Battery Systems Integration, Energy Management Systems & Testing

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Content

- Types of hybrid & electric vehicles
- What are the electrical energy storage requirements for these types
- Battery systems integration
- Testing
- Energy management systems (BMS)
- Example
- Summary/Conclusions

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Simplest option "Idle Stop"

Stop-start

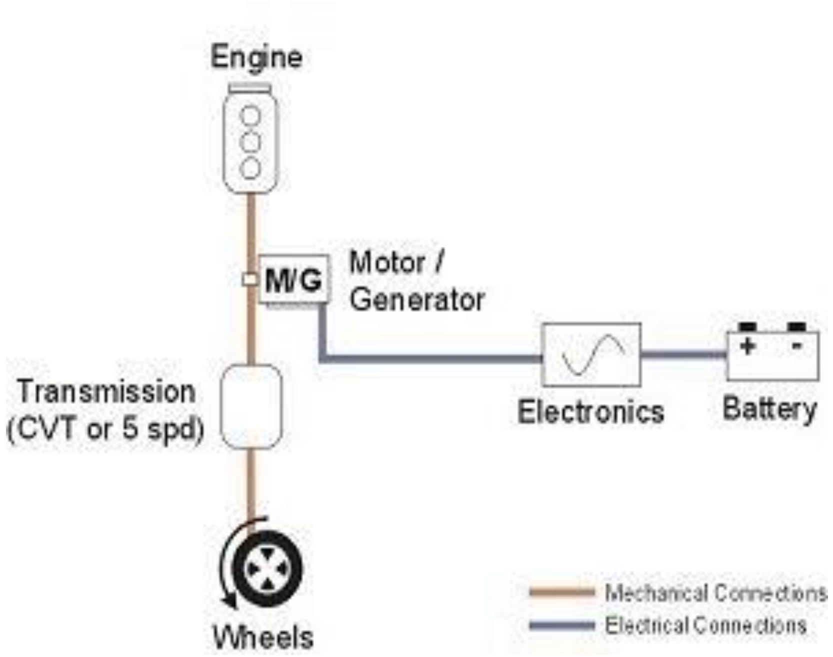
- Stop/start applications typically allow functionality of
  - Stop/start
  - Regenerative braking (limited)
  - Boost (limited)
- These systems offer a very easy fuel saving
  - Just idle stop gives about 4-6% on the European standard test cycle.
  - The most advanced systems give ~20% fuel improvement.
- Very low cost (£100-£400)
- This type of technology will be standard on cars in Europe by 2015
  - Almost all use lead-acid batteries.

- Many examples of production vechiles: Landrover Freelander, BMW 1 & 3 series 4cyl, MINI, Fiat 500, Citreon C1/C2/C3......

Picture Source: land Rover webs

Hybrid vehicles – A full hybrid can move the vehicle purely using electricity or by using a combustion engine

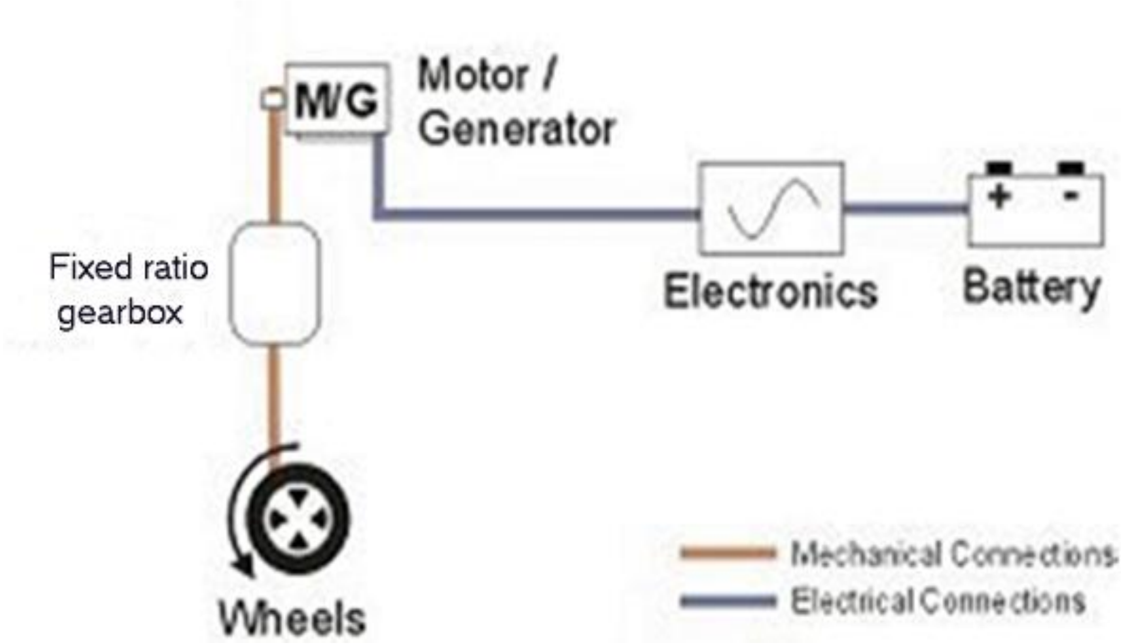
Basics of Hybrid Vehicles



- A hybrid vehicle uses an electric motor as well as a conventional engine (gasoline or Diesel) to move the vehicle.
  - The electric motor acts as a generator when braking to recharge the battery - this is called ***regenerative braking***
  - The electric motor can potentially power the vehicle by itself - this is called ***EV mode***
  - The electric motor can assist the conventional engine - this is called ***boost mode***
- The diagram shows the simplest type of hybrid.

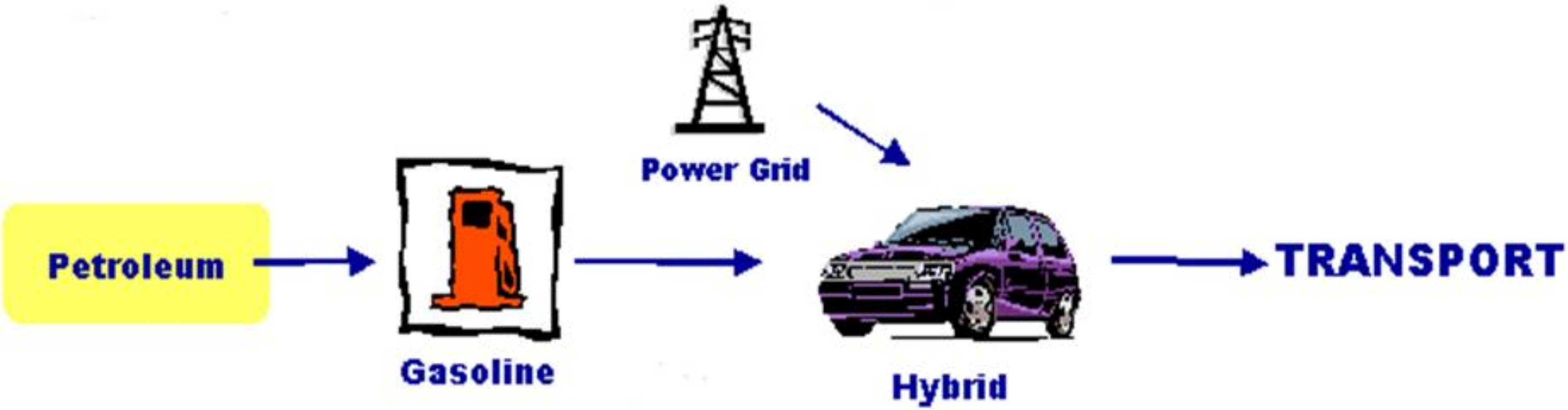
EV (Electric Vehicle)

Basics of Electric Vehicles



- No combustion engine its replaced by an electric motor (a battery replaces the fuel tank)
  - Simpler
  - Should be more reliable
    - Compare an electric lawn mower to a gasoline powered one
  - NOT cheaper ! (€250 fuel tank replaced with €25000 battery [350 mile range]).
    - Limited to around 100 mile range by cost of the battery.

PHEV (Plug in Hybrid Electric Vehicle)



- PHEV is a mixture of an EV and a hybrid.
  - It can be charged from the power grid and run for a number of miles on this energy, when this energy runs low it uses its combustion engine and runs like a hybrid.
- It’s a way to get around “range anxiety” – ie you can drive / refuel it like a conventional vehicle, but if you refuel it with electricity frequently you get lower running costs (and lower CO_2 emissions)
- RE-EV’s (Range Extended Electric Vehicles) are a type of PHEV that give full functionality as an EV (ie maximum acceleration, maximum speed)

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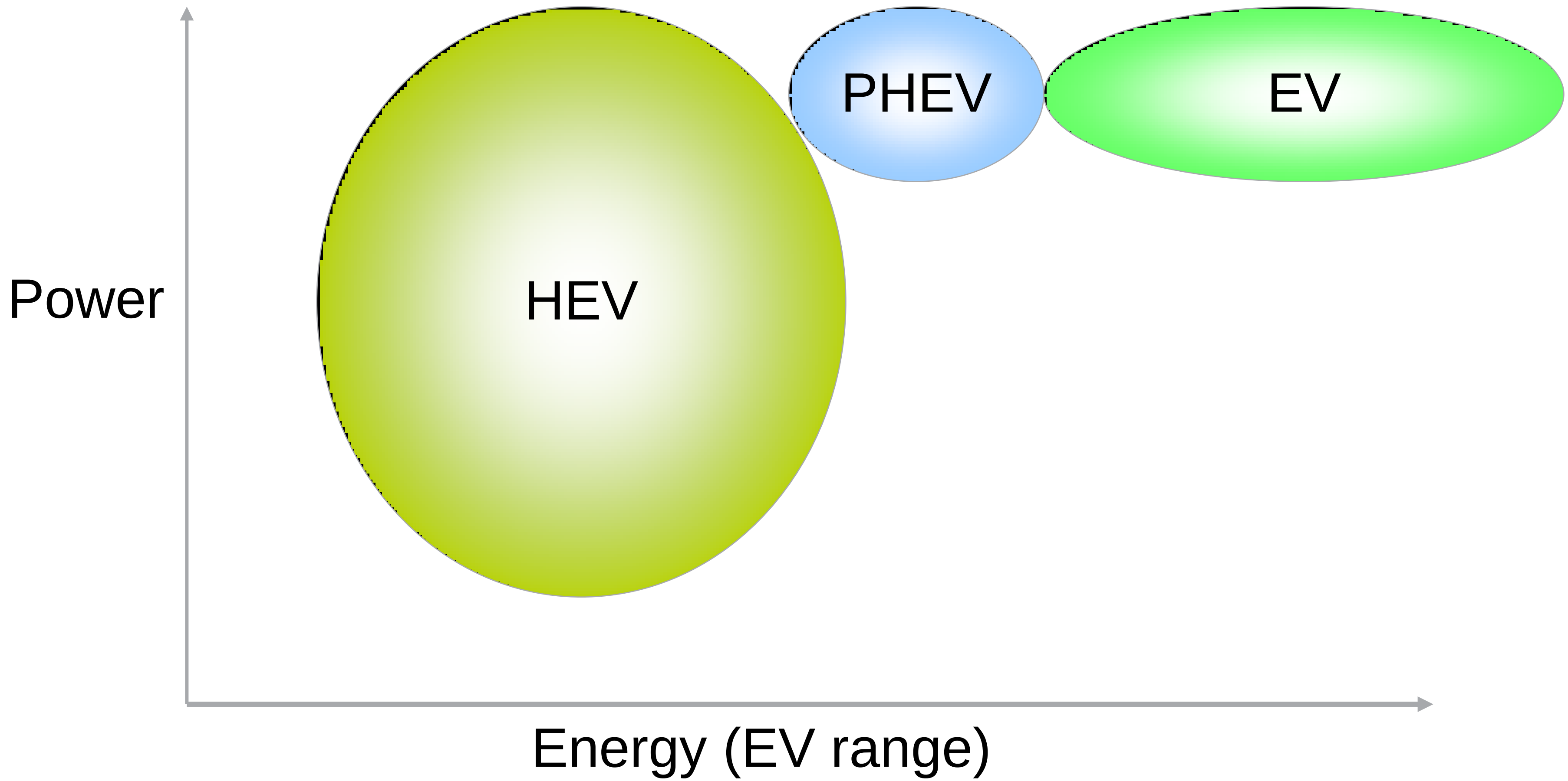
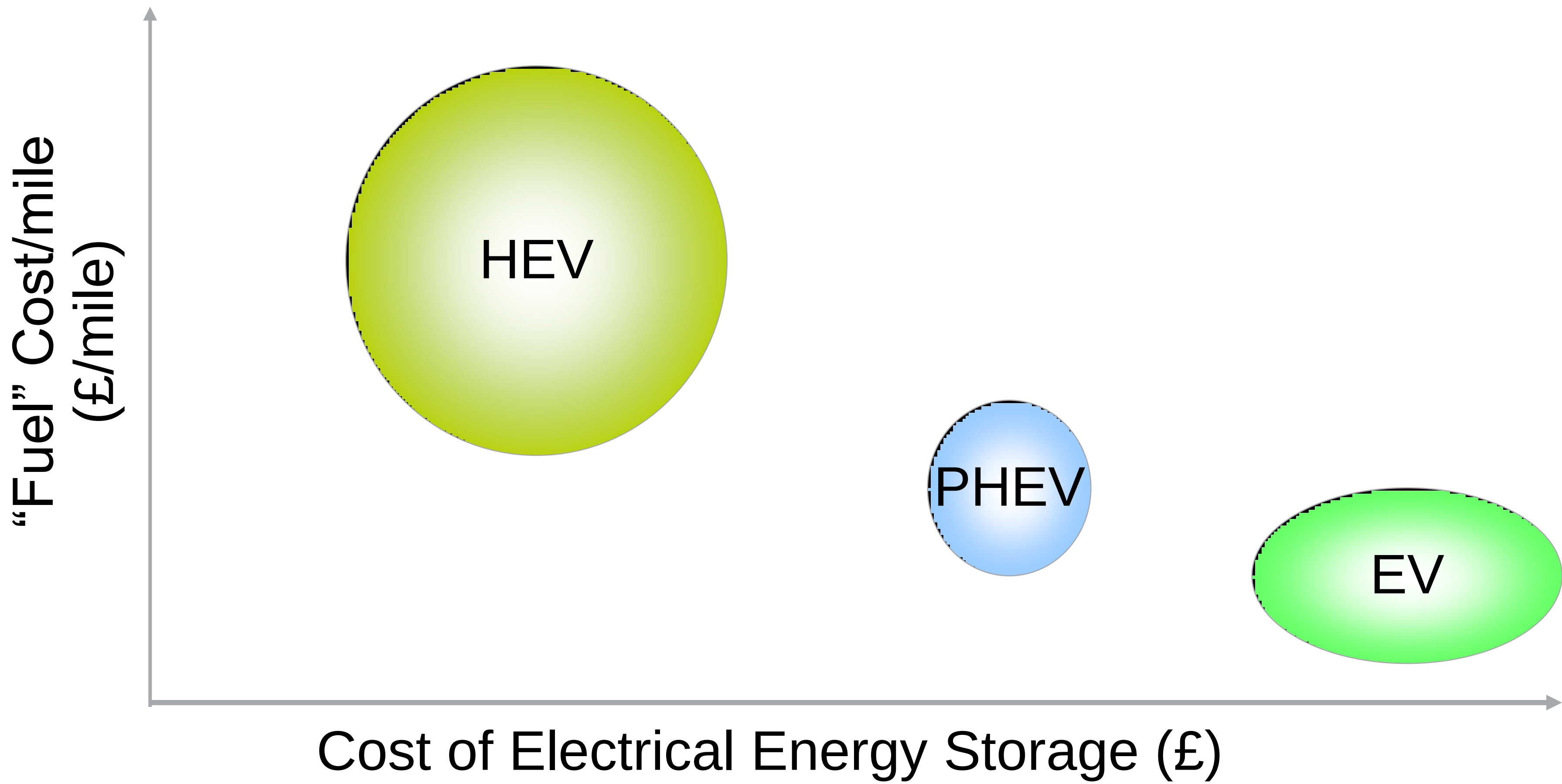
Electrical Energy Storage Requirements for Different Applications (EV, HEV, PHEV)



- The HEV area is the largest as the designers have the greatest flexibility
  - In general hybrids towards the top right of the HEV circle would tend have the lowest fuel consumption

Cost/mile vs. Cost of Energy Storage for Different Applications (EV, HEV, PHEV)



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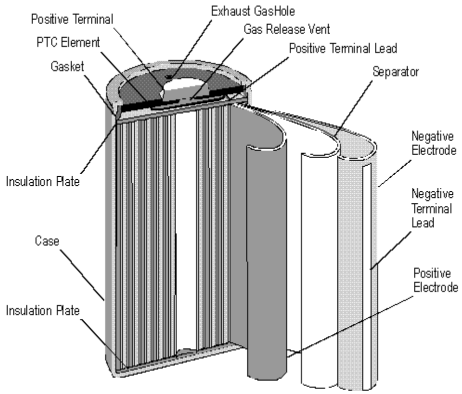
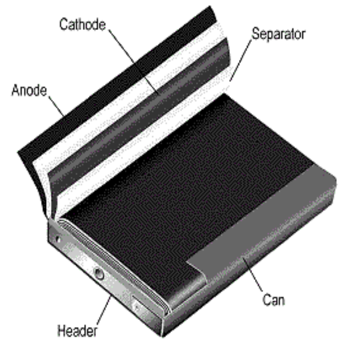
What do we need to integrate?
Cell package types

- Cells are available in a variety of packages :
  - Cylindrical
  - Prismatic
  - Pouch



Design courtesy of Panasonic



Design courtesy of Polystor

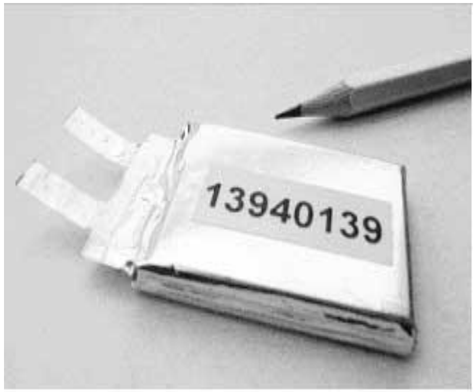


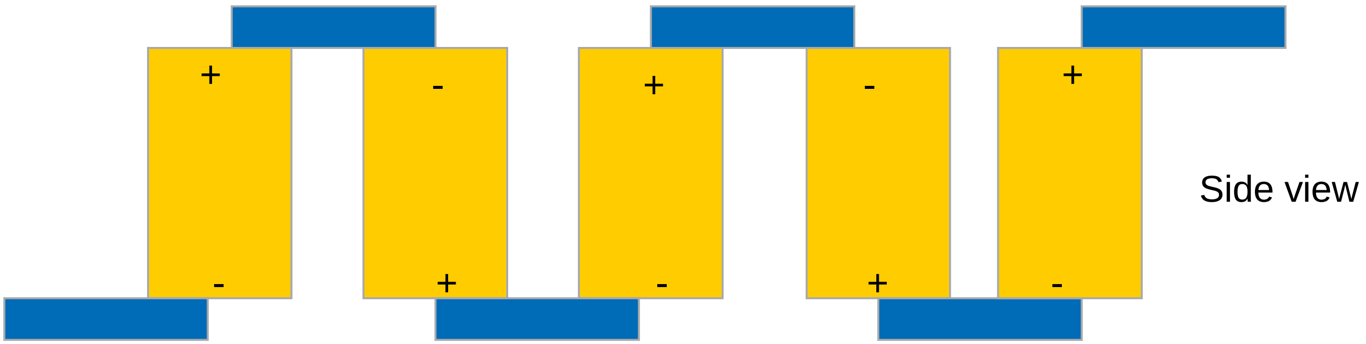
Photo courtesy of Cadex Electronics

	Cylinder	Prismatic	Pouch
Energy Density	Medium	High	Highest
Mechanical Stability	High	Medium	Low
Thermal Performance	High	Highest	Medium
Space Utilization	Low	High	Highest
Manufacturing cost	High	Medium	Low
Pressure Withstand	High	Medium	Low

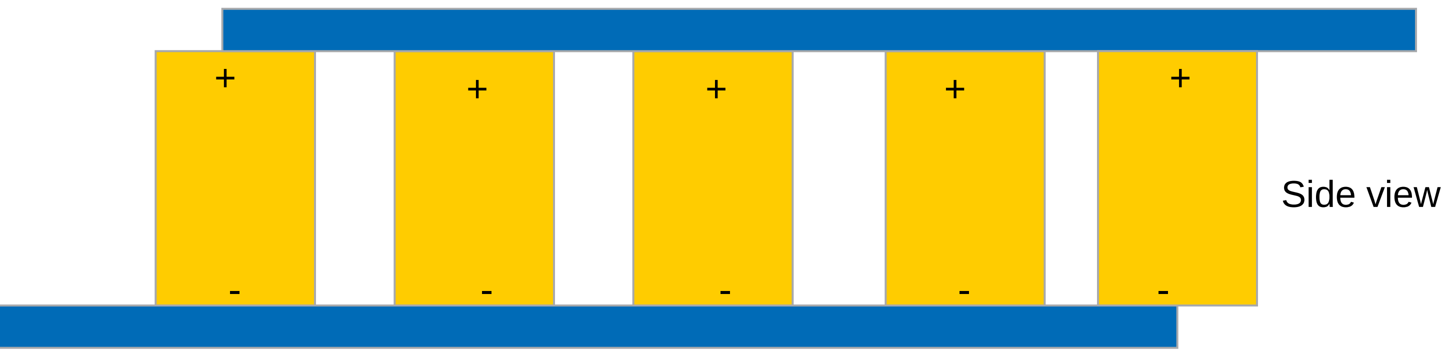
Key:
- Desirable (green)
- Acceptable (yellow)
- Undesirable (red)

•Cell package selection is a trade-off, no one package is universally best

Cells need to be interconnected

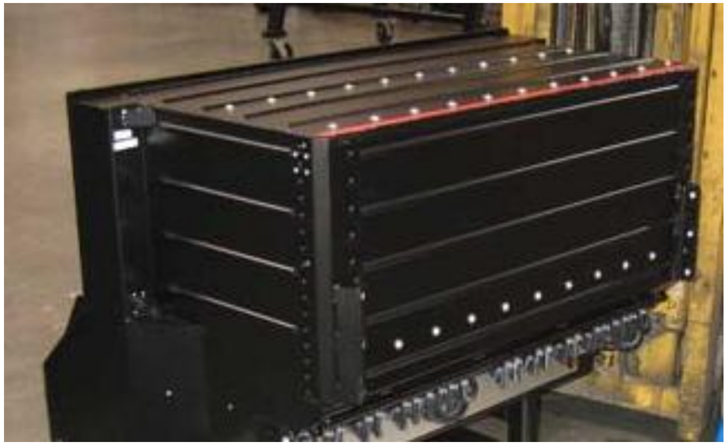


Cells in series:
•Voltage increased
•Power increased
•Energy increased



Cells in parallel:
•Voltage unchanged
•Power increased
•Energy increased

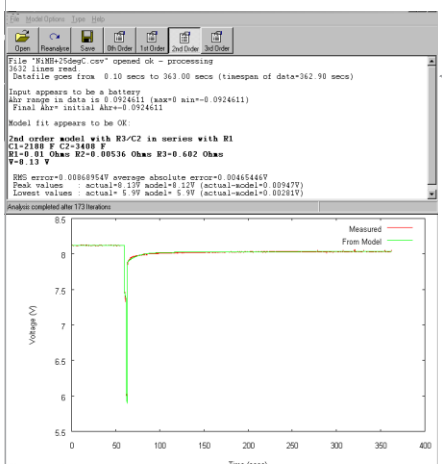
- A combination of series and parallel cells can be used, eg The Tesla Roadster EV has a total of 6831 cells arranged in a 99 series, 69 parallel configuration
  – This gives a pack with 375V, 200kW power , 53kWh energy weighing 450kg.



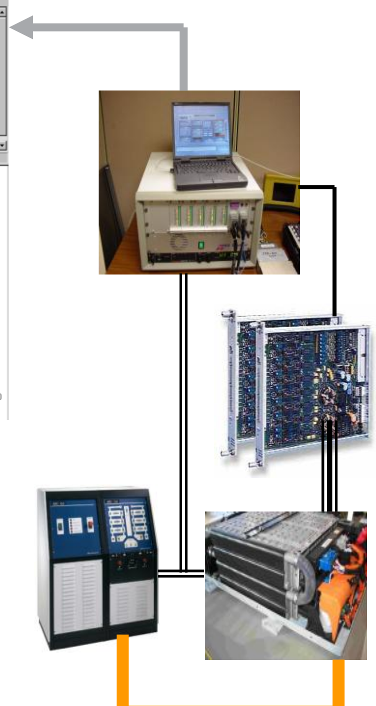
So how do we select the best structure for a pack ? Software tools are required.

Cell / Pack Data Analyser

- This software directly loads test data from a cell or pack tester and creates an accurate model that captures all the key characteristics



Ricardo s/w tools shown



Pack Designer

- Selects the best series/parallel combination of cells from the Cell Data Analyser data to meet a number of constraints, including
  - Pack Weight/volume
  - Max / min voltages
  - Temperature limits

- Finds either the smallest number of cells to meet the constraints (“the cheapest”), or the maximum energy possible within the constraints (“longest EV range”)

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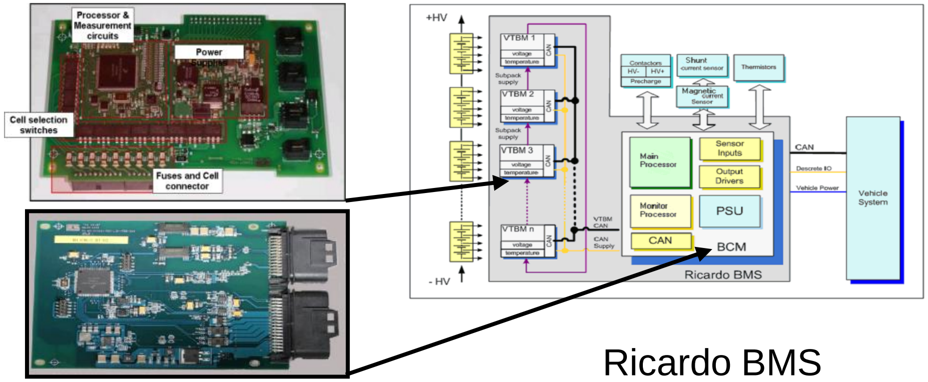
Testing

- Testing starts at with the cells
  - Electrical characteristics
    - How they vary with temperature and age
  - Safety
  - Life
- Then pack level testing is conducted
  - Electrical
  - Safety
  - Life
  - Integration with rest of vehicle
    - Simulation
    - Dyno
    - Vehicle
- For example Ricardo recently opened its 2600 square foot Battery Systems Development Centre located on Ricardo's Detroit Technology Campus in Van Buren, Michigan for pack testing.

What else do we need in the pack ?

- Safety is a key issue for battery pack designs
  - The packs need to be at least as safe as the fuel they replace.
  - Vehicle level testing includes for example crash testing.
- Some new safety hazards are introduced into the vehicle like the possibility of an electric shock from the high voltages present.
- Complex systems within the Battery Management System (BMS) monitor the individual cells & the pack
  - Both voltage and temperature is monitored.
    - Complex software maximises pack life & safety
  - "event detectors" (crash etc) also switch off the pack for safety.

Tesla Roadster after a crash test



Ricardo BMS

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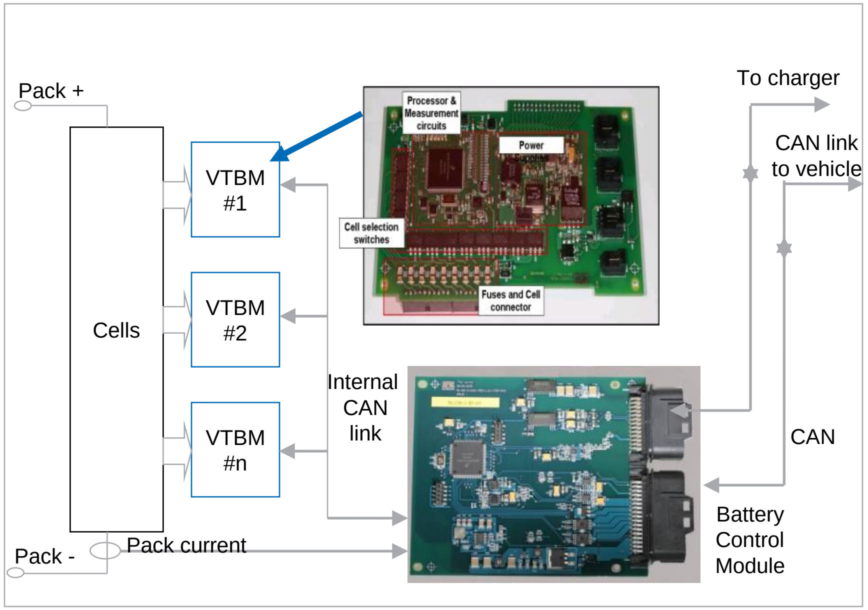
Design for a universal BMS, suitable for any Li-Ion chemistry, NiMH or capacitor energy storage



Ricardo's Approach

- Generic Battery Management System (BMS) comprises a BCM board with a number of VTBM boards depending on cell quantity
- VTBM board measures the voltage & temperature of each cell, and does cell balancing (up to 16 cells/ VTBM board).
- Contactor board measures Pack Current, pack insulation resistance, and reads cell data from VTBM boards; it also drive fans, contactors, etc.

Situation and objective

- Create a universal Battery Management System (BMS) that's independent of cell size/chemistry
- Create a tool set to
  - Allow rapid pack design from cell data
  - Allow rapid calibration of the BMS from cell data
- Design BMS so it will adapt to cell production variations and aging to minimise production/field issues

Results and benefits

- Design includes cell safety strategy (overcharge etc), electrical safety (eg protection against electric shock) and vehicle safety (e.g. EV losing power at a critical time)
- Methods developed for cell/battery pack testing and characterization including a patented approach to SOC calculation

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Example: EVAB^{2}MS: Electric Vehicle Advanced Battery and Battery Management System

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- This TSB funded program replaced the existing battery pack in an Allied EV with one using cells with a significantly higher energy density.
- The new pack gives 10% more energy with an 18% weight reduction and a 9% volume reduction.
- This is 94Wh/kg, a 35% improvement over the original pack.
  - For comparison the Nissan Leaf is 79Wh/kg and the Mitsubishi i-MiEV is 80Wh/kg

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Allied electric
zero emission vehicles

axeon

Technology Strategy Board
Driving Innovation

The Replacement Pack was fully designed in CAD to address all assembly, cooling and high voltage interconnection requirements

- The pack is based on production NCM cells combined with an advanced battery management system (RU-BMS) supplied by Ricardo in a housing designed and manufactured by Axeon.
- The new pack requires no changes to the existing Allied vehicle.
- People driving the EV immediately notice the higher power available from the new pack which combined with its lower weight gives a noticeably higher acceleration and top speed.

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Summary/Conclusions

- Battery systems integration consists of
  - Working out how to best use cells in a vehicle
    - Life
      - Typically 8-10 years warranty is offered by volume OEM's
    - Safety
    - Performance
    - Cost
      - A replacement pack for the Tesla Roadster costs about $30k (£19000)
- A Battery management system is then added to monitor / control all the cells
- The system is then robustly packaged to survive in the automotive environment
  - This includes cooling, vibration, crash, etc.
- Extensive testing is then undertaken to validate the solution.