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Can Advanced Valve-Regulated Lead-Acid Batteries Contribute in the Demand for PHEVs ?

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The Advanced Lead Acid Battery Consortium

ALABC

- Formed in 1991
- Now has 53 Members Worldwide
- Lead Producers, Battery Companies, Other Suppliers to the Battery Industry, Car Makers
- Sponsors research on advanced valve-regulated lead acid batteries (VRLA)
- Initially concentrated on EV applications but since 1999 has worked largely on batteries for HEV duty (micro to mild hybrid)

The Advanced Lead Acid Battery Consortium

- **EV (Deep Cycle) Duty**
  - Positive plate issues
    - Grid to paste adhesion problems
    - Active material growth on cycling – loss of connectivity
  - Solved by improved tin-containing grid alloys and compression on the active material by the separator – resulting in greatly improved cycle life.
- **HEV (High Rate Partial State-of-Charge) Duty**
  - Failure occurs in the negative plate
    - HRPSoC cycling without reaching top of charge induces sulfation
  - Solved by the addition of extra carbon to the negative active material

The Advanced Lead Acid Battery Consortium

ALABC

- **Now in a demonstration phase**
  - Have fitted 144V UltraBattery pack into a Honda Insight
  - Achieved 100,000 miles on a GM durability cycle at Millbrook, UK.
  - Car still running on these batteries
  - A Honda Civic has been retro-fitted with an Effpower Bipolar Lead Acid Battery and is also under test at Millbrook
- **The PHEV work to be described should be seen in context of this demonstration program.**

EMC MEC Electric Mobility Canada Mobilité électrique Canada

ADD*ZEV*

- **AFFORDABLE ADD-ON *ZERO EMISSIONS VEHICLE***
- **Funding Organisations:**
  - **The Energy Saving Trust**
  - **The EALABC**
  - **In-kind from Partners**

ADD*ZEV* : System Overview

Aim of the ADD*ZEV* project

- To build a demonstration vehicle with low cost, additional electrical drive, capable of covering 20km on electric drive only.
- Target: a light urban delivery vehicle.

Objectives

- System must be sized to achieve 20km zero emission range
- Parts must be chosen to reduce costs (especially energy store)
- Must be designed for minimal vehicle integration (post-production and retro-fit options)
- Must be capable of plug-in recharge
- Cost target in production £2,000 - £3,000

ADD*ZEV* : System Overview

Functional requirements for system sizing:

- **Range:** In electric drive only the vehicle shall be capable of covering 20km, over the ECE phase of the NEDC.
- **Load:** In electric drive only the vehicle shall be capable of operating with the load range expected of a standard vehicle.
- **Speed:** In electric drive only the vehicle shall be capable of sustaining a maximum speed of 50km/h over flat ground.
- **Incline:** In electric drive only the vehicle shall be capable of progressing up an incline of 10% at 40km/h.

  In electric drive only the vehicle shall be capable of progressing up an incline of 14% at any low speed.
- **Headwind:** In electric drive only the vehicle shall be capable of fulfilling all above requirements, when encountering a headwind of 10km/h.
- **Efficiency:** The vehicle shall demonstrate increased efficiencies over existing technologies.

ADD*ZEV* : Project Partners & Responsibilities

- Cranfield University
  - Project Coordination
  - Vehicle modelling and simulation for feasibility
  - Systems engineering approach to interface definition
  - Supervisory control system design
  - Dynamometer testing of full system
- EALABC
  - Battery Acquisition
  - Assistance with Coordination

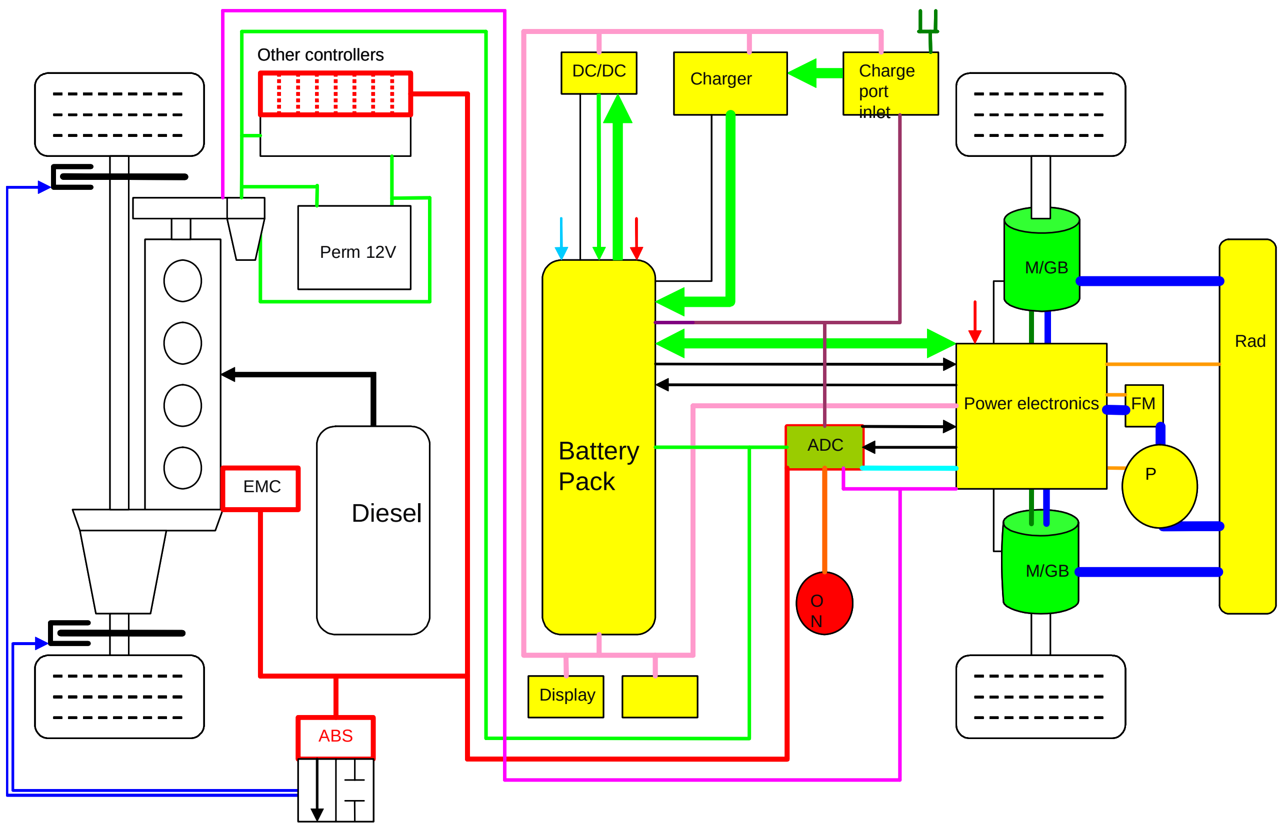
ADD*ZEV* : Project Partners & Responsibilities

- **Millbrook Proving Ground**
- **Test vehicle provision**
- **Mechanical design and integration**
- **Data acquisition from providers (e.g. Royal Mail)**
- **Dynamometer & track testing facility**
- **University of Oxford**
- **YASA electrical machine design**
- **Machine bench testing**
- **Provector**
- **Battery pack design & construction**
- **Battery management control system**
- **Electric machine drive electronics**

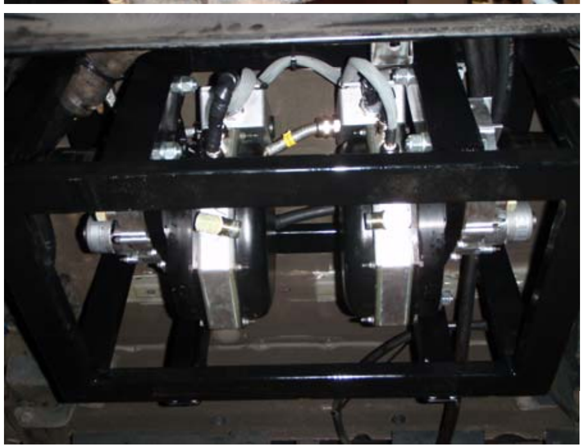
ADD*ZEV* : Systems Engineering

- Vehicle based on Vauxhall (GM) Combo van
- Diesel engine with front wheel drive
- Modification of rear axle to accommodate two electric motors and drive to rear wheels
- Conversion designed to use as many standard GM parts as possible for low cost
- Battery pack and power electronics mounted at front of load space in the van
- Hand over system from ICE drive to electric designed for maximum safety
- Cooling system incorporated for motors and power electronics.
- System designed to accept regen energy.

ADD*ZEV* : Systems Engineering



ADD*ZEV* : Systems Engineering



- Modified rear EV drive assembly
- Electric motors mounted in protective cradle

ADD*ZEV* : Battery Pack

- Requirement to provide 3 kWh of energy during ZEV operation while optimizing cycle life
- Also needs to provide 50kW peak power in drive and accept 30kW+ in regen to maximise energy recovery
- Rechargeable from 13A supply with on-board charger
- Utilised 6V 25Ah (C_{20} rate) Exide Orbital spiral-wound modules
- To allow for lower capacity at higher discharge rates a 240V pack was designed with air cooling (approx 5kWh)
- Battery management was provided to control charge/discharge of the battery and equalisation of the modules.
- Data logging was also fitted to monitor battery parameters when in use.

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ADD*ZEV* : Battery Pack

- Battery pack under construction
- Battery pack and power electronics in the vehicle
- Two interchangeable packs produced to maximise testing in the time available

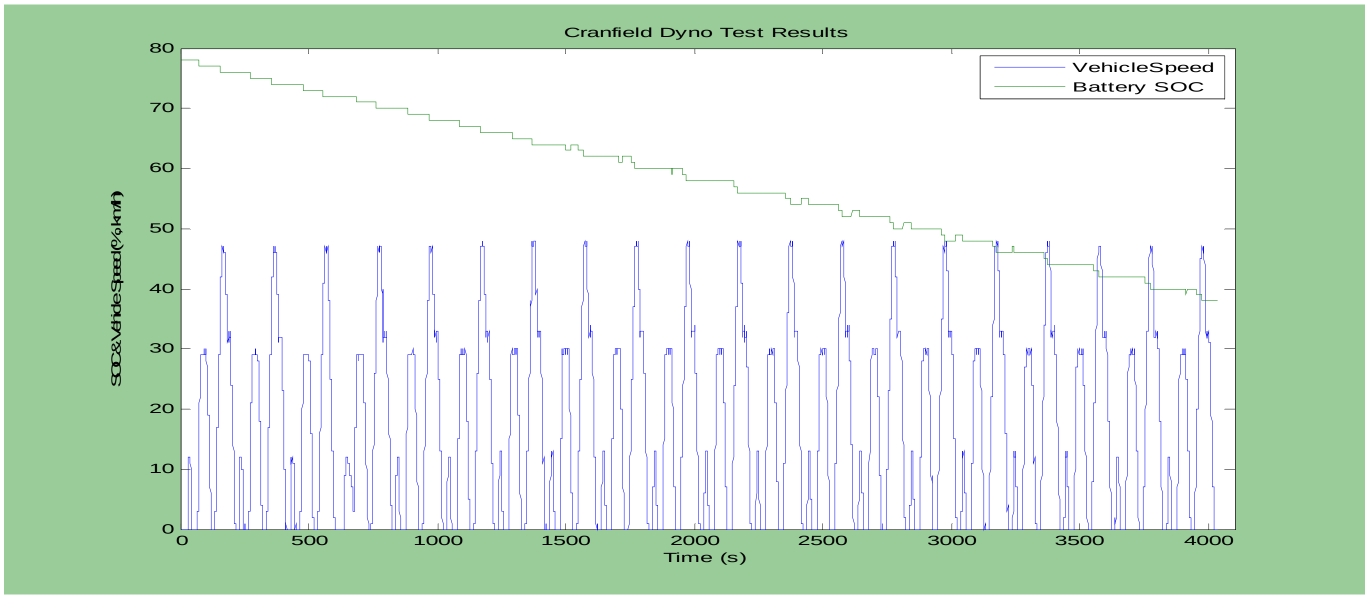
ADD*ZEV* : Project Problems

- Major delays in the completion of the BMS and power electronics delayed integration into the vehicle
- There were further problems arising from the added complexity of the 6-phase motors – further compounded by the encoders slipping in use
- Additional problems with the cooling system caused a motor burn-out in the integration and shake-down phase at Cranfield
- As a result there was very little time available for testing of the vehicle - other than the testing required to confirm that the vehicle could complete the 20km required on the ECE section of the New European Drive Cycle.

ADD*ZEV* : Testing - Cranfield

Vehicle on the Cranfield dynamometer

ADD*ZEV* : Testing - Cranfield



- SoC and vehicle speed v time. Analysis shows vehicle covered 19km
- While below the target of 20km – battery charge was from 78% down to 38% - so looked promising

ADD*ZEV* : Testing - Millbrook

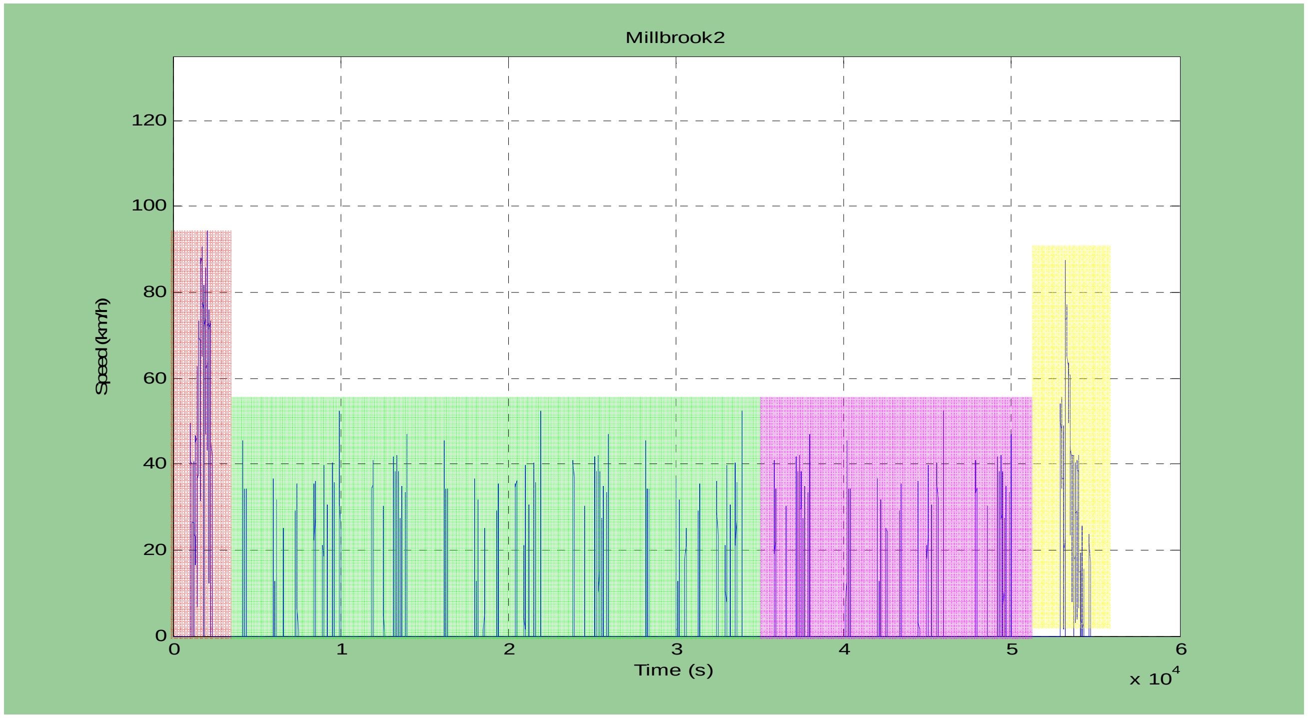
- In a test to the NEDC at Millbrook the vehicle achieved a range of 20.6 km with the battery SoC going from 87% to 35% - thus should be capable of 22-24km on a full charge.
- The energy consumption was 0.13 kWh/kg
- On the Urban Delivery Driving Cycle the range was 13.6 km and the power consumed was 0.29 kWh/kg

ADD*ZEV* : Testing - Millbrook

- **CO_2 Figures**

- Vehicle not fully hybridised – need to idle engine to provide for power steering and braking.
- This emits 49.4 g/km over NEDC cycle
- Using EU energy mix value for CO_2 of 430 g/kWh for the electric part of the cycle – this calculates as 56 g/km over the NEDC
- Thus the total CO_2 emitted over the cycle is 105.4 g/km. This compares with a figure of 137.1 for the original vehicle.

ADD*ZEV* : Testing - Millbrook



Millbrook 'real world' cycle derived from field data (53km)

ADD*ZEV* : Testing - Millbrook

	Baseline CO_2			ADD*ZEV* CO_2		
Cycle	Combo	Zafira	Movano	Combo	Zafira	Movano
NEDC	137	165	240	105	122	180
UDDC	238	284	419	106	130	170
Millbrook	251	324	440	204	232	351

Modelling of results to different vehicle sizes

ADD*ZEV* : Positives

- While VRLA batteries are not really a candidate in passenger cars, they could be possible for light commercial vehicles where cost and available volume rather than weight are more important e.g. mail.
- The 20 km electric range was achieved with effective reductions in CO_2 emissions in urban delivery duty.
- The system would be suitable for retro-fit.

ADD*ZEV* : Negatives

- Re-vamping of project at start put additional work on Provector
- There was added complexity of the power electronics due to the use of the two 6-phase electric motors
- Unreliability of the motors
- Resulting delays in the full integration of the vehicle limited testing time due to EST deadlines and financial restraints.
- The rush to meet the targets of the call meant the BMS was not properly implemented and modules became out of balance – this was the reason for the packs not being fully charged.
- Because of the time restraints we have only limited data on battery operation under this type of deep cycle/hybrid operation.

ALABC

ADD*ZEV* : What next ?

- The ALABC declined to contribute to further testing on the present vehicle because of the motor issues
- The Partners may seek additional funding to progress the work but:
  - Need to run with single motor driving the rear wheels through a differential to simplify the electronics
  - Should probably utilise single fixed pack in conjunction with a fast charging option to reduce weight and volume
  - Look at additional means of reducing battery weight and volume with new battery developments
- Should consider some bench testing of batteries to this type of cycle to determine if there is any effect on life.