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A123 SYSTEMS

12V Li-Ion Batteries – Ready for Mainstream Adoption

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Outline

- 12V Li-Ion Battery Characteristics
- Cold Cranking
- Crash Case Study
- Under Hood Package Case Study
- CO_2 Saving Potential
- Value Analysis
- Moving to Mainstream - Manufacturing in Europe
- Summary

12V Li-Ion Battery

Characteristics

CHARGE ACCEPTANCE

Significantly higher rate of charge acceptance than lead acid, no recovery period required after previous charge or discharge, and maintains charge performance through the life of the battery. This behavior results in better regenerative charge performance for improved fuel economy/emissions

LIFE

Considerably longer life and great usable energy support warranty reduction and consumer total cost of ownership value

WEIGHT

Approximately 50% lighter than lead acid battery replaced

INTELLIGENCE

LIN communication can report state of charge, state of health, diagnostics, and precise current and voltage measurements. Allows for elimination of intelligent battery sensor

SAFETY

Lead-free product that is highly abuse tolerant compared to other lithium-ion chemistries

Weight reduction has been the main driver for early 12V Li-Ion adopters

A123s 3rd Generation Li-Ion 12V Battery

Featuring UltraPhosphate™ Technology

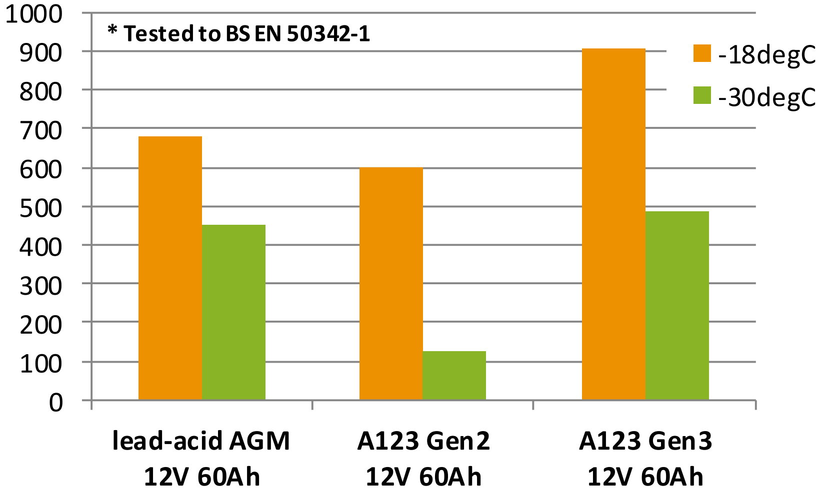
	Unit	Performance
Chemistry	-	UltraPhosphate™
Nameplate capacity	Ah	60
Nominal Energy	Wh	792
Minimum Voltage	V	8.0
Nominal Voltage	V	13.2
Maximum Voltage	V	14.4
EN cold crank amps (-18°C/-30°C)	A	900/480
Communication / disconnect	-	LIN / relay
Mass	kg	< 12.5
Operating Temperature Range	C	-30 to 65
Recommended Storage Temp	C	-40 to 65
Dimensions (LN3/H6)	mm	278 x 175 x 190

Li-Ion 12V Battery

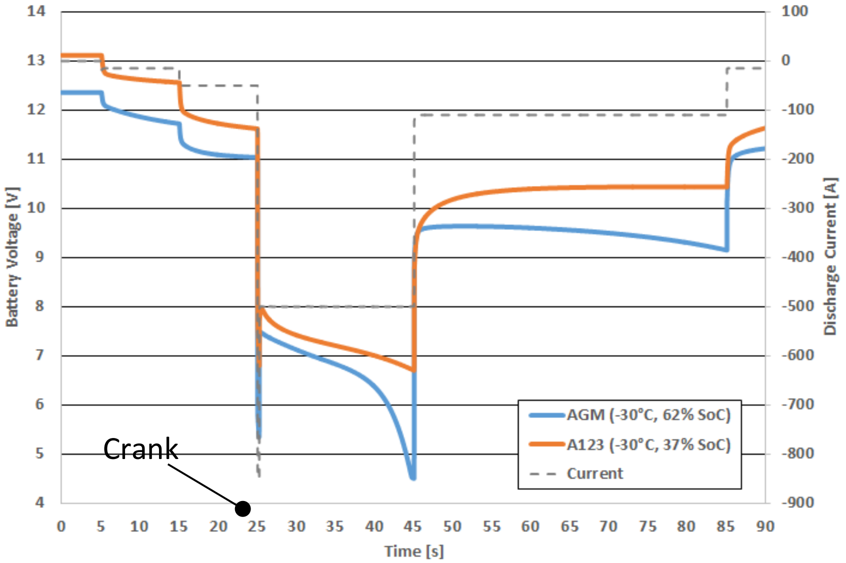
UltraPhosphate™ Technology enables Cold Crank Improvement

Cold Cranking Amps

(7.5V minimum for 10 seconds*)



Extreme Cold Temperature Test @ -30°C *



* Test is more severe than BS EN 50342-1 and performed at partial SOC

A123 has reached parity with lead-acid on cold cranking erasing performance barriers to mass market

Li-Ion 12V Battery

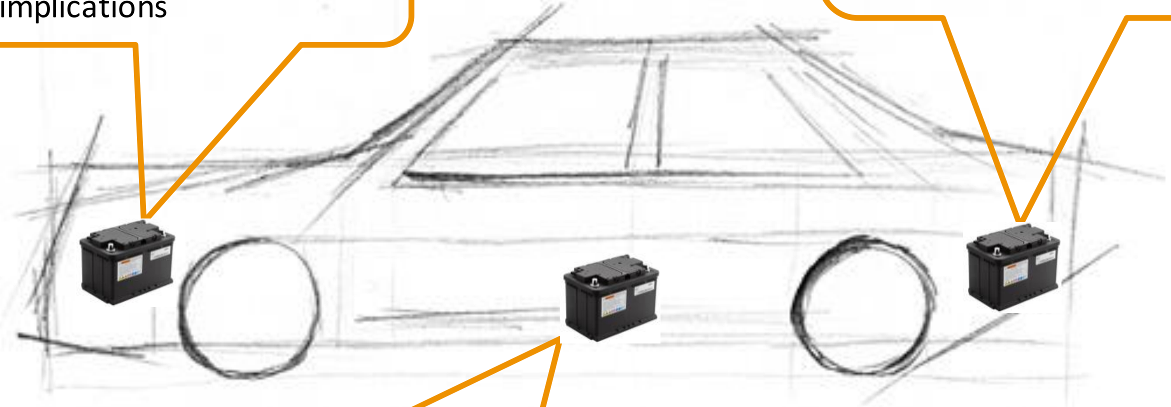
Package Options and their Implications

Under Hood

- High temperature effect on battery life
- Crush zone implications

Trunk

- Crush zone implications
- Electrolyte fumes from inadvertent leakage
- Gassing caused by inadvertent overcharge



Passenger Cabin or Open Cargo Area

- Electrolyte fumes from inadvertent leakage
- Gassing caused by inadvertent overcharge

Crash Safety

Case Study Pole Crash

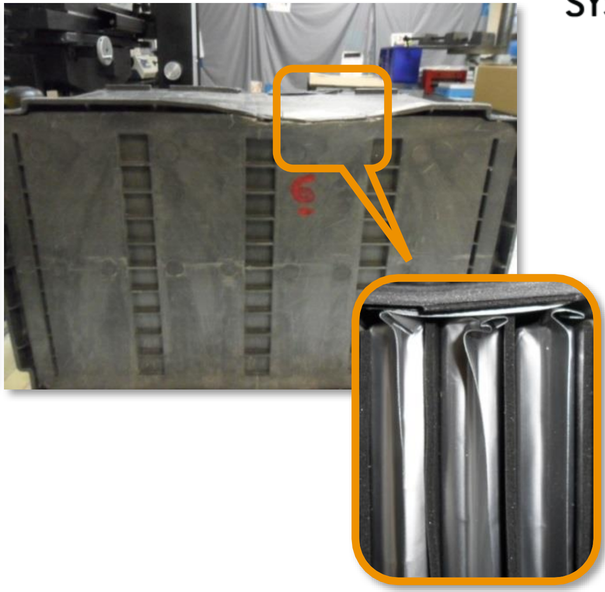
Pole crush test of
12V starter battery

- In a government crash test, the car is propelled sideways at 32km/h against a pole to determine vehicle ability to protect passengers
- The bench level test proxy for a battery packaged in the cabin is a 150kN pole crush test

Crash Safety

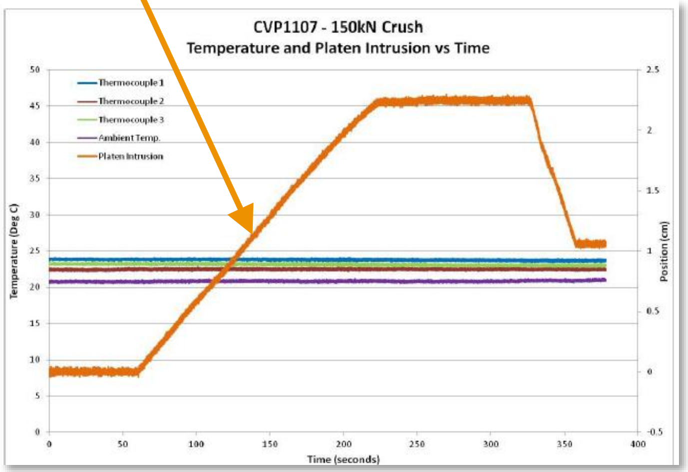
Case Study Pole Crash

150kN Pole Crush Test



Test in process

Travel of pole



Exterior pole damage resulted in no permanent battery cell deformation

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Under Hood Package

Case Study Minivan

- US OEM minivan measured battery surface temperatures
- EU OEM measured µHEV duty cycle in Stuttgart rush hour traffic
- 25k km driven per year
- Calendar and cycle data fit into weekday commute and long weekend trip
- Compare life in Detroit and Phoenix (worst case)

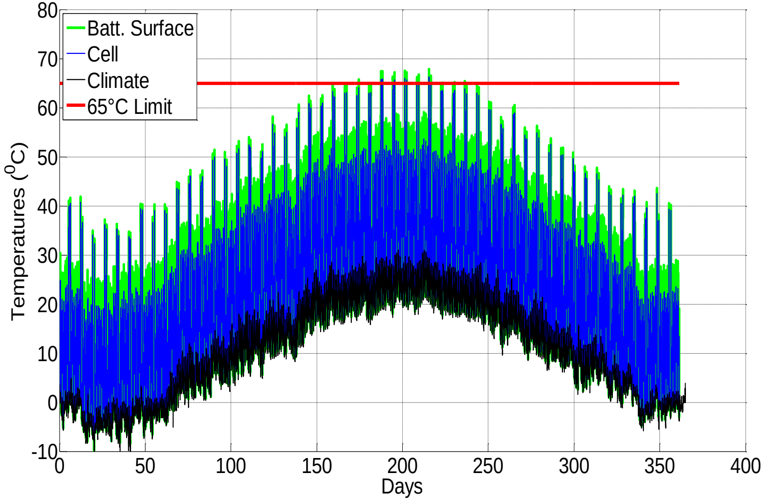
Battery location

Under Hood Package

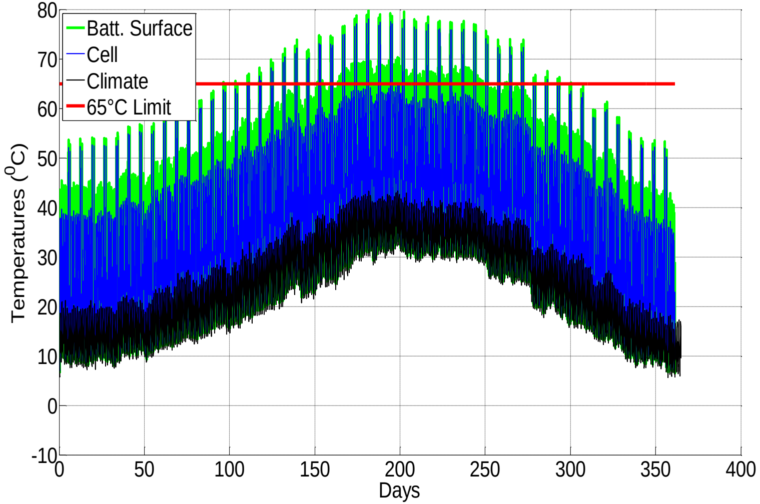
Case Study Minivan

Battery temperatures under hood

Detroit



Phoenix

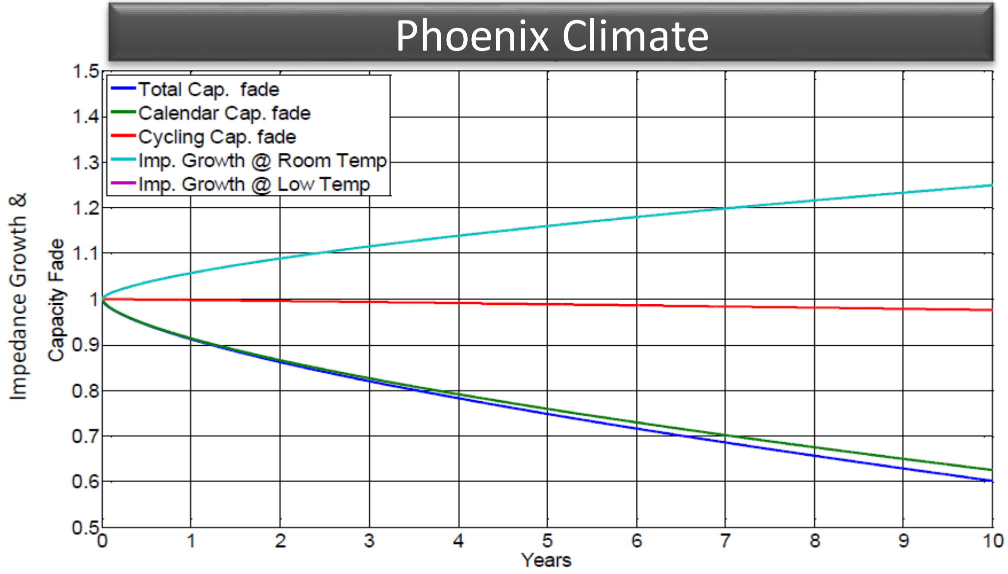


- Max battery cell temperature in Detroit climate is ~65°C
- Max battery cell temperature in Phoenix climate is <80°C

Under Hood Package

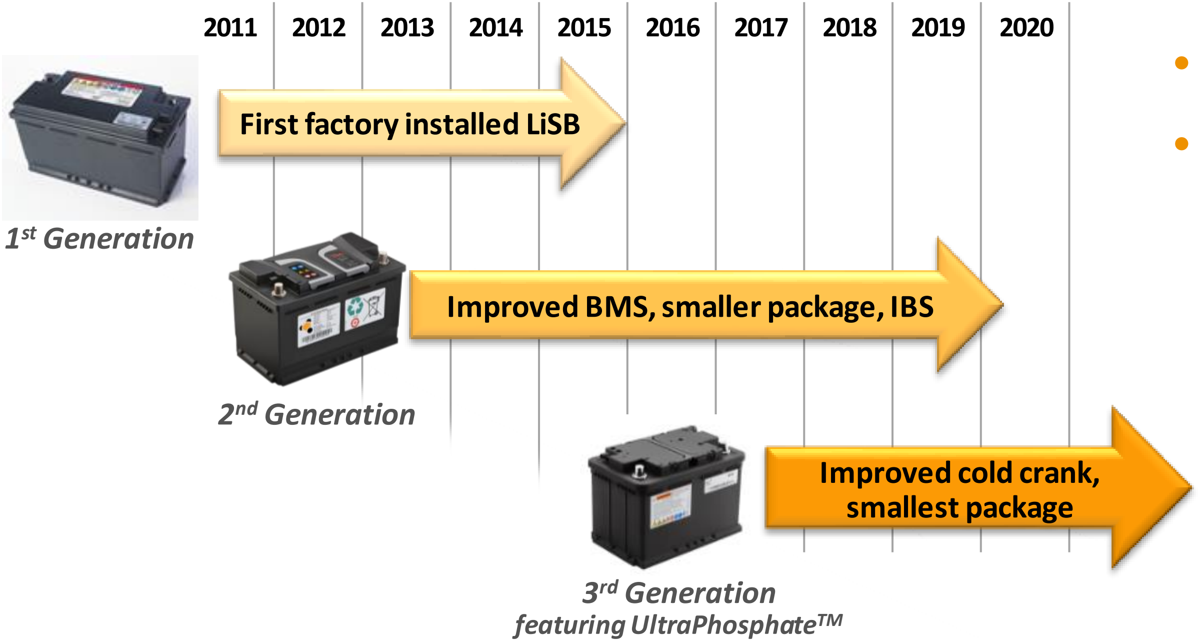
Case Study Minivan

Battery life prediction



- Imedance growth after 10 years is predicted to be 25%
- Capacity fade after 10 years is predicted to be 40%
- The case study presented represents an under hood battery packaged away from the exhaust manifold
- The under hood temperature distribution is different per vehicle and per under hood package location

Optimization



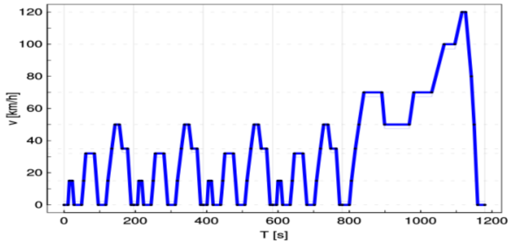
Further optimization of weight and cost through refined requirements definition

- Longterm (field) experience
- Review requirements to balance cost drivers
  - + Capacity requirements
  - + Crash/crush requirements
    - – Safe battery behaviour with relaxed hazard level requirements
  - + Overcome legacy lead acid requirements
    - – standard cell geometry
    - – terminal location/type
    - – housing material
    - – …

Li-Ion 12V Battery

Battery Operation Strategy in Legislation Cycle

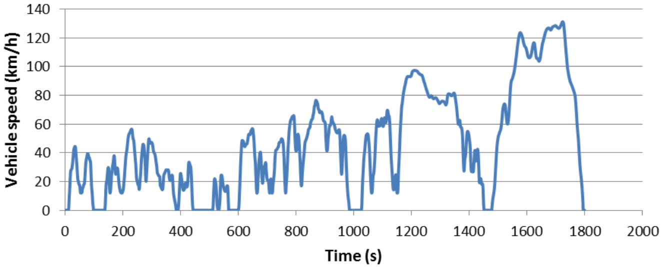
- NEDC



- No requirements regarding 12V battery SOC
- Typical strategy is to support power net loads from the battery, no alternator usage
- Battery is depleted during cycle

Battery regen capability enables on cycle CO_2 benefits in WLTP

- WLTP

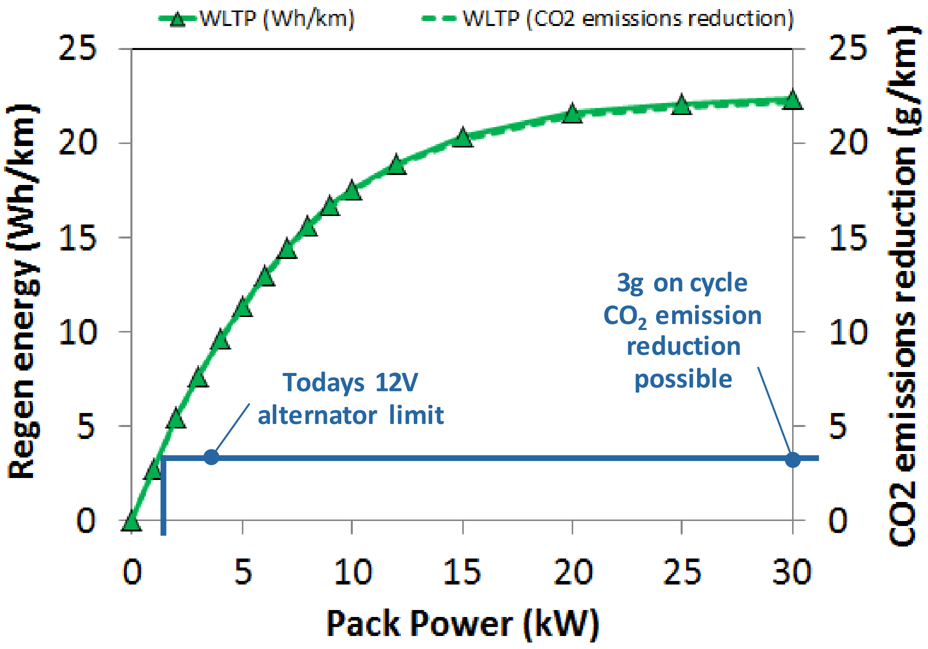


- New requirement: same battery SOC at beginning and end of the cycle
- No alternator usage required if the energy used to support power net loads can be recoverd through regenrative braking
- High charge acceptance required, only possible with advanced 12V batteries

Li-Ion 12V Battery

Fuel Economy Benefits from Regenerative Braking

- “Autonomie” software simulation, midsize vehicle, BISG, WLTP drive cycle
- 60Ah pack, constant impedance set to 20s value, no capacity limitation imposed



Simulation shows that 3g on cycle CO_2 emission reduction is possible in WLTP

Rick et al, SAE, 2015, doi:10.4271/2015-01-1151.

Li-Ion 12V Battery

Value Analysis [12V 60Ah]

"Drop in replacement" value	Value
Baseline AGM battery cost (80Ah)	€70
AGM warranty + 'lot rot' cost on stop-start vehicles	€11
Weight save value (10kg at €5/kg)	€50
Intelligent battery sensor	€9
Sub-total	**€140**

Conservative number, value can be significantly higher dependent on vehicle weight targets

Recuperation value	Value of emissions improvement
Penalty avoidance in EU in 2020 (3g CO_2 at 95€/g)	**€285**

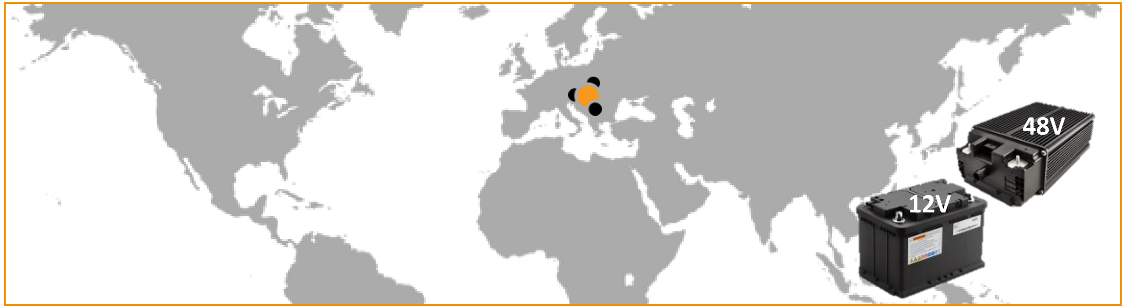
Value may be lower based on alternative emission reduction technologies cost and impact, and OE specific needs to comply to legislation

Total value of a 60Ah 12V Li-Ion battery is €425

Moving to Mainstream

Low Voltage Li-Ion Batteries will reach Millions of Units

- Driven by global clean air legislation, low voltage hybrids are a key part of most OEM product strategies globally
- A123 is ramping up to support volumes indicative of mainstream technology
- Total annual volume of low voltage batteries produced by A123 expected to be >1M units by 2020
- A123 has established a battery assembly plant in Czech Republik to support European volumes



Summary

- Driven by global clean air legislation, low voltage hybrids are a key part of most OEM product strategies globally
- Weight reduction has been the main driver for early 12V Li-Ion adopters
- On cycle CO_2 emission benefit in WLTP has the potential to be a game changer
- Barriers to mass market adoption have been addressed:
  - + The total value of a Li-ion battery exceeds cost
  - + Cold crank performance gaps have been closed
  - + Crash safety has been proven
  - + Under hood package seems to be possible
  - + Battery manufacturing is ramping up
  - + Further optimization of weight and cost through refined requirements definition

- **12V Li-ion batteries are ready for mainstream adoption**

A123 SYSTEMS

Battery cells for high performance hybrids

Advanced energy storage for micro-hybrids

Market leader in commercial vehicles

Complete battery systems for vehicle electrification

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