Cenex

Centre of excellence for low carbon and fuel cell technologies

EV performance study by driving style and duty

Electric Vehicle Studies dissemination event

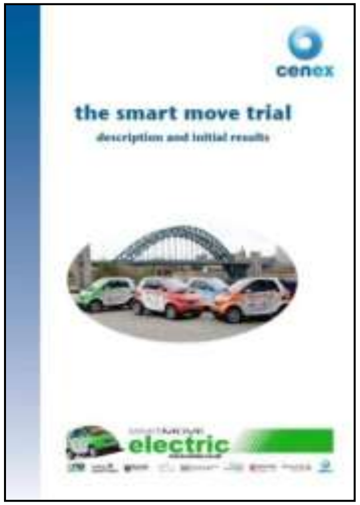
Millbrook proving ground

November 2010

smart move trial

Introduction

- Smart move trial phase 1
  - Study of electric vehicle integration into fleets
  - Perception and attitudes towards EVs
  - **EV performance analysis by driving style and duty study**



Available from www.cenex.co.uk

- Smart move trial extension
  - EV range testing (lab, track and drive event)
  - EV traffic flow studies
  - User group workshops
  - **EV passenger car case studies**

smart move trial

EV performance by driving style and duty

- Investigate the influence of driving style and duty on energy use
- EV track cycle at Millbrook
- Driver selection methodology
- Energy efficiency and variation by motoring and regeneration
- Regeneration rate variation over track cycle
- Diesel / EV efficiency comparison
- Comparison to real world trial data

EV driver and duty energy variation study

Vehicle specifications

- Vehicle specifications – smart ED 2007 model

- **smart ED phase 1 demonstrator**
- 20 kW DC PM motor
- range 71 miles (114 km) NEDC
- 15 kWh Sodium-Nickel-Chloride 'Zebra' battery
- Top speed 60 mph
- Charge time : 8 hours @ 240 v
- Seating capacity : 2

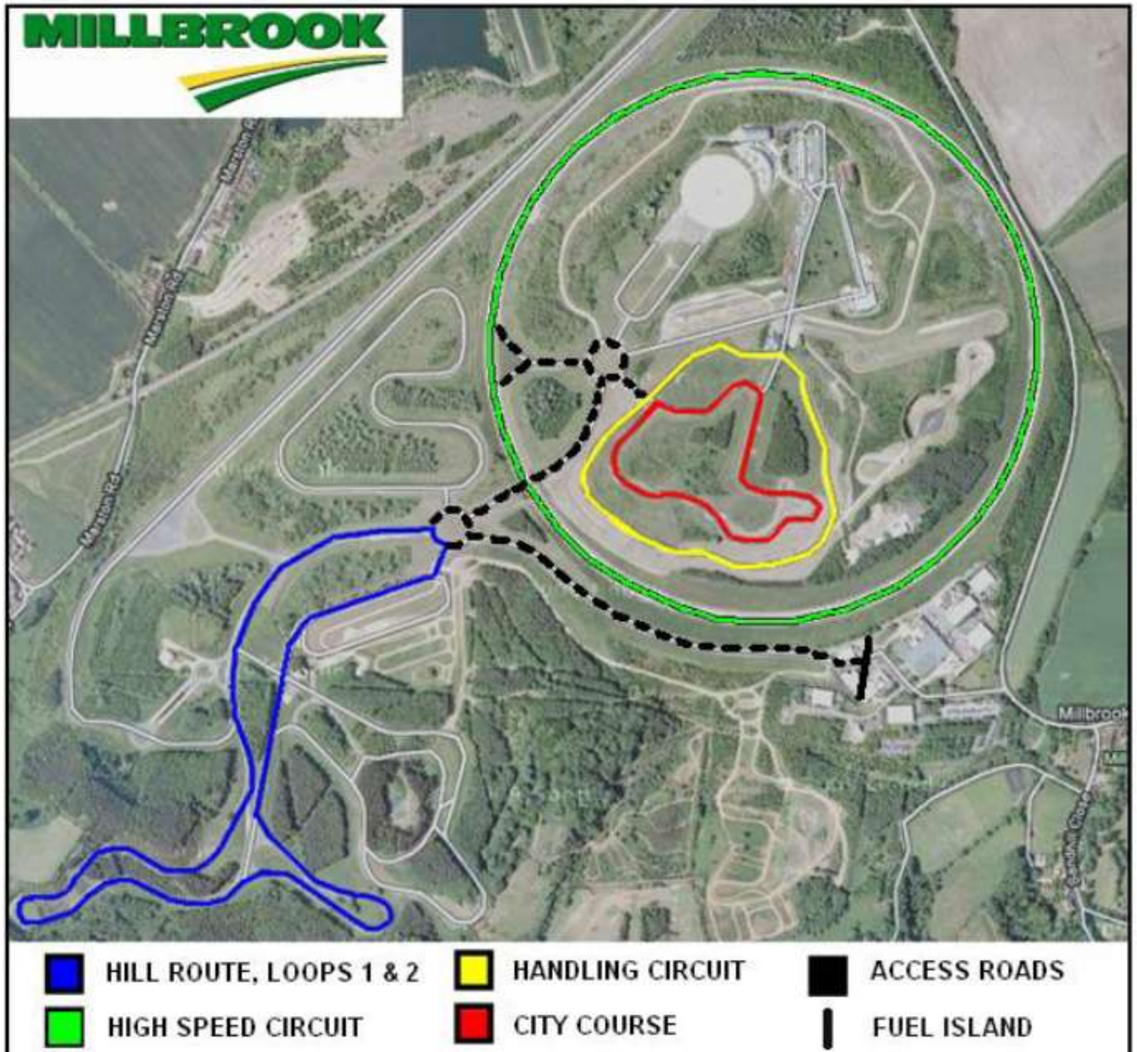
Not to be confused with......

Smart ED 2010 model

- **smart ED,** 30 kW
- 30 kW DC PM motor
- range 84 miles (135 km) NEDC
- 16.5 kWh Li-on battery

EV driver and duty energy variation study

Millbrook EV track cycle



- **High speed circuit (HSC)**
  - 3.2 km
  - Enter 30 mph
  - Accelerate to 70 mph in between four predefined rest points
  - Exit 30 mph
- **City course (City)**
  - 1.4 km
  - Urban city course (max speed 30 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 driver and duty energy variation study

Driver selection and range variation

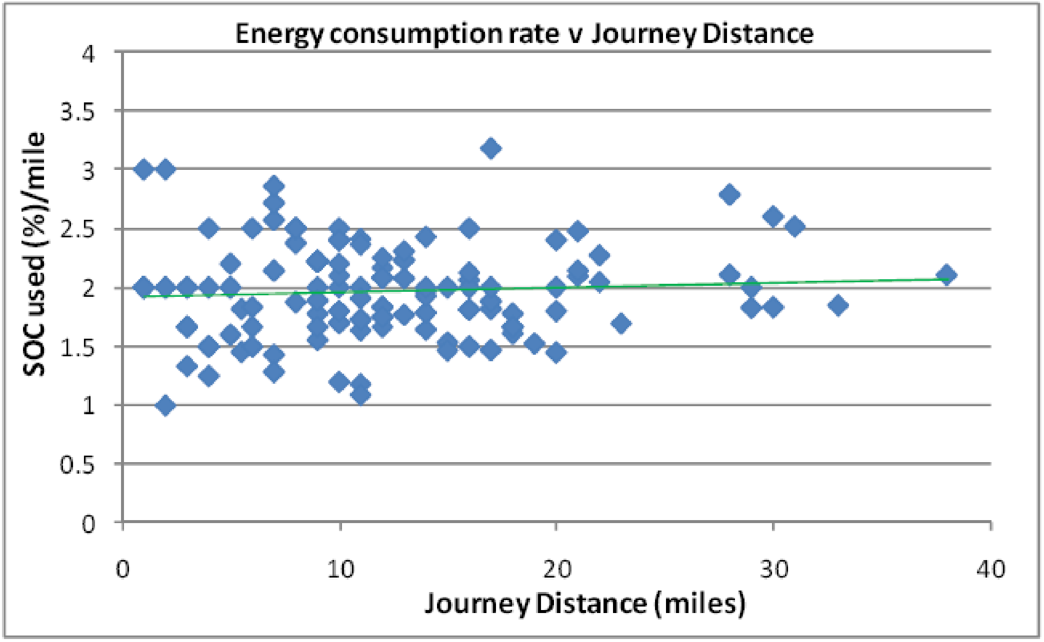
- Six drivers selected from a pool of 25 completing 140 monitored journeys representing spread of driving styles

- Avg energy consumption 1.9% SoC/mile
- +/- 1% SoC/mile

- Theoretical range 53 miles (85 km) compared with 71 miles (114 km) achieved over ECE R101

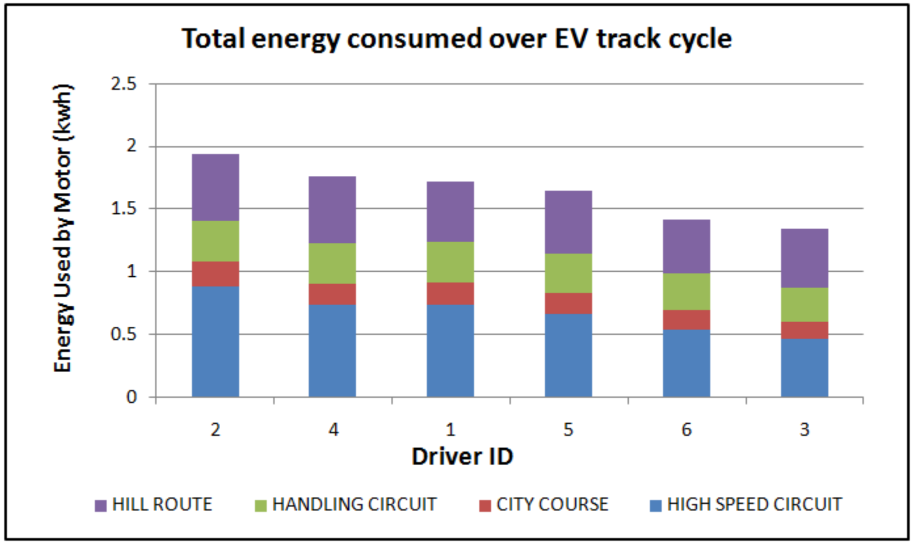
Range by individual driver

- Most efficient 1.5% SoC/mile
- Lease efficient 2.8% SoC/mile
- 35 – 67 miles range (52% variation)



EV driver and duty energy variation study

EV track cycle energy use



- Energy consumed varied between different drivers influenced by route
- Ranking of driver efficiency is consistent between each circuit
- HSC showed most variation

Circuit	Min to max energy increase
Hill	23 %
HC	19 %
City	46 %
HSC	91 %

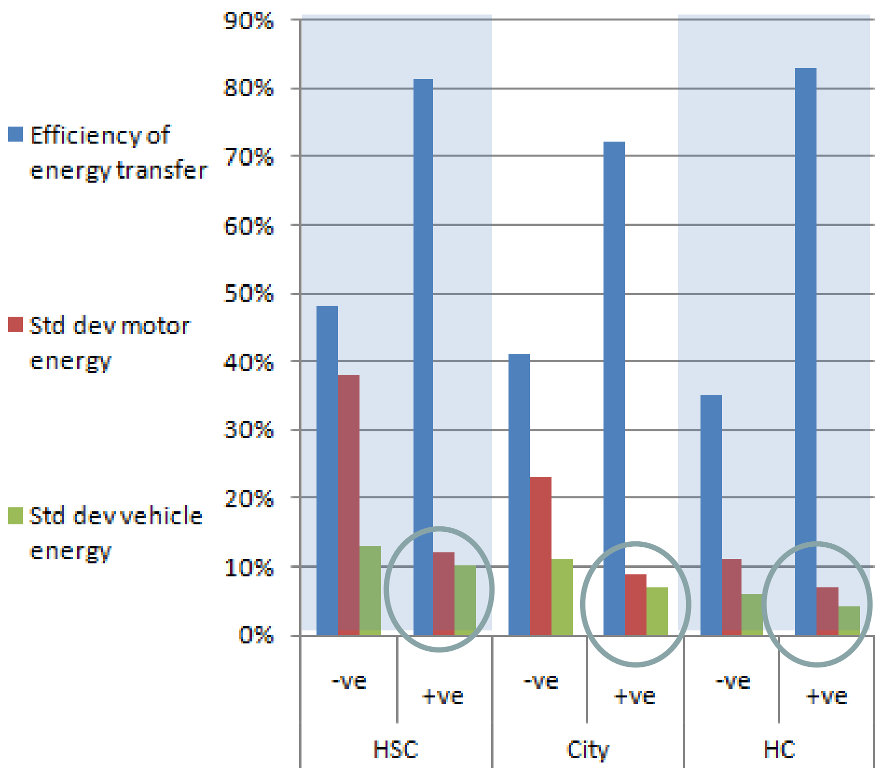
Circuit variation analysis

- **Hill route (Hill)** – Gradients required full throttle and coasting was generally applied for descents
- **Handling circuit (HC)** – Smooth, progressive in nature, variation in maintaining max speed limit between corners
- **City course (City)** – Point of acceleration and deceleration rates from corners, braking events and speed limits
- **High speed circuit (HSC)** – Consistent full throttle accelerations, variation in max speed duration and deceleration rates

EV driver and duty energy variation study

Regeneration and motoring performance

Efficiency and standard deviation of energy transfer

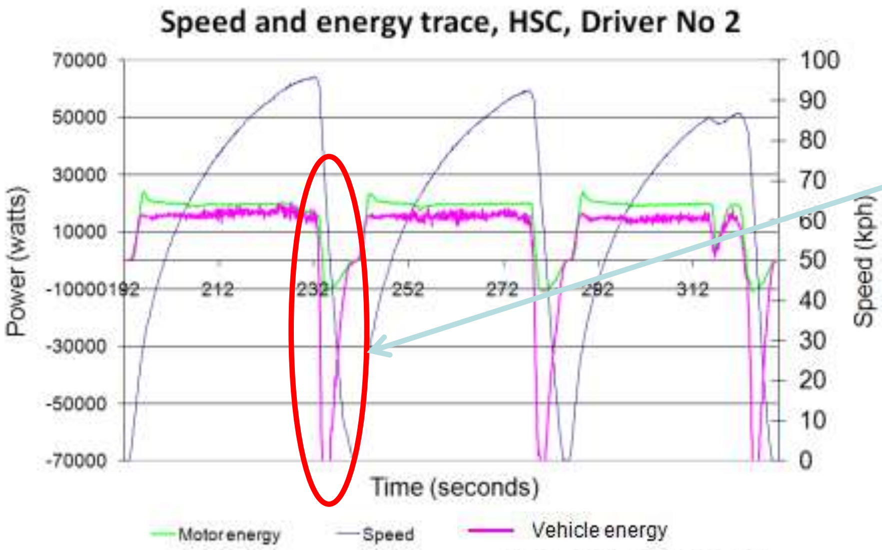


	HSC -ve	HSC +ve	City -ve	City +ve	HC -ve	HC +ve
Efficiency of energy transfer	48%	81%	41%	72%	35%	83%
Std dev motor energy	38%	12%	23%	9%	11%	7%
Std dev vehicle energy	13%	10%	11%	7%	6%	4%

- Motor energy - EV electric drive motor terminals monitored
- Vehicle energy – vehicle road load model applied to determine theoretical energy for vehicle motion or available for regeneration
- +ve shows motoring events
- -ve shows deceleration events
- Hill circuit removed as model doesn't include gradient functionality
- Motoring efficiency has comparatively little variation compared with regeneration efficiency which is highly influenced by driver and circuit

EV driver and duty energy variation study

Regeneration performance analysis

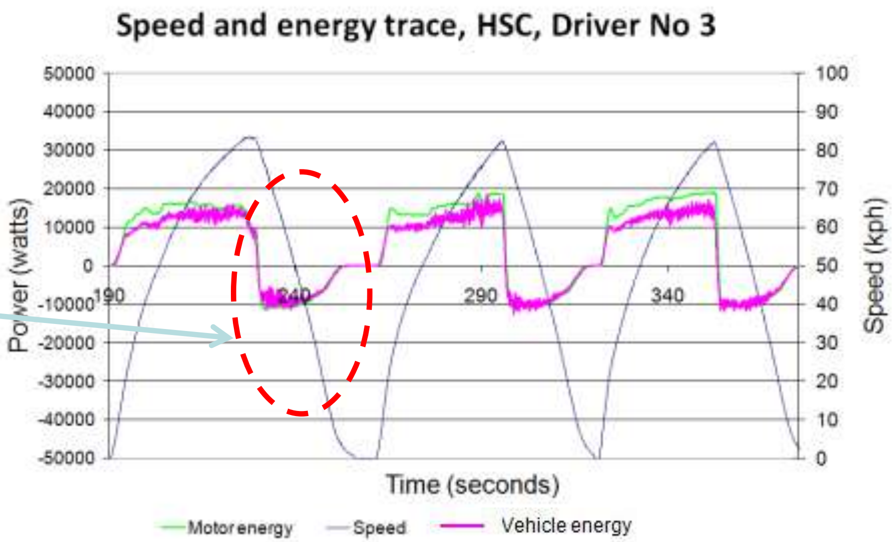


<u>Least efficient driver</u>

Regeneration energy is a small proportion of vehicle energy available

<u>Most efficient driver</u>

Regeneration energy tracks available vehicle energy

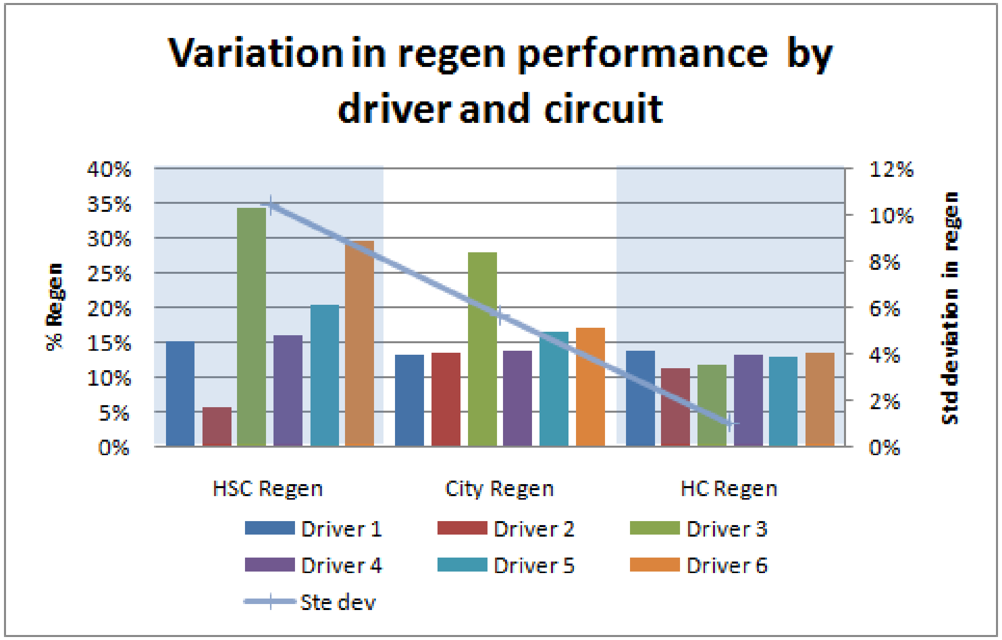


- Motoring efficiency changes by 4% (80-84%) between drivers and regeneration 78% (15% - 93%)
- Similar condition on other circuits to a lesser magnitude, overall efficiency for motoring 79% and regeneration was 46%

EV driver and duty energy variation study

Track cycle regeneration rates

- Displayed as amount of drive cycle energy regeneration as a percentage of energy consumed. sum[-ve] / sum[+ve]



Circuit variation analysis

- **High speed circuit (HSC)** – Significant energy available due to high speed decelerations, variation friction/regen blends
- **City course (City)** – Low speed stop start allows little regen. Driver 3 recaptures 87% more energy than average
- **Handling circuit (HC)** – Little performance variation due to progressive uninterrupted nature of UK B roads

Driver 3 teachers eco driving at Millbrook!

EV driver and duty energy variation study

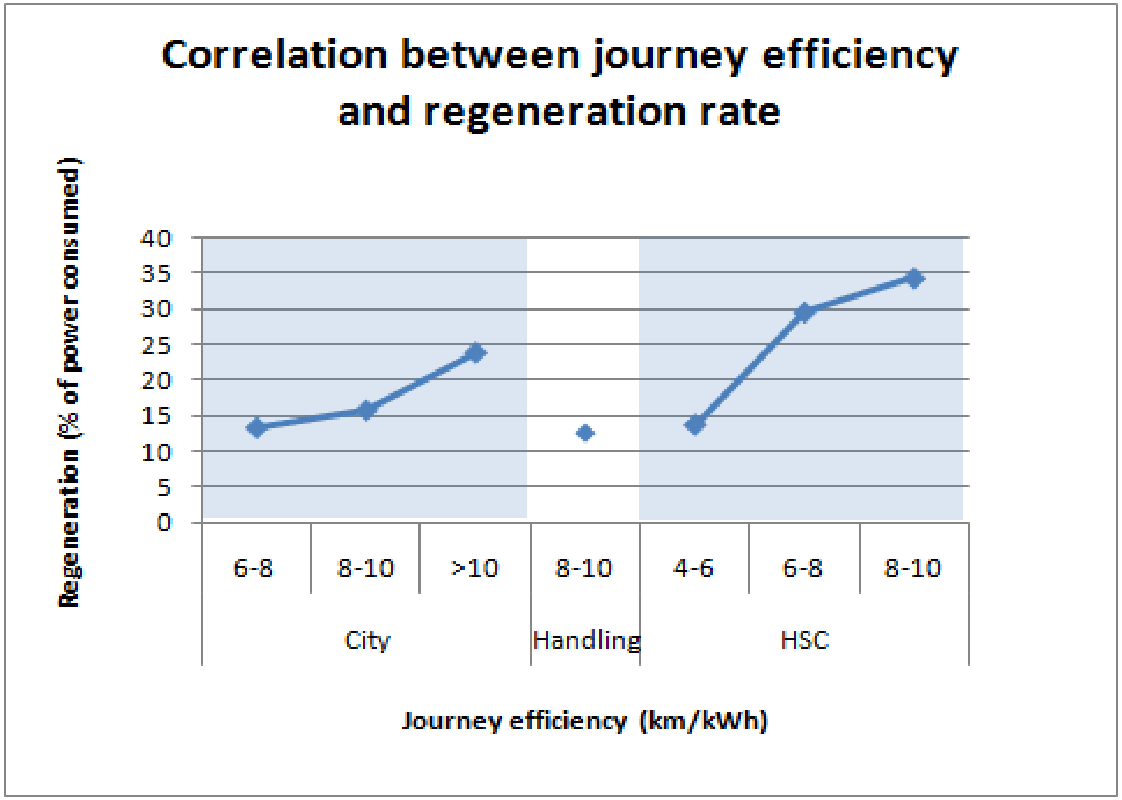
Journey efficiency and regeneration rate

- Journey efficiency increases with regen rate. This demonstrates benefits of maximising regen on deceleration events

Journey efficiency improvements

	City	HC	HSC
% improvement	47	13	90
Effective range increase km	40	11	77

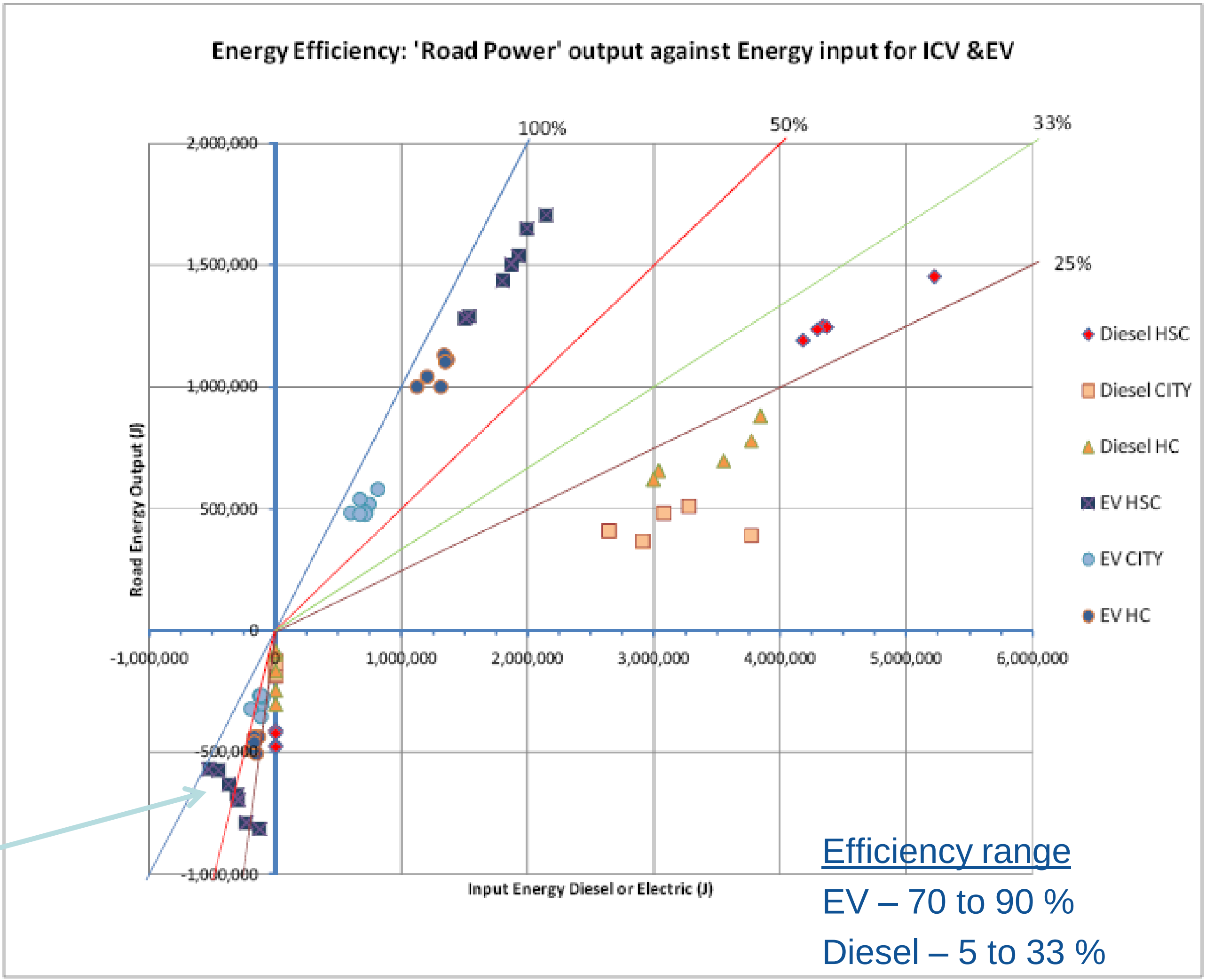
Repeated acceleration and deceleration not representative of real world scenarios



EV driver and duty energy variation study

Diesel efficiency comparison

- Diesel CDi using CAN based fuel logger
- Ed using motor energy (negating charging and driveline efficiency losses)
- Smart CDi has a lower road energy due to decreased weight
- CDi & ed least efficient in city course
- CDi is at most efficient in the HSC
- Smart ed is most efficient in HC (B-road)



Efficiency range

EV – 70 to 90 %

Diesel – 5 to 33 %

smart move trial

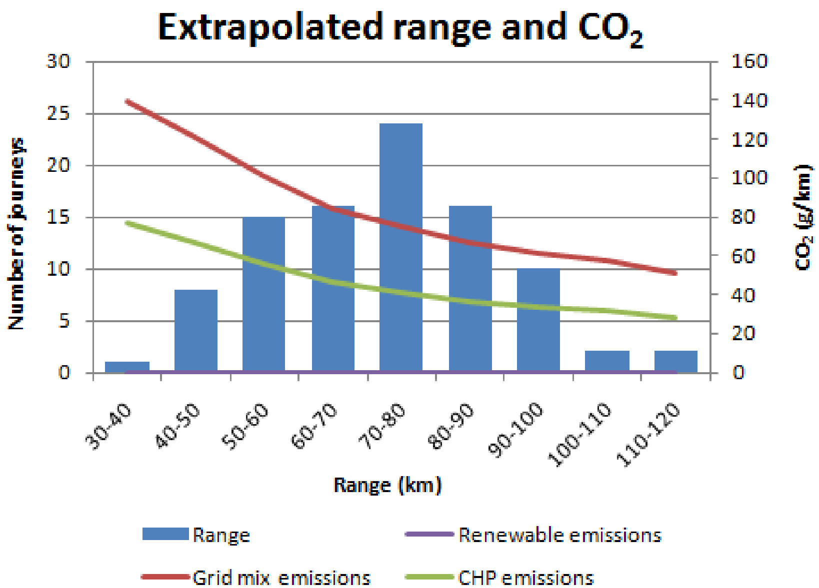
Real world fleet performance comparison

- Four smart 'fortwo' electric vehicles were deployed in the North East of England, aims:
  - Increase exposure of electric vehicles
    - Integration of vehicles into fleets
    - Public drive events
  - Collect data for analysis and dissemination
    - Build on past EV learning
    - Quantitative and qualitative data
    - Focusing learning on fleet integration

- Four regional vehicle hubs were created for deployment to
  - Eight public sector fleets
  - Two private sector fleets
  - Three public drive events

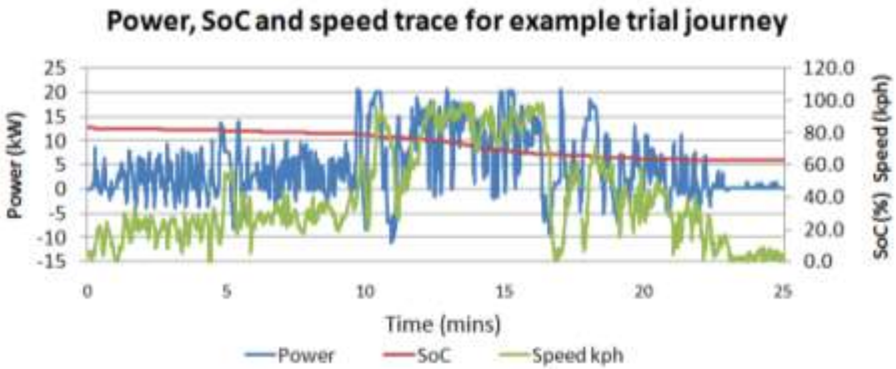
smart move trial

Real world fleet performance comparison



- Average range 72.4 km
- Significant range variation
- 81.4 g CO_2 / km (Defra 2009)

- Millbrook driver selection process achieved a range of 56 to 107 km compared to 35 to 115 km during fleet trials

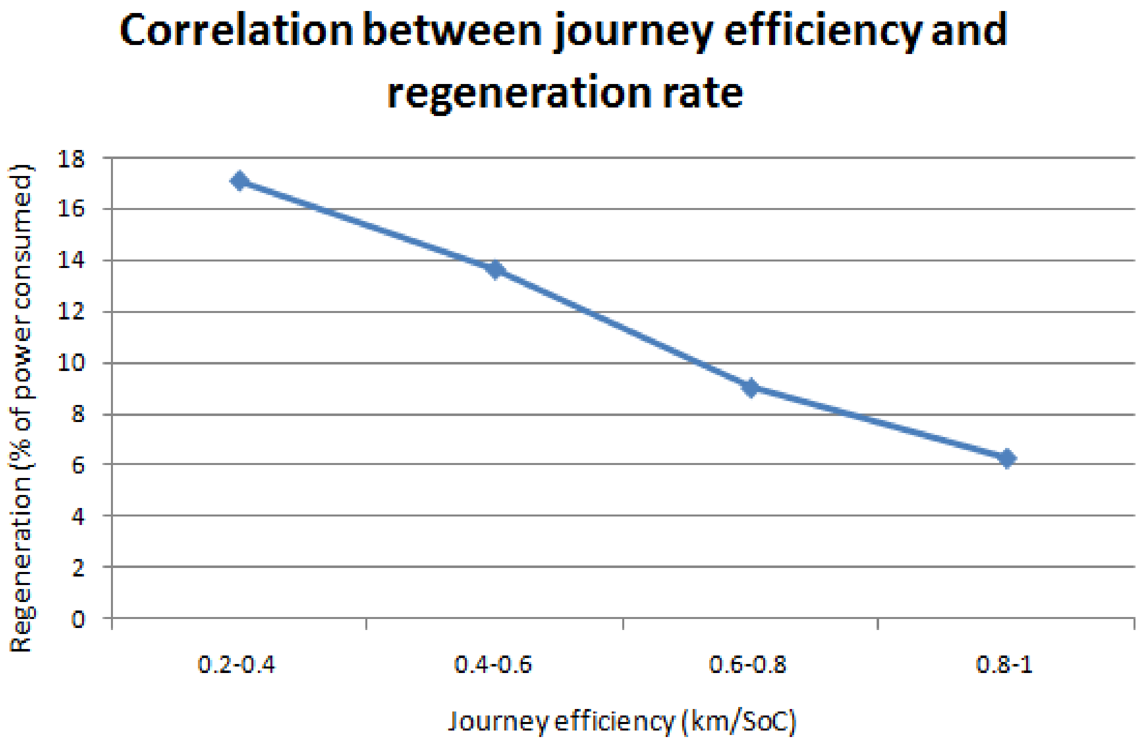


- Regeneration rate 3 – 29 %
- Average regeneration rate 11.3 %

- Compared to 6 – 34 % and an average 16% over test track circuits

smart move trial

Real world fleet performance comparison

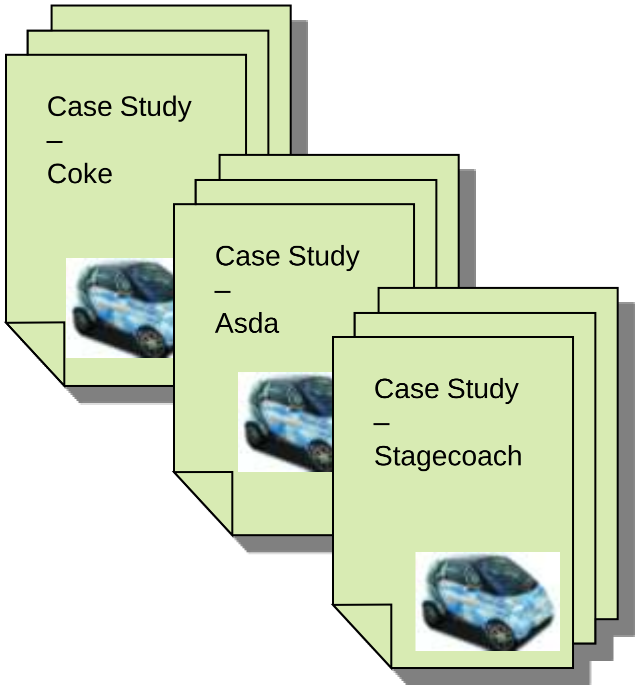


- Inverse relationship between regeneration rate and journey efficiency shown in real world trials due to interaction between traffic and traffic management
- Most efficient journeys occur with lower regeneration rates showing primary efficiency is achieved through reduction of ‘non essential’ braking and secondly through maximising regeneration and deceleration events

smart move trial

Fleet case studies

- Integration of Cenex EVs to high profile users to facilitate production of a fleet application case study pack



Varied EV application for mass fleet relevance

High profile fleet innovators give higher impact trial results and reach a wider audience

- EV application and integration
- User and fleet acceptance
- EV energy and CO_2 performance
- EV and diesel comparator
- Business case and economic breakthrough analysis

+ more

EV driver and duty energy variation study

Conclusions

- Six drivers selected were representative of the drive efficiency variation displayed in real world vehicle trials
- Most variation exists where numerous deceleration event dominate the drive cycle
- For different driving styles the range in motoring efficiency was low, 80 – 84%, compared to 15 – 93% range in deceleration efficiency. Lower efficiency decelerations were due to high blends of friction braking being used
- When comparing a diesel smart CDi and smart ED, both vehicles were least efficient over the City track circuit. The most efficient application for the smart CDi was on the high speed circuit, the smart ed was most efficient on the lower steady speeds representative of UK B roads. During positive energy transfers EV efficiency ranged from 70 to 90% (excluding energy storage and electrical conversion losses) compared with a lower and wider range of 5 to 33% for the smart CDi
- Average regeneration rates of 16% were seen during test track studies compared to 11.3% in real world trials. Reflecting the less predictable deceleration scenarios of public roads
- The study highlighted the advantages of driver training for regular EV users as driver 3, an eco driving instructor at Millbrook, achieved an average of 87 % more energy regeneration over the City circuit
- Smart move EV duty case studies due for release in April 2011, email technical@cenex.co.uk to reserve a free copy.

Thank you for your attention

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