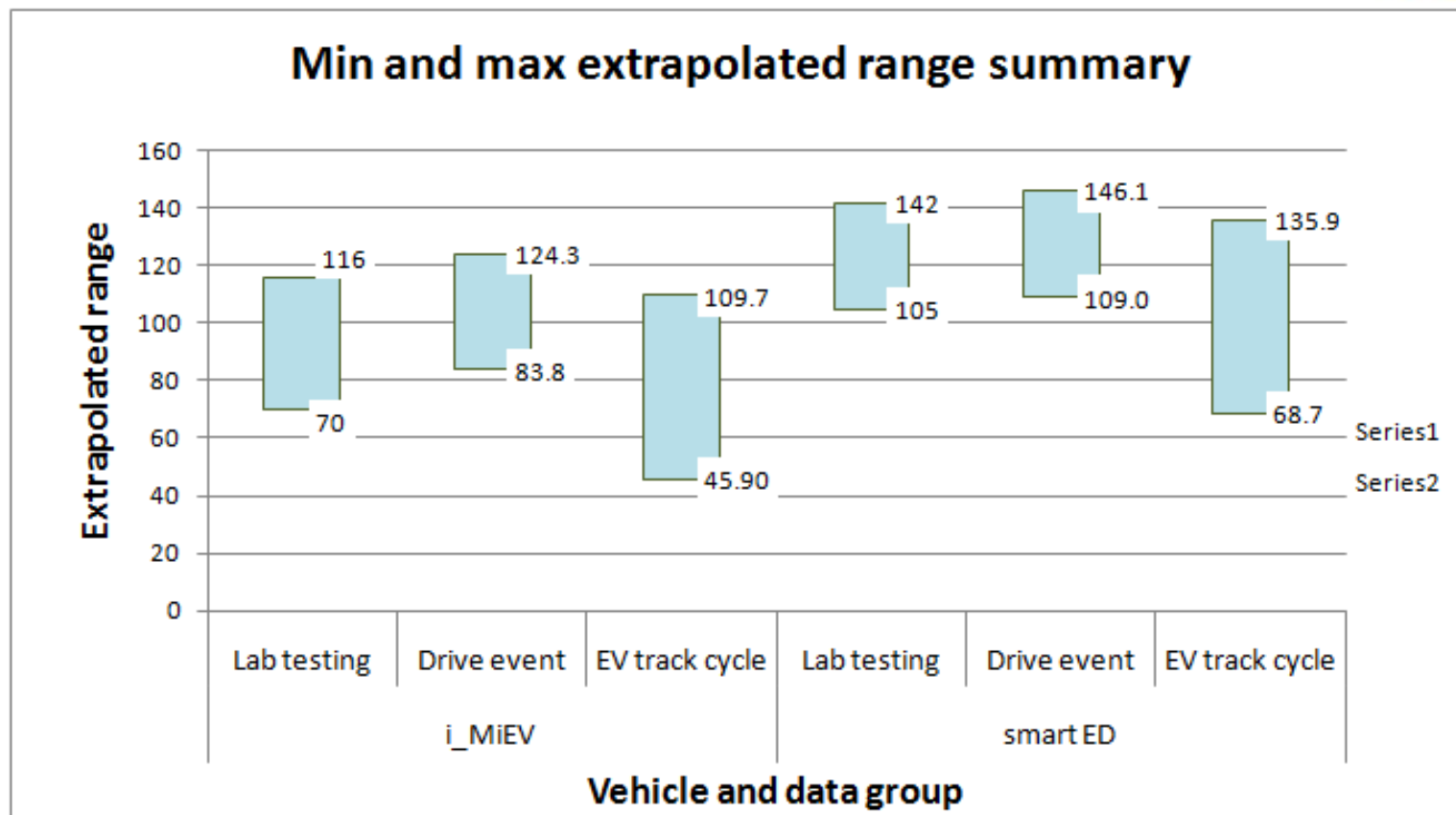
EV range testing



- Summary and conclusions

EV real world range testing

Range variation summary



- Mixture of regulation and real world drive cycles is a good representation of real world (drive event) range variation
- Higher range variation shown in EV test track cycle due to extrapolated HSC duty not representative of a driving duty, however does demonstrate worst case range

EV real world range testing



Conclusions

- 2 vehicles tested over in three experiments
 - Miev and smart – similar specifications
- Lab testing shows
 - Step performance increase from 450 to 451 smart
 - Considerably more range from the smart over the i MiEV on all cycles
 - I MiEV shows higher regen and effect of gearbox modes
 - High speed cycles severely limit range, speed limiting on the smart helps
- Track cycles show
 - Good co-relation between lab and track results for real world cycles
 - I MiEV work shows - increasing regeneration rate is more effective in extending the range of an EV than limiting power consumption
- Real world drive event
 - Data backs up the conclusions of the lab and track work
 - Demonstrates typical driver behaviour in EV's, accel/decel rates far exceed the NEDC
- Heating/cooling
 - Load levels demonstrate typical use range reduction of 10% and worst case of 33%



Thank you for your attention

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