# Cenex

Centre of excellence for low carbon and fuel cell technologies

## EV range testing

November 2010

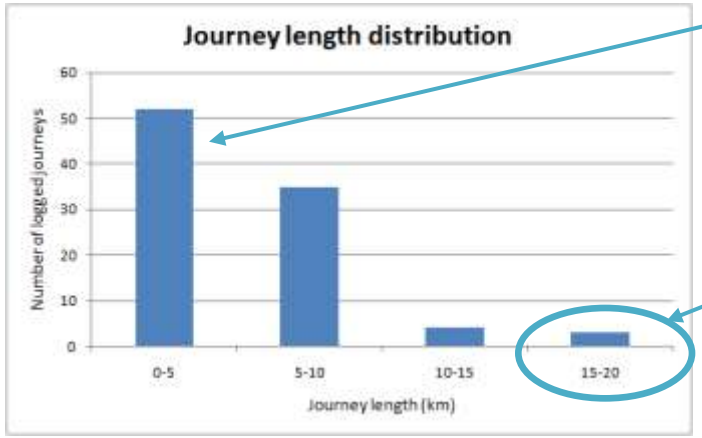
# EV range testing

## 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

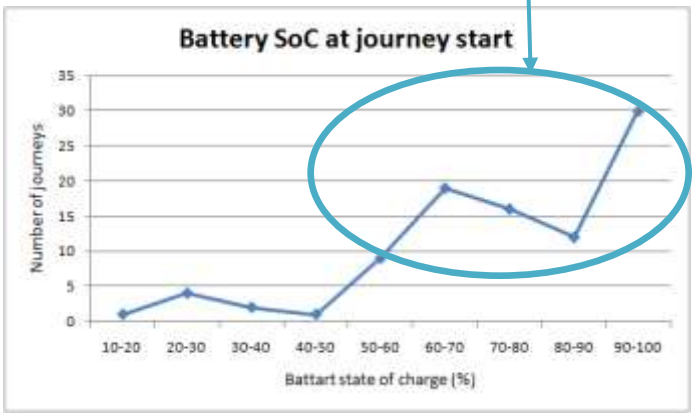
## introduction - why range?




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

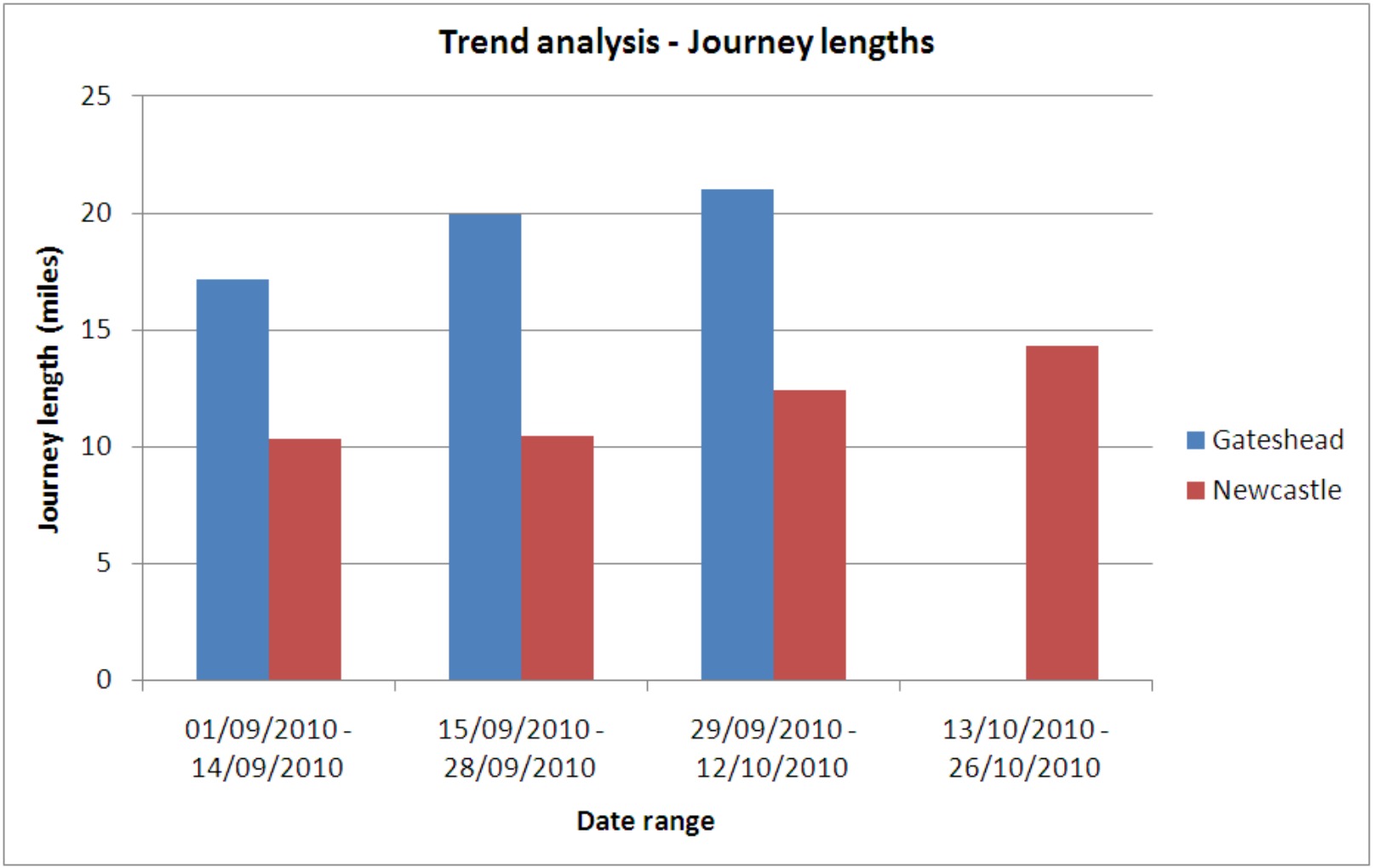
The maximum journey length is 17.8 km. This represents only 46% of the minimum extrapolated range observed during the trial, or 25% of the average range

93 percent of journeys are started with above 50% SoC



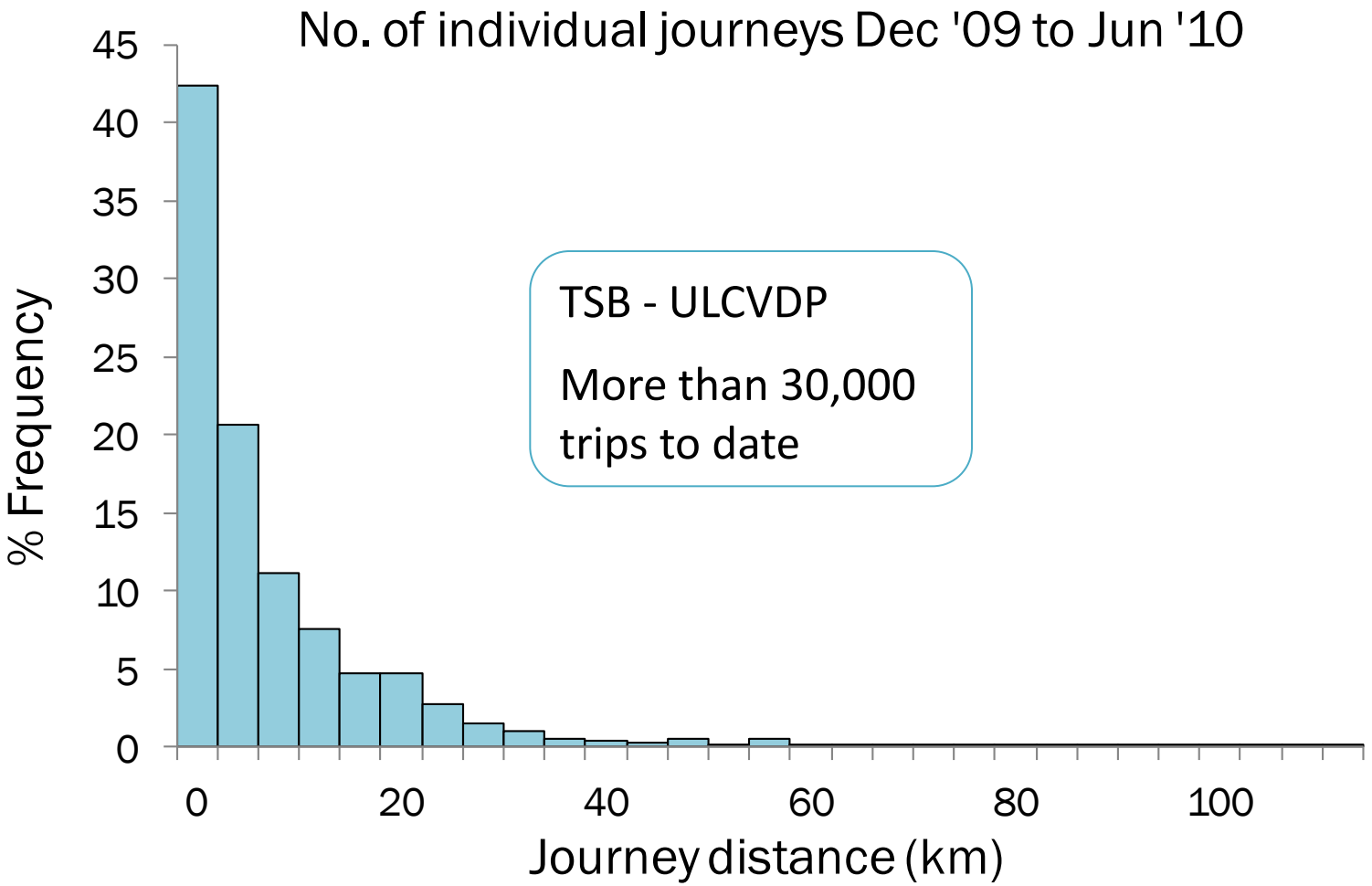
# EV range testing

## 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

# EV range testing

- 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

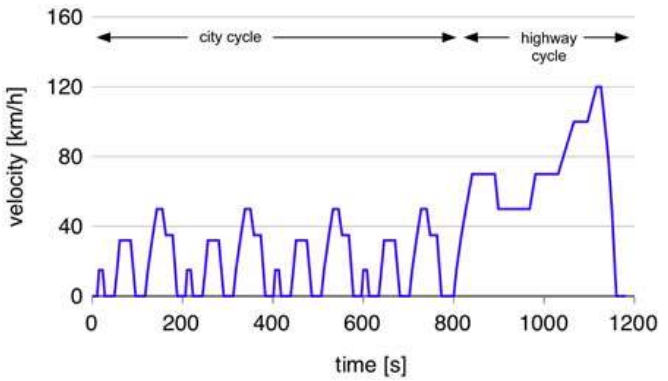
# EV laboratory range testing

## Regulatory range testing to R101

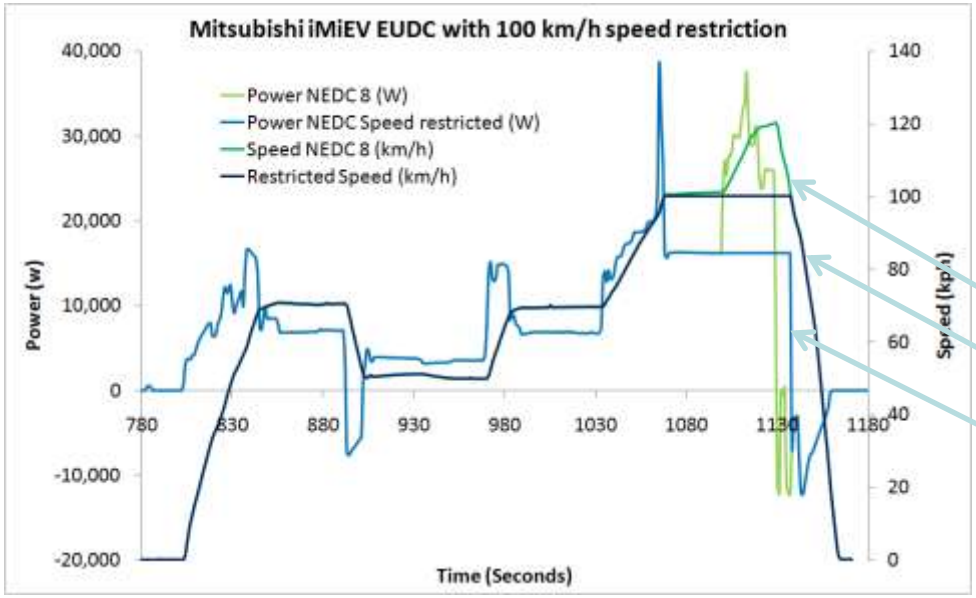
| | smart | i_MiEV | i_MiEV (100 km/h) |
|---|---|---|---|
| Range | 142 km | 116 km | 120 km |

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

Ref. 2010 DECC/Defra emission factors for company reporting, 617.07g $CO^2$/kWh

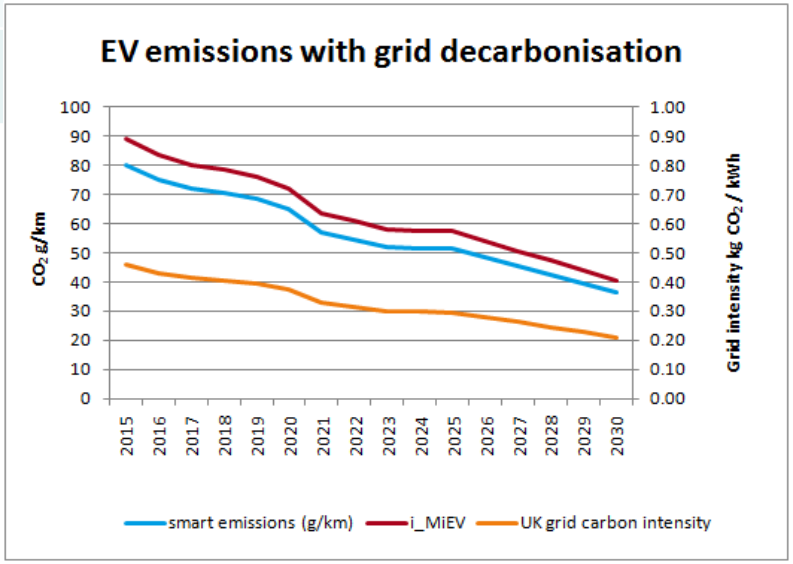
# EV laboratory range testing

## Regulatory range testing $CO_2$ 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 $CO_2e$ (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 %

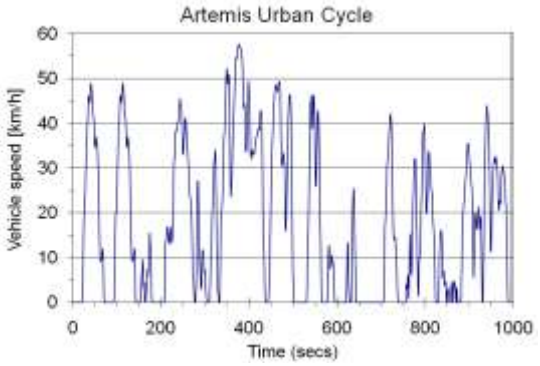
[1] – DEFRA guidance for company emission reporting 2010
[2] – DECC Marginal emission factor used for energy policy appraisals



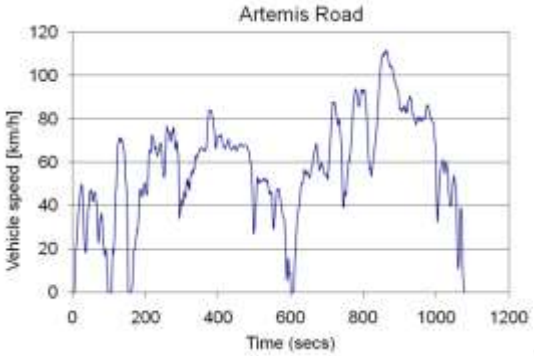

[1] Ref. 2010 DECC/Defra emission factors for company reporting, 617.07g $CO^2e$/kWh
[2] DECC Inter-department analysis guidance on valuation of energy use and greenhouse gas emissions

# EV laboratory range testing

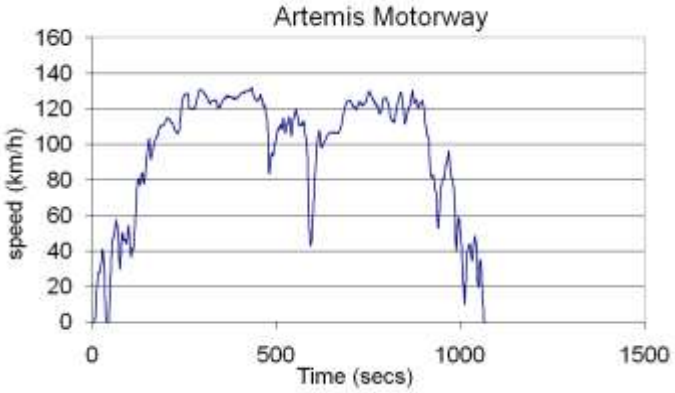
## Extrapolated real world drive cycles




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



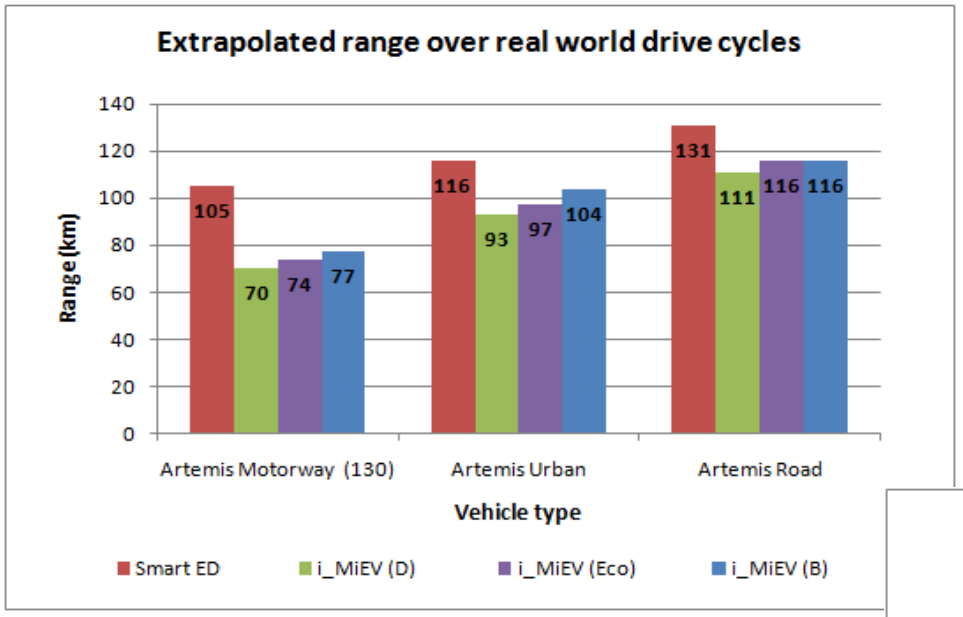

Distance: 28.7 km
Average speed: 97 km/h
Max speed: 131.8 km/h

- 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 |

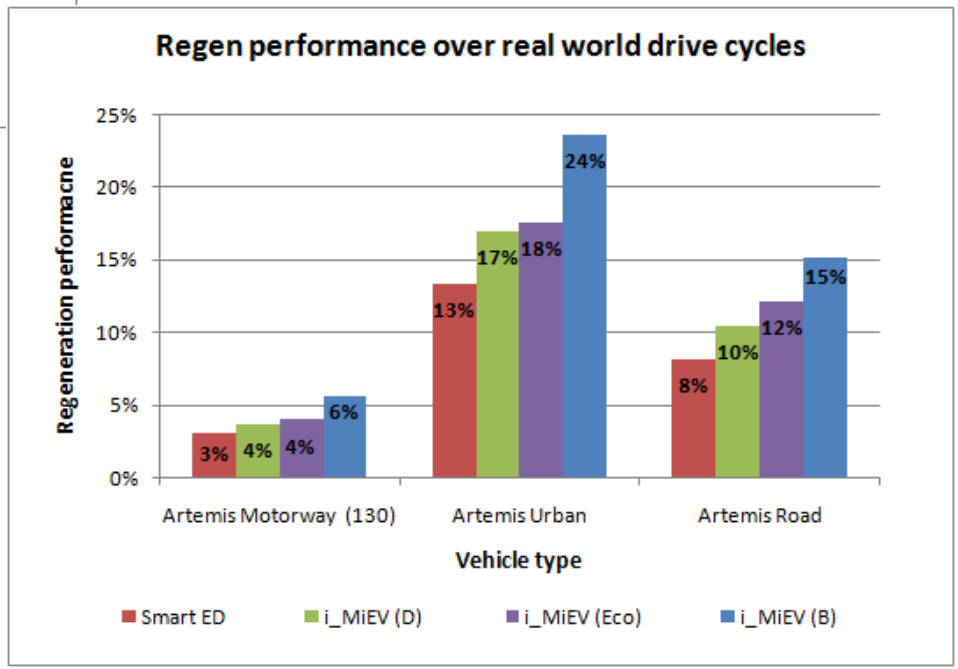
# EV laboratory range testing

## 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 |



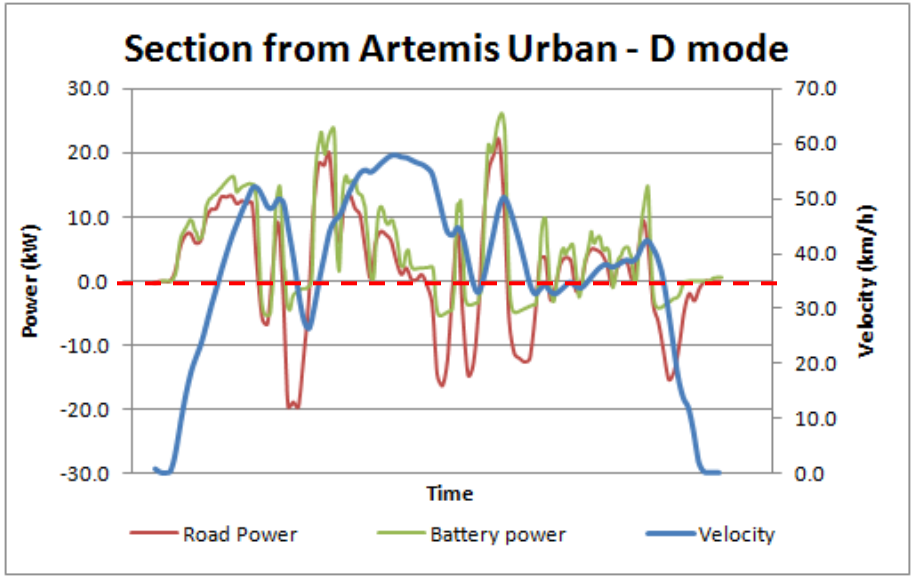
# EV laboratory range testing

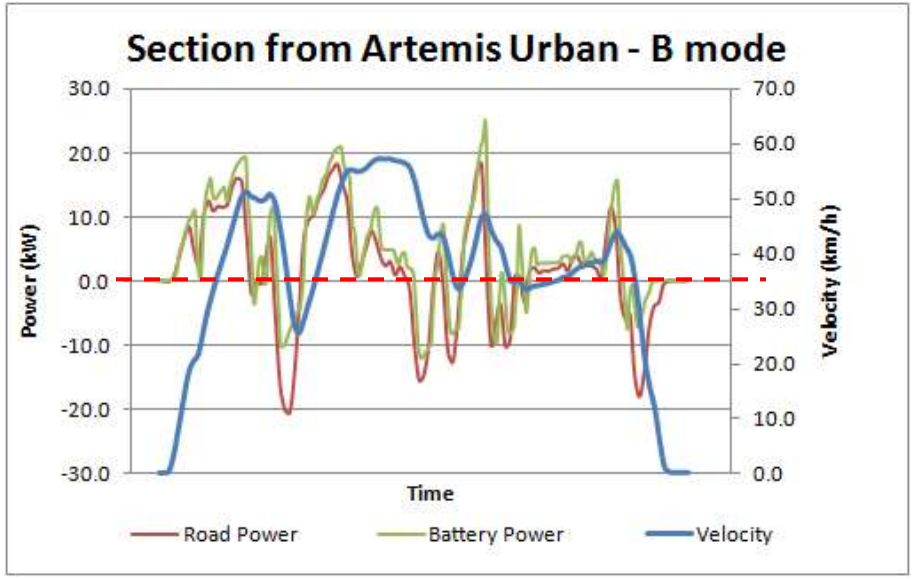
## i_MiEV drive mode focus

| 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



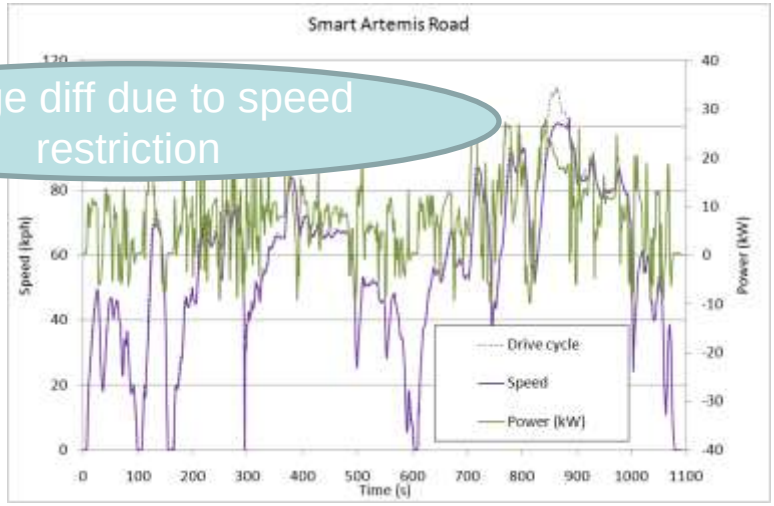



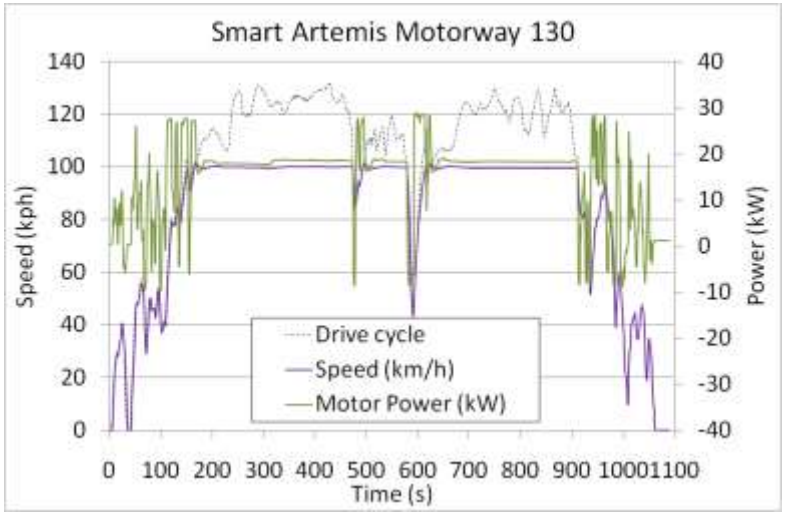
# EV laboratory range testing

## 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 % |


Range diff due to speed restriction



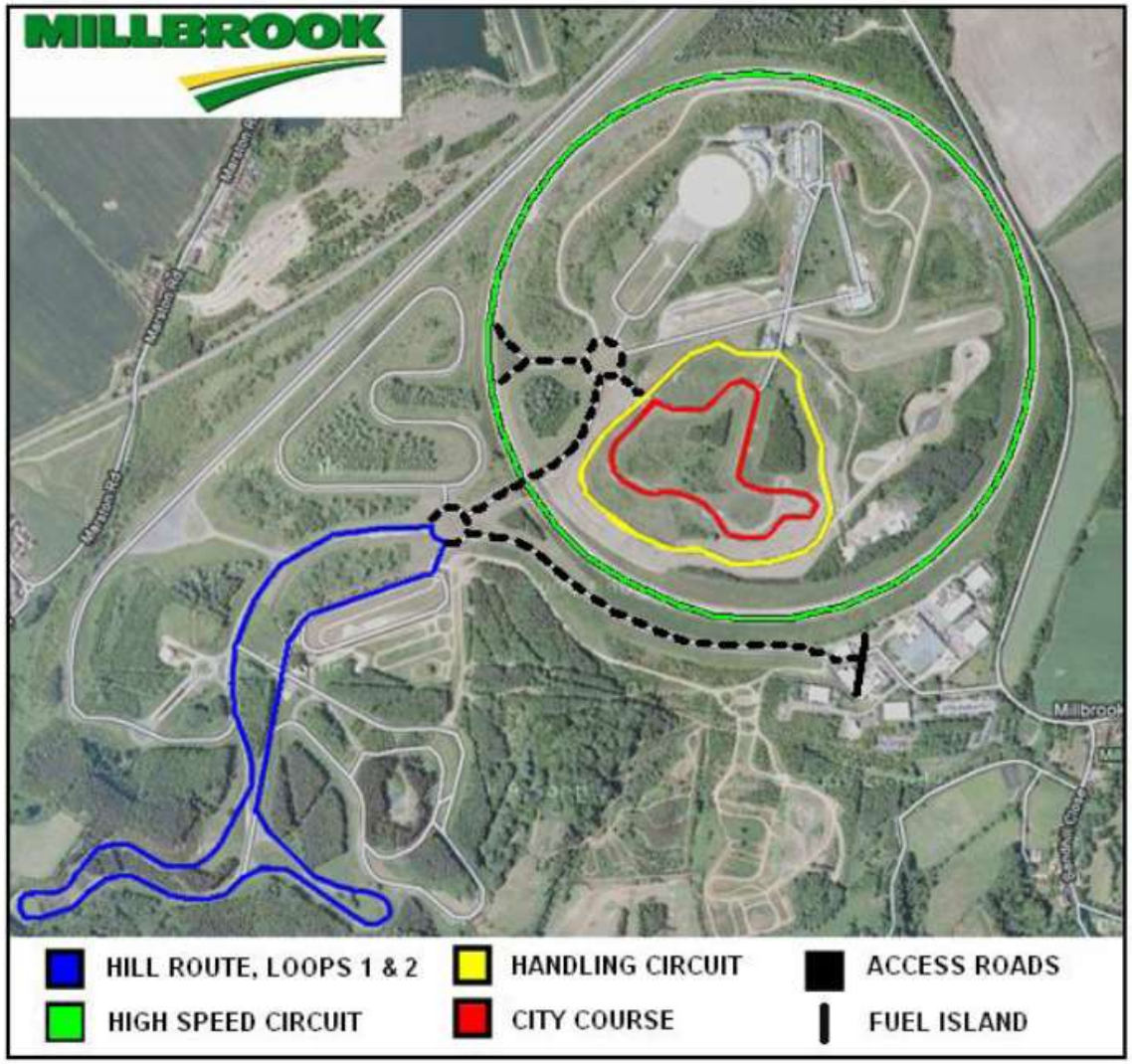



# EV range testing

- 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 track cycle range testing

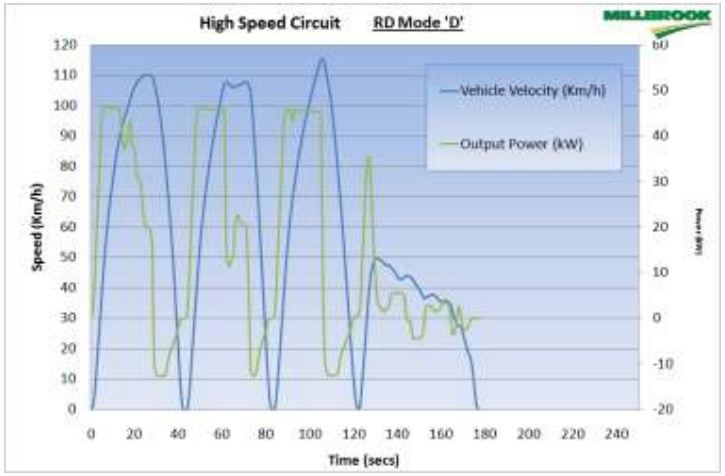
## Millbrook EV track cycle

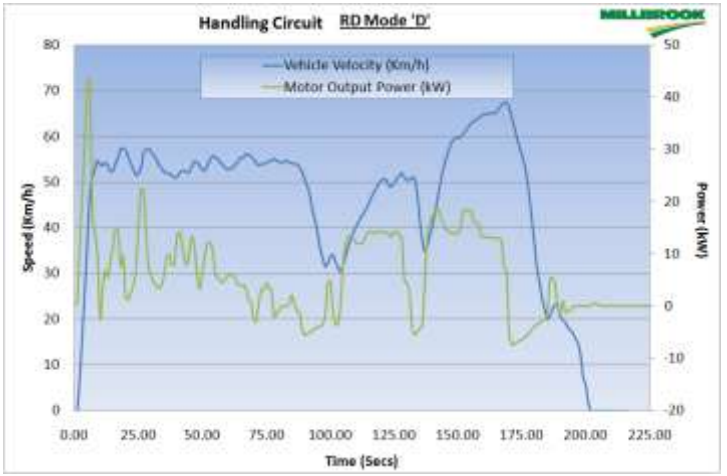



- **High speed circuit (HSC)**
  - 3.2 km
  - Enter 30 mph
  - Accelerate to 112 kph in between four predefined rest points
  - Exit 30 mph
- **City course (City)**
  - 1.4 km
  - Urban city course (max speed 48 kph) with numerous stops
  - Reverse park
  - Posted speed limits
- **Hill route (Hill)**
  - 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

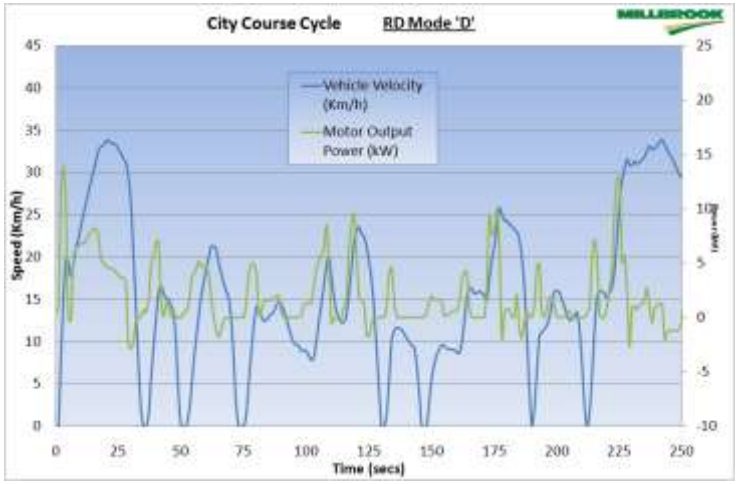
# EV track cycle range testing

## Millbrook EV track cycle



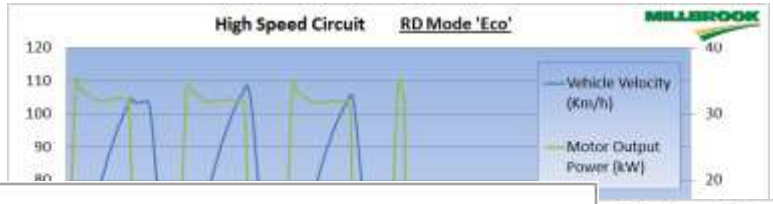



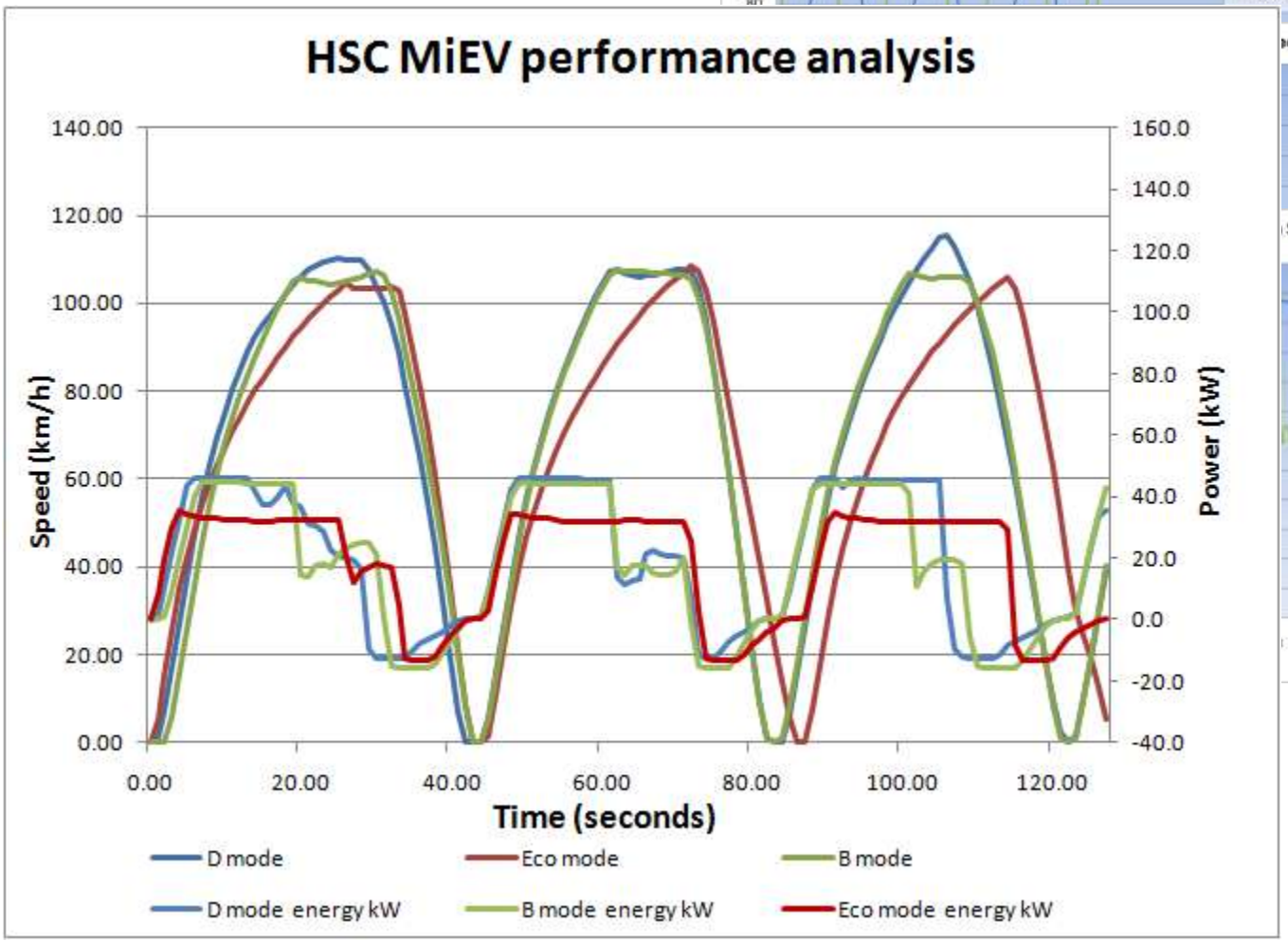


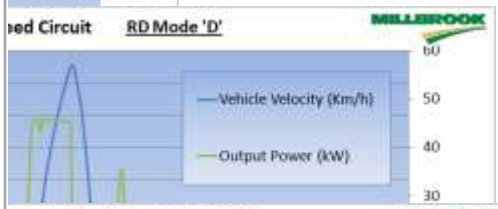


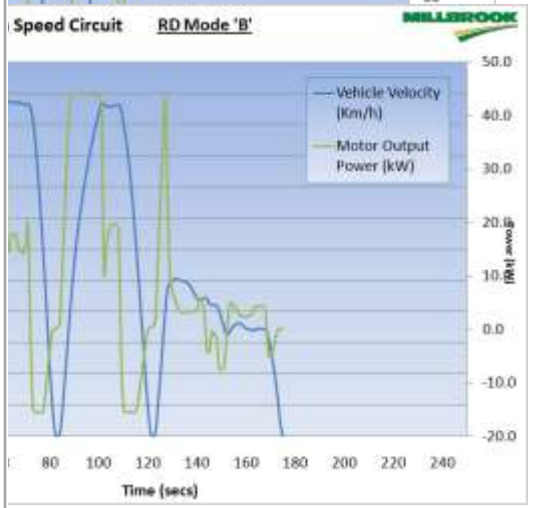
# EV track cycle range testing

## i_MiEV drive mode analysis



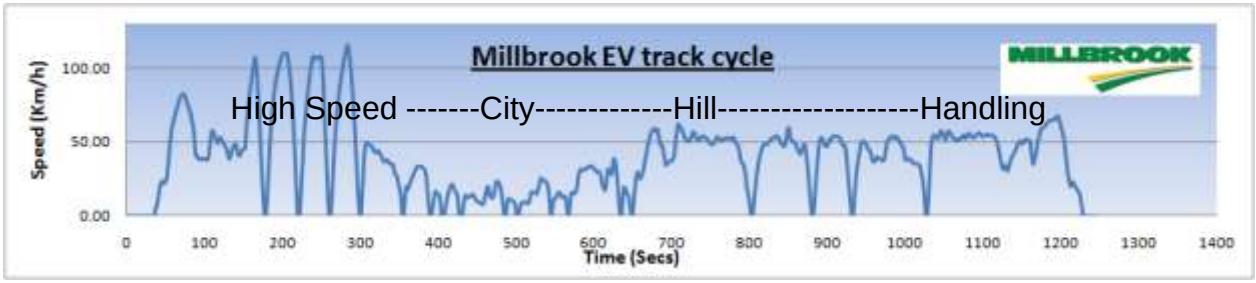



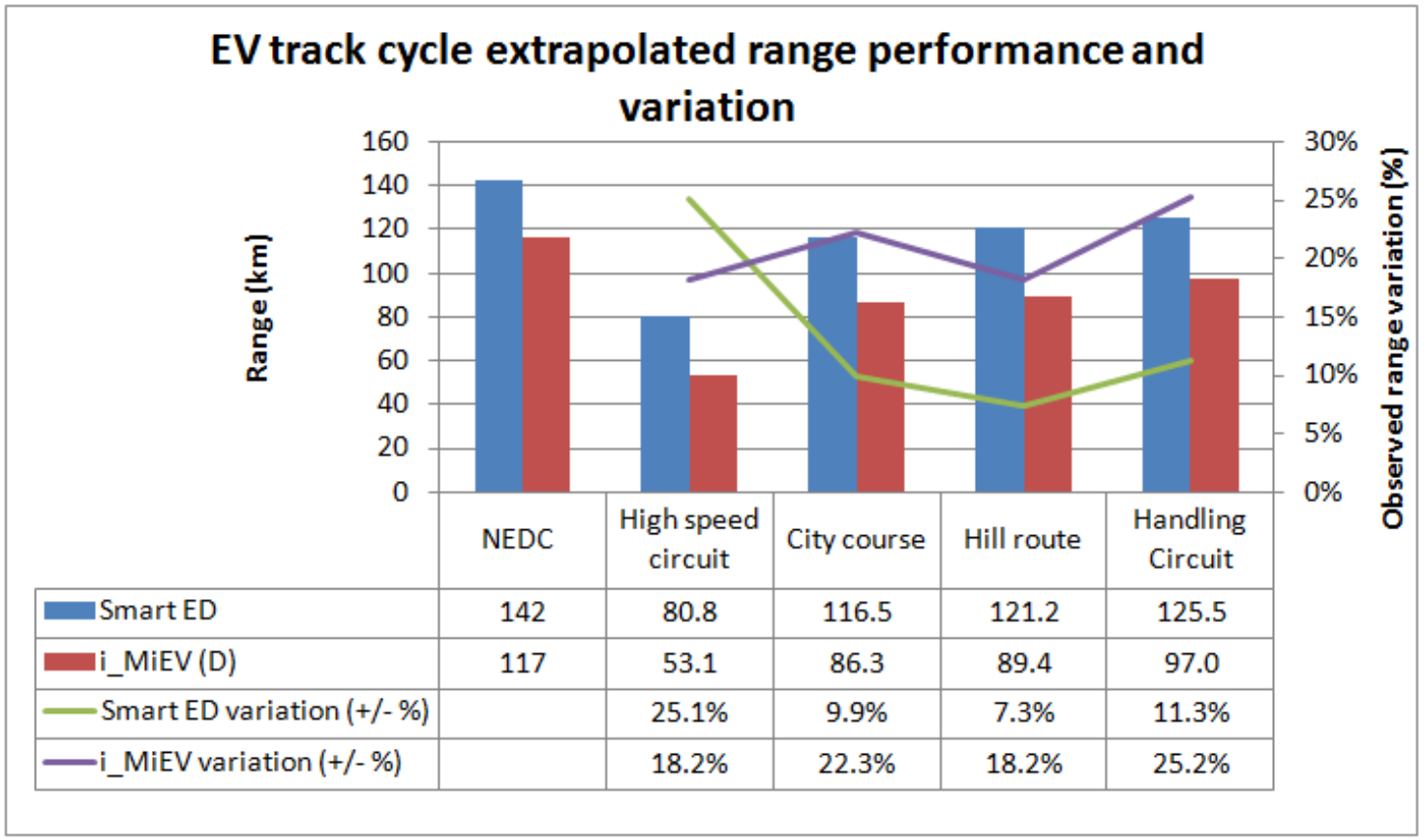



# EV track cycle range testing

## Range performance and variation



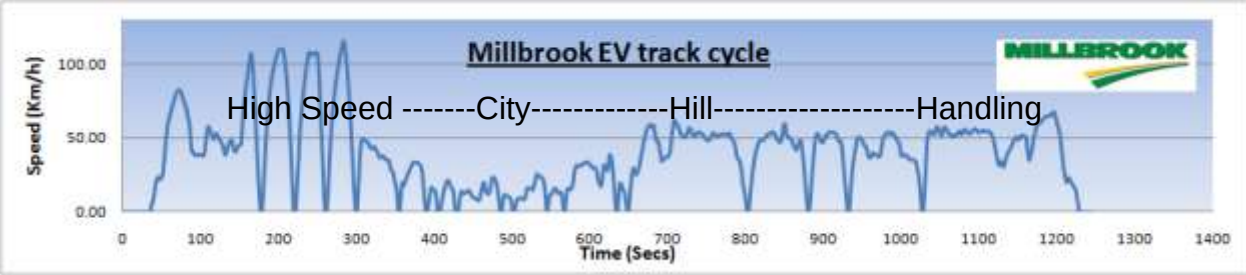

- High speed circuit has sever impact due to large accelerations and high speeds
- Hill route has little impact

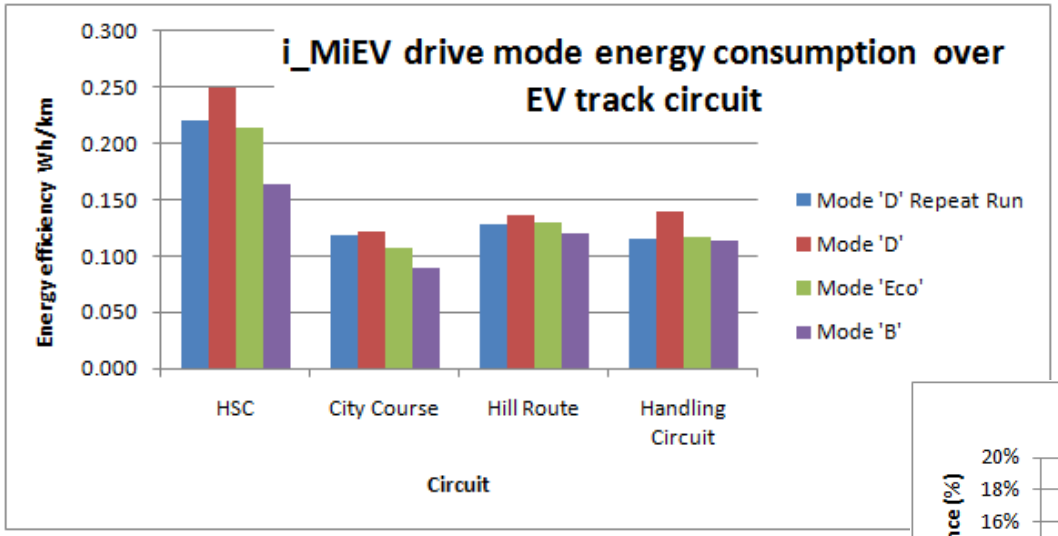



| | NEDC | High speed circuit | City course | Hill route | Handling Circuit |
|---|---|---|---|---|---|
| Smart ED | 142 | 80.8 | 116.5 | 121.2 | 125.5 |
| i_MiEV (D) | 117 | 53.1 | 86.3 | 89.4 | 97.0 |
| Smart ED variation (+/- %) | | 25.1% | 9.9% | 7.3% | 11.3% |
| i_MiEV variation (+/- %) | | 18.2% | 22.3% | 18.2% | 25.2% |

# EV track cycle range testing

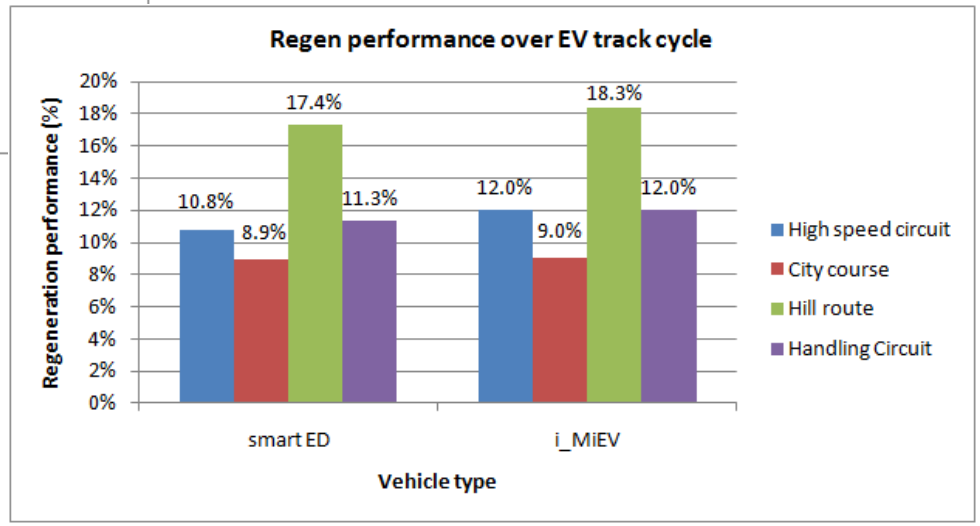
## Range performance and variation




- 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

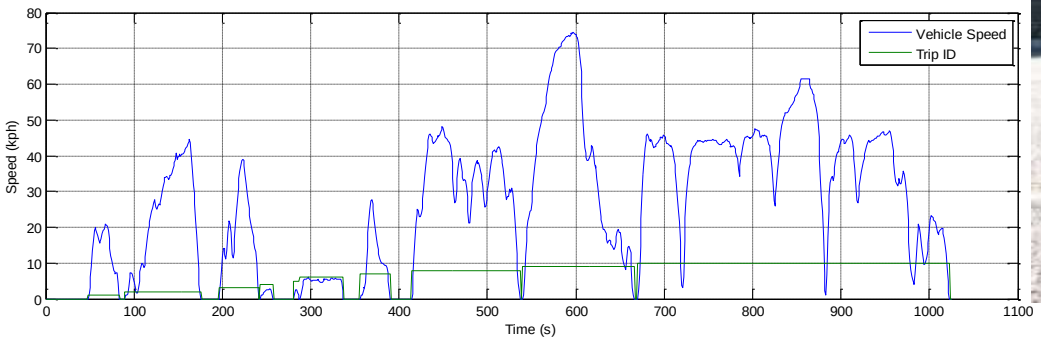
## Introduction

- 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 drive event range testing

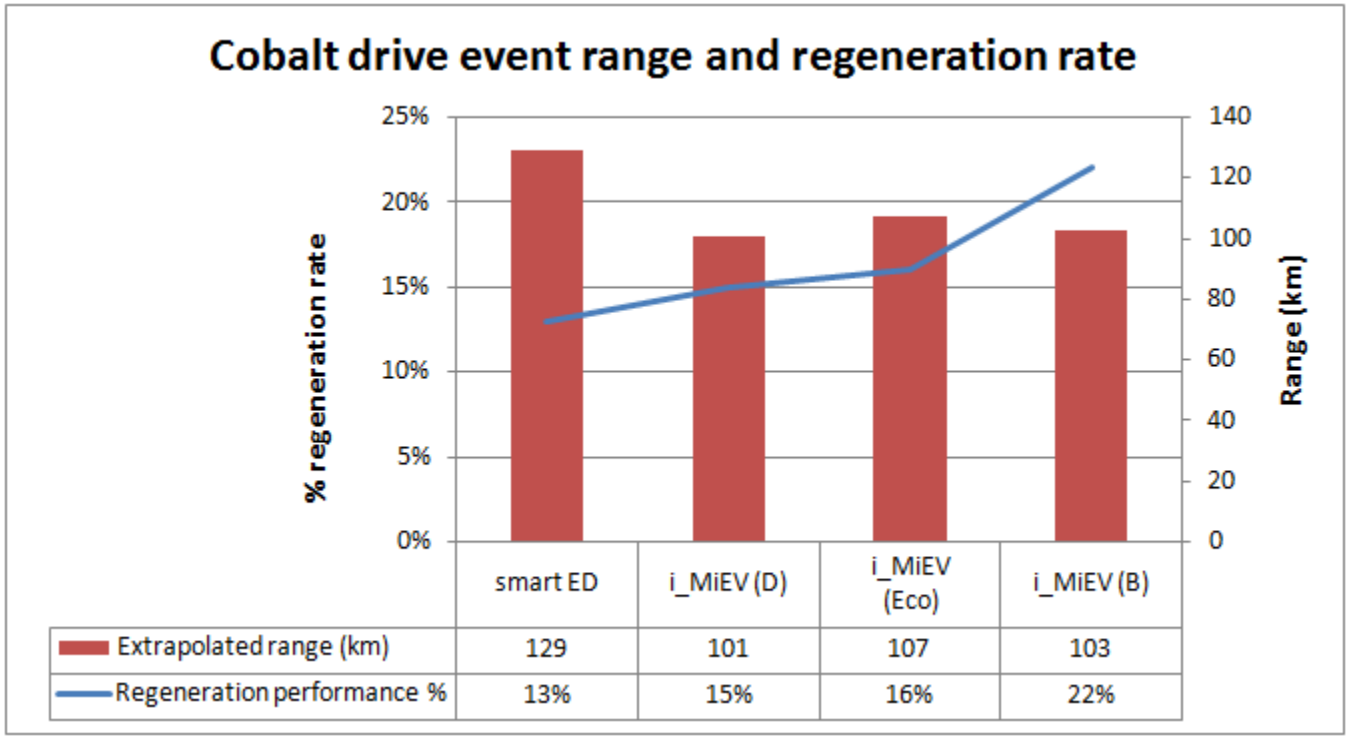
## Cobalt business park – drive event

- 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

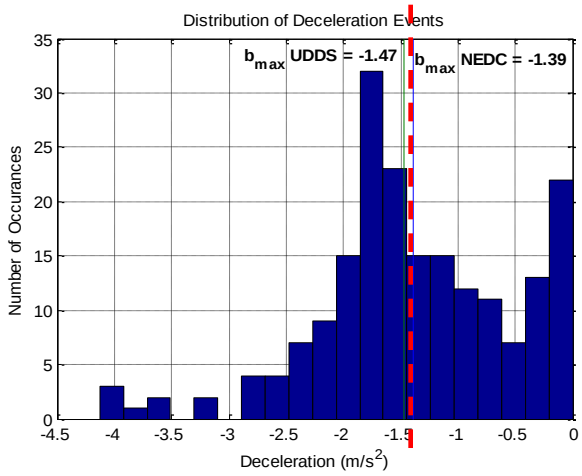


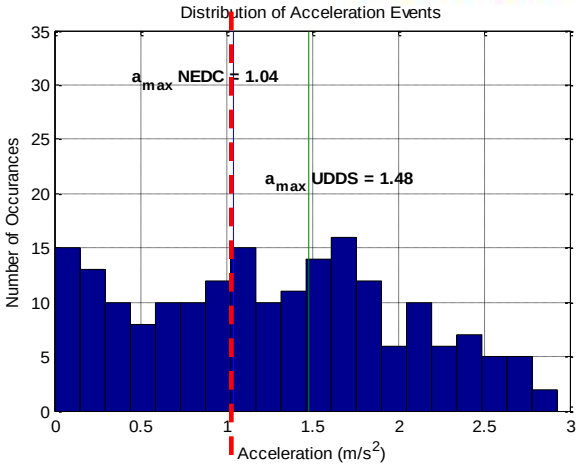

- Real world ranges reflect well to other tests, artemis road/urban and HC track values
- Regeneration performance follows similar pattern in drive event
- B Mode shows decrease range to lab and track work due to first time drivers not driving modifying driving style for increased regen rates

# EV drive event range testing

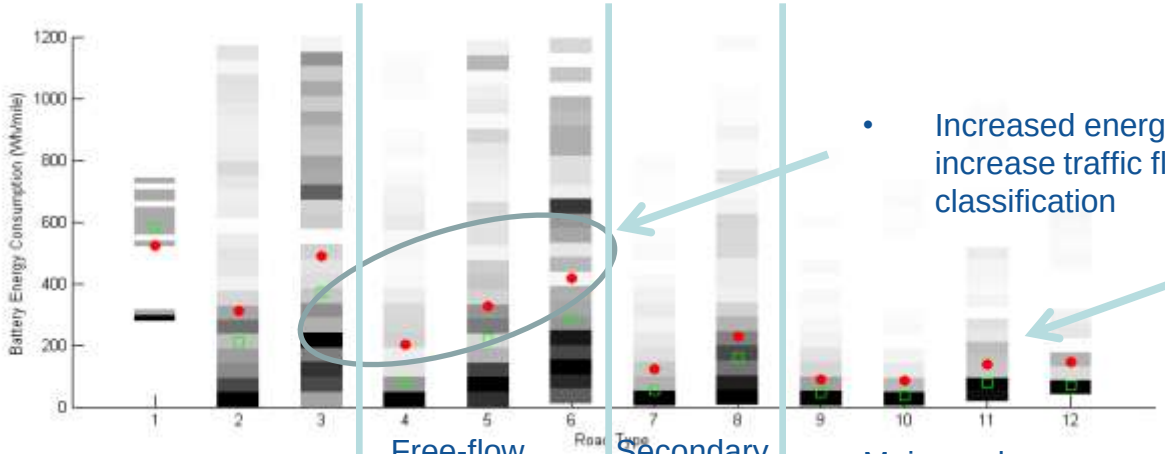
## Cobalt business park drive event

- 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

# EV range testing

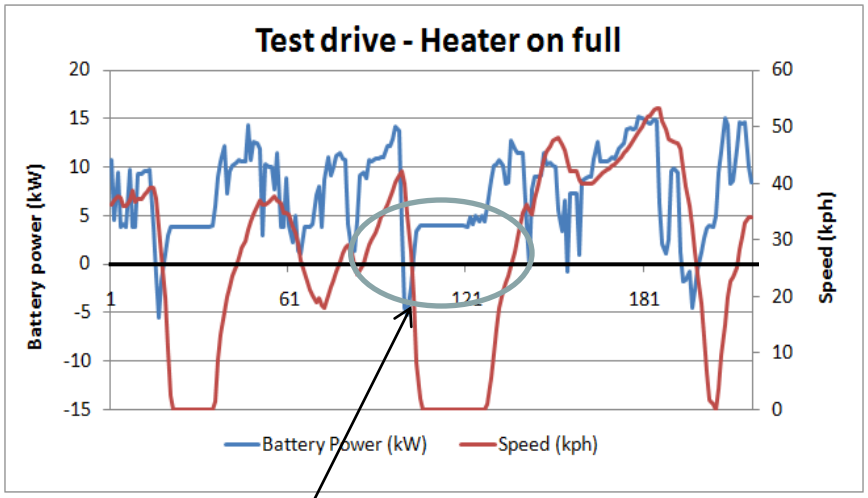
- Study of EV range under different test scenarios
  - Laboratory range testing
    - Regulated cycle R101 over NEDC
    - Real world drive cycles, artemis urban, rural and motorway
  - Millbrook EV track cycle
    - High speed circuit
    - City course
    - Hill course
    - Urban circuit
  - Cenex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

# EV ancillary load range testing

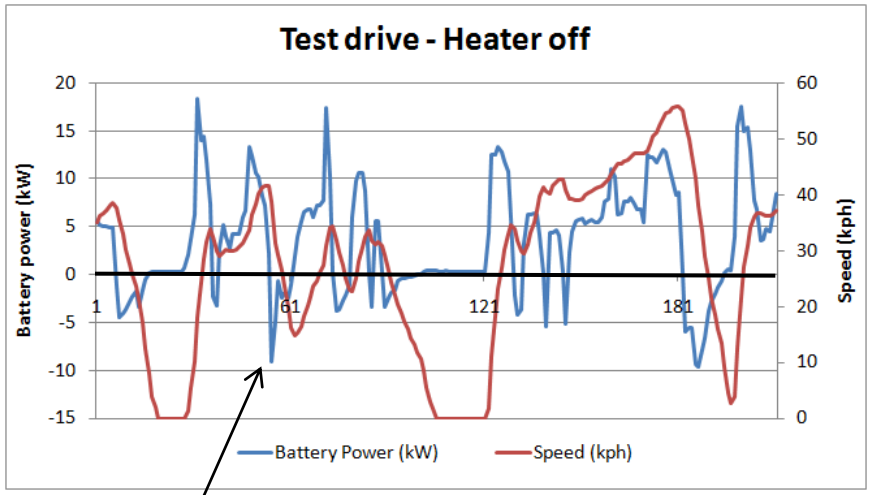
## Vehicle heating demand range analysis

- 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



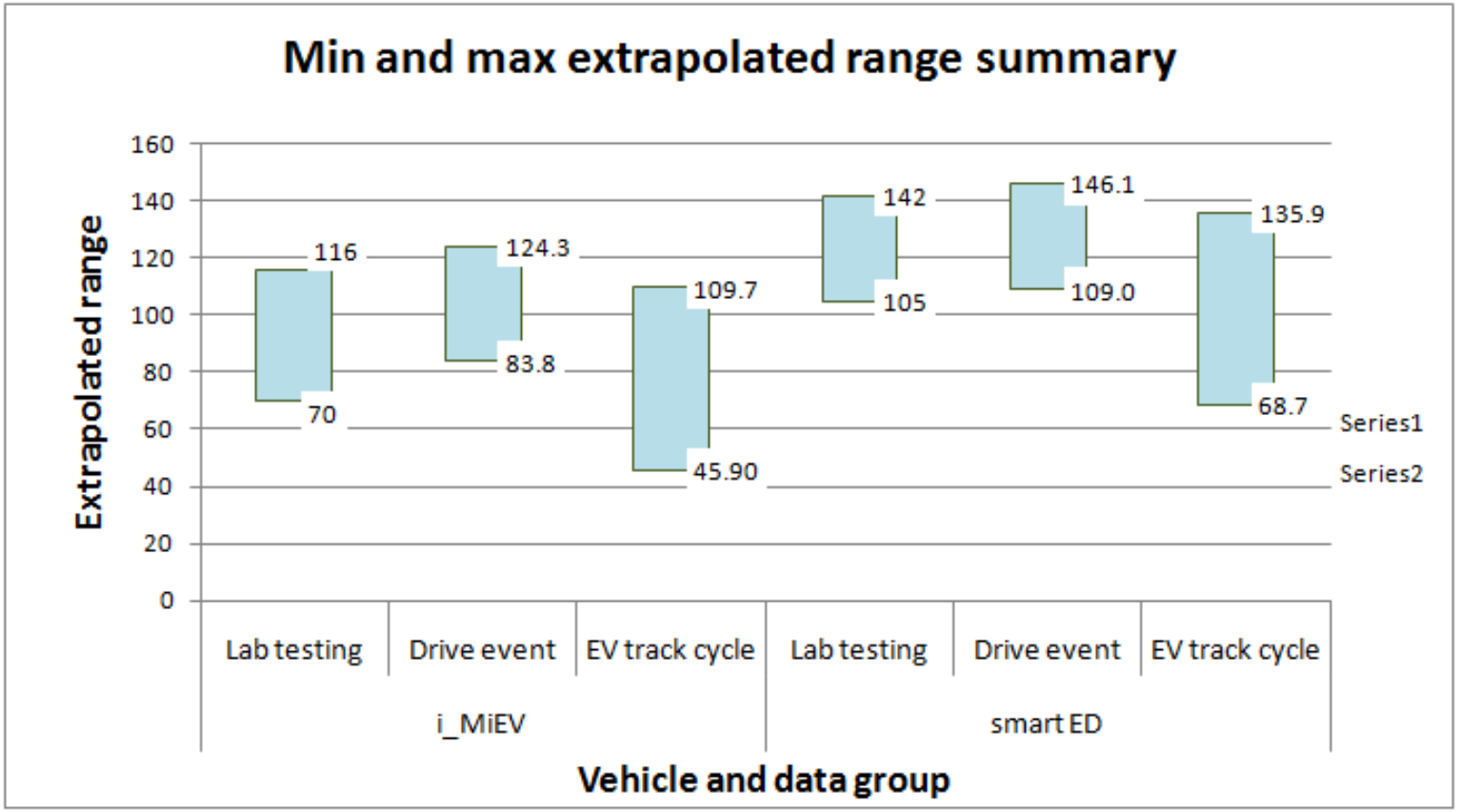

Increased regeneration into battery

# 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

www.cenex.co.uk