

# **[CBI] Recommendation for 12V Charging Strategy in BEV**

## **CBI ALBA Plus project #1**

Draft Status for ALBA 2026

# Content

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## Introduction: 12V lead batteries in BEV

- Lead battery basics – key facts
- Case studies: Observations in OEM strategies
- Field data analysis: How 12V batteries fail in real-world HEV and BEV
- Differences versus conventional (ICE) cars, application categories
- Basic requirements to battery and monitoring system
- Use cases for auxiliary and backup batteries

## The core of the strategy: voltage setpoint

- battery-driven requirements to setpoint choice, Z curves, charge modes, ramps
- integration of charge modes with vehicle operating modes, energy management aspects
- IBS-driven requirements to setpoint modulation

## Other system design aspects

- cyclic throughput: prediction and control
- charge recovery: discharge power is restored much faster than state of charge
- relationship to Functional Safety (ASIL functions)
- package location, heat exposure

# Lead Battery Basics – key facts 1/2

## Some battery basics

- How are lead batteries different from rocking-chair intercalation batteries?
- Facts you may use to justify the requirements in this document

## Materials

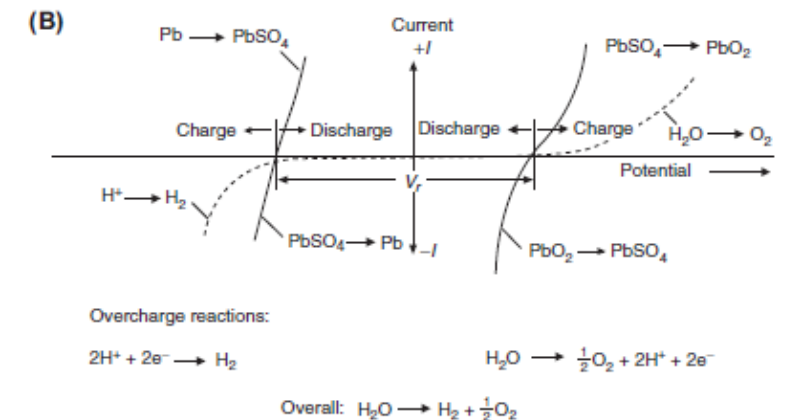
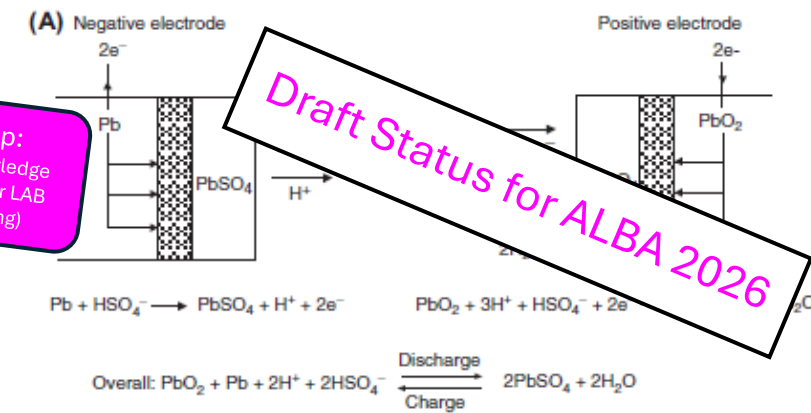
- only one metal in active materials (pos.: porous  $\text{PbO}_2$ , neg.: sponge Pb – no binders) and current collectors (Pb grids)
- aqueous electrolyte: sulfuric acid – is consumed during discharge (full: 35~40%, empty: 10~15%): This gives rise to  $\text{OCV} = f(\text{SOC})$ , conductance  $= f(\text{SOC})$ , concentration gradients and inhomogenous current distribution over plate height and depth

## Electrochemical reactions

- main (storage) reactions are true electrochemical conversions (dissolution/precipitation): limited cycle life
- side reactions: water dissociation, neg. oxygen reduction, pos. grid corrosion
  - thermodynamically enabled at equilibrium potentials of main reaction and accelerated while charging
  - only kinetically hindered: standby batteries can last 15 years and longer, automotive: “very low” water consumption
  - allow internal balancing by 8~24 h overcharging (equalization charge)
  - central degassing and venting hose are mandatory when installed in vehicle interior

first draft – target group: engineers with some Li-ion knowledge who happen to be responsible for LAB (trying to be quick and surprising)

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D.A.J. Rand, P.T. Moseley: Lead-acid battery fundamentals, Fig. 3.1, in: J. Garche, E. Karden, P.T. Moseley, D.A.J. Rand (eds.): Lead-acid batteries for future automobiles, Elsevier: Amsterdam 2017

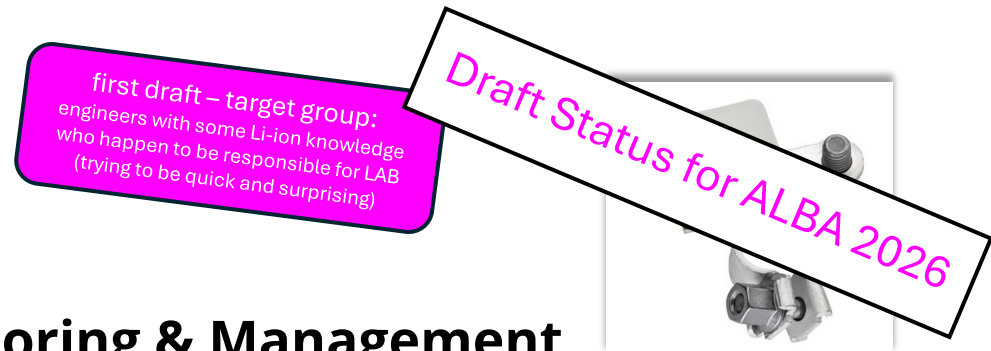
# Lead Battery Basics – key facts 2/2

## Ageing / failure mechanisms

- serviceable wear parts: designed for **replacement**
- very **abuse-tolerant**, high performance even while shorted
  - no hazardous failures (if safety rules around hydrogen venting and electrostatic ignition are followed)
- if nothing else happens earlier: positive grid & connectors **corrosion** will cease product life
  - corroding grids expand in wire length and grow and/or bulge macroscopically – this may cause cell shorts in late life
- pos. **cyclic wear** after “deep” cycling that goes along with volume change and structural rebuilding of porous PbO<sub>2</sub>
  - mechanical support extends cycle life of EFB (enhanced flooded) and AGM (absorptive glass-fibre mat) cell designs
- **sulfation** = growth of discharged material (PbSO<sub>4</sub>) particles: “ripening” spontaneously or by microcycling – until no longer rechargeable
  - dominant in neg. electrodes during microcycling (e.g., stop/start) – additives may prevent growth and improve chargeability
- **water loss** (dissociation), particularly in hot climate and engine bay
  - flooded and EFB “recombine” ⅓ ... ½ of oxygen formed at positive, AGM closer to 100% recombinant but with smaller reservoir volume
- **passive components** (separator, lid, valves, ...) may cause premature failures if design or process weak

## Monitoring & Management

- lead batteries come without integrated electronics (cell stack = commodity in standardized containers, easy to service, easy to recycle, need no balancing)
- modern vehicles often have *I,U,T* sensor integrated in terminal clamp (stays in vehicle when battery replaced)
- where battery is required for Functional Safety: ASIL requirements apply to battery monitoring, not to battery nor charging system (QM only)
- vehicle controls are essential for good service life
  - charging system (alternator, dc/dc converter): voltage setpoint to compensate temperature, avoid sulfation, etc.
  - load control to avoid excessive cycling and low SOC
  - 100 years experience for ICE cars, now apply to BEVs
- battery replacement strategy
  - ICE car: usually replace battery after no-start, typically without preceding reliable driver warning
  - BEV: no engine start – vehicle should call for replacement



# Case Studies: Observations in OEM strategies

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**Many BEVs employ poor 12V operating strategies.**

## **1) Constantly low voltage and high key off load**

- OEM claims only fixed setpoint be possible and chose it <14V
- field issue: undercharge, sulfation – partly resolved by higher (yet constant) setpoint

## **2) Field SOC distributions for flooded versus AGM batteries**

- AGM battery is more robust against sub-optimum operating strategy

## **3) 12V recharge strategy for parking BEV**

- parking lights may drain the 12V battery to “battery flat” breakdown condition
- Surprisingly, some BEVs do not utilize highvolt-to-12V transfer in parking condition.

## **4) Supply key-off loads out of high-volt battery**

- continuous 12V supply through main dc/dc converter goes along with high losses for HV system safety functions
- alternative topologies may supply 12V low-moderate power (e.g., 5...10A) out of HV battery while HV main relay off

## **5) One good example**

- parking lights supplied out of 12V battery
- 12V battery replenished regularly

# Case Studies: Observations in OEM strategies

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## 1) Constantly low voltage and high key off load

- OEM claims only fixed setpoint be possible and chose it  $<14V$
- field issue: undercharge, sulfation – partly resolved by higher (yet constant) setpoint

ALBA 2025: CSO1, Kevin Luo / Camel



### Typical Failure Cases and Analysis---abnormal discharge and low charging voltage



#### 1. Background:

- ◆ **Chinese start-up OEM 1: XX model,**
- ◆ **Complaint:** In September 2023, feedback showed that the battery on one of the vehicle was frequently recharged, resulting in low capacity and unable to charge to 100% SOC or near 100%SOC due to low charging current.
- ◆ **Battery status:** SLI 45AH, After cyclic charging and discharging in lab, the battery capacity shows a slight increase, but still with a measured capacity loss of about 10-20%.
- ◆ **Phenomenon:** There is a continuous low current discharge cycle condition (**frequent wake-up of Bluetooth key**) on vehicle, and the battery cannot reach full charge for a long time.

# Case Studies: Observations in OEM strategies

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## 1) Constantly low voltage and high key off load

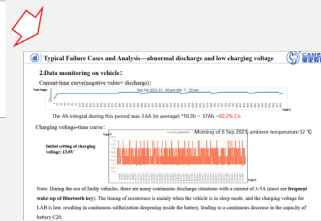
- OEM claims only fixed setpoint be possible and chose it <14V
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ALBA 2025: CSO1, Kevin Luo / Camel

4 Typical Failure Cases and Analysis—abnormal discharge and low charging voltage

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- ◆ Complaint: In September 2023, feedback showed that the battery on one of the vehicle was frequently recharged, resulting in low capacity and unable to charge to 100% SOC or even 100% SOC due to low charging current.
- ◆ Battery status: 51.1 kWh, after cyclic charging and discharging in lab, the battery capacity shows a slight increase, but still with a measured capacity loss of about 10-20%.
- ◆ Phenomenon: There is a continuous low current discharge cycle condition (frequent wake up of Bluetooth key) on vehicle, and the battery cannot reach full charge for a long time.



ALBA 2025: CSO1, Kevin Luo / Camel

## 5. Problem Solving:

After internal discussion, OEM1 resolved the complaint through adopting the following two suggestions:

- ◆ Through software control, limit the frequent wake-up and continuous low current discharge of electrical appliances during sleep mode;
- ◆ The charging voltage for the LAB has been increased from 13.8V to 14.3V, with constant voltage charging and no temperature or SOC compensation.

# Case Studies: Observations in OEM strategies

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## 2) Field SOC distributions for flooded versus AGM batteries

- OEM uses constant dc/dc setpoint of 14.5V only (no Z curve, no boost charge as would be recommended)
- flooded SLI battery: low SOC frequently observed in car population (mainly due to stratification)
- AGM battery: more robust against sub-optimum operating strategy

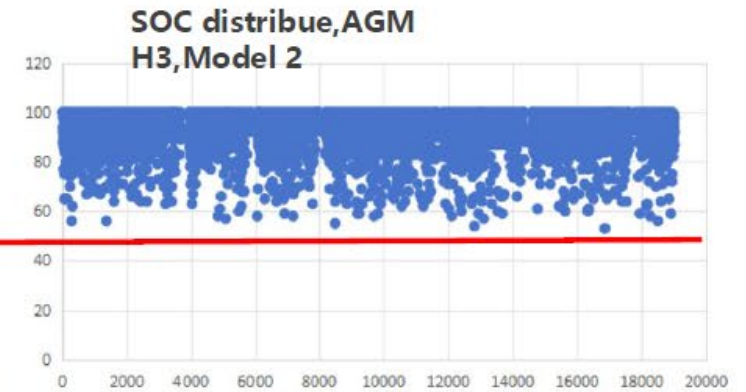
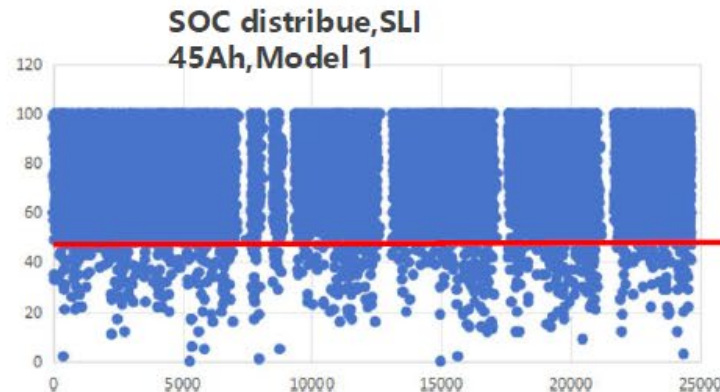
ALBA 2025: CSO1, Kevin Luo / Camel



Case **without** Intelligent charging strategy:

Chinese NEV brand A under a conventional carmaker ,

|                   | Model 1                             | Model 2 |
|-------------------|-------------------------------------|---------|
| Battery type      | SLI 45Ah                            | AGM H3  |
| Vehicle number    | 24000                               | 19000   |
| Charging strategy | Charging strategy: Constant 14.5V . |         |

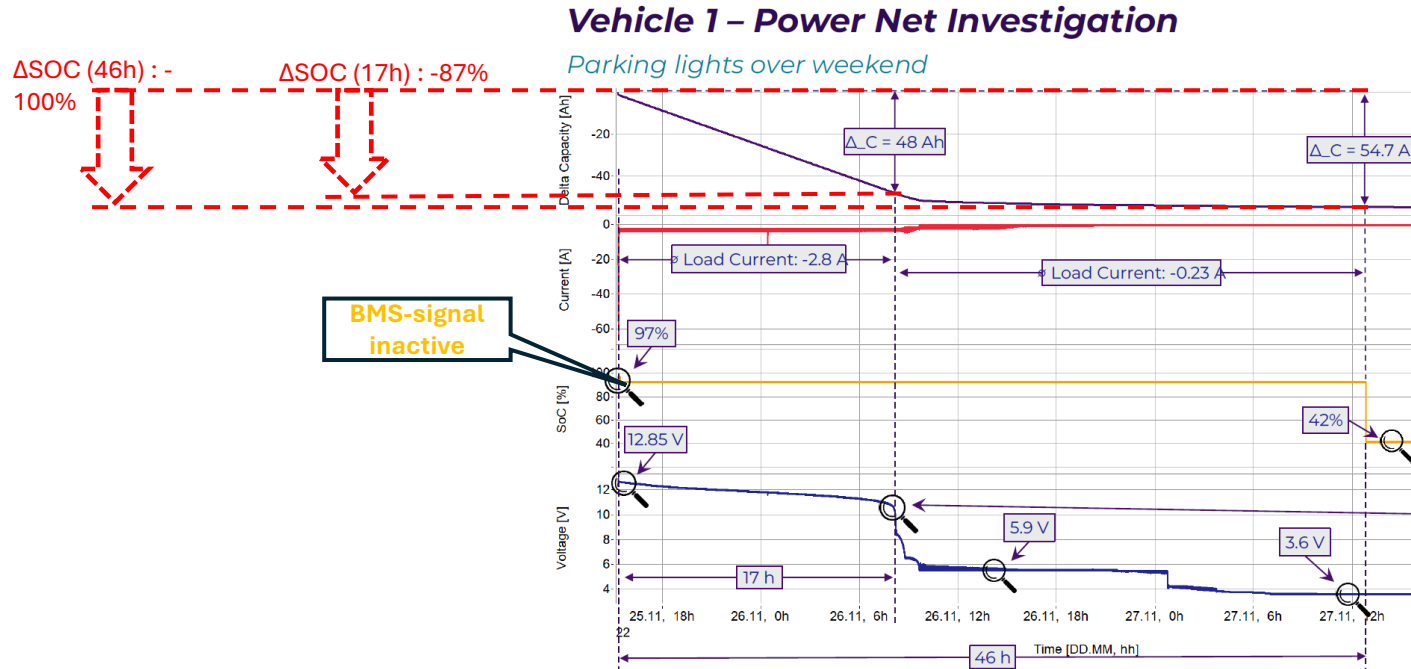


# Case Studies: Observations in OEM strategies

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## 3) 12V recharge strategy for parking BEV

- parking lights may drain the 12V battery to “battery flat” breakdown condition
- Surprisingly, some BEVs do not utilize highvolt-to-12V transfer in parking condition



CLARIOS

- 87.3% of Nominal Capacity discharged in ~17 h
- 100% of Nominal Capacity discharged in ~46 h
  - Deep Discharge possible
  - DC/DC does not recharge H5 SLI
- SoC (Battery sensor data) is not updated during discharge
  - After discharging Nominal Capacity: SoC = 42% (allegedly)
- Once reaching 11.05 V, Voltage rapidly drops down to 5.9 V

ALBA 2025: CSO2, Michael Gossner / Clarios

**Vehicle 1:** Exclusive usage of the 12V Lead Battery over the weekend leads to its deep discharge and inability to start the vehicle

# Case Studies: Observations in OEM strategies

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## 4) Supply key-off loads out of high-volt battery

- continuous 12V supply through main dc/dc converter goes along with high losses for HV system safety for
- alternative topologies may supply 12V low-moderate power (e.g., 5...10A) out of HV battery while HV main relay on

### Vehicle 2 - Power Net Investigation

#### Parking lights over weekend

- 12V power net load **~9A** → 122W
- Loads powered by HV battery (via DC/DC)
- No charge or discharge of 12 V battery
- Floating voltage ~13.5 V
- HV SOC: 50% → 34 %  
→ ~9.6 kWh/66h → ~3.48 kWh/24h → **145 W**

Recommendation: Deactivate HV system and only power needed loads over 12 V battery until a defined SoC is reached. Then recharge 12V battery via DC/DC.

→ Lowers overall power consumption and requires only short activation of HV system for recharging 12 V battery



CLARIOS

ALBA 2025: CSO2, Michael Gossner / Clarios

🙄 **Vehicle 2:** Exclusive usage of the HV battery to power 12V system (via DC/DC) leads to significant loss of traction battery SoC (→ Loss of vehicle range)

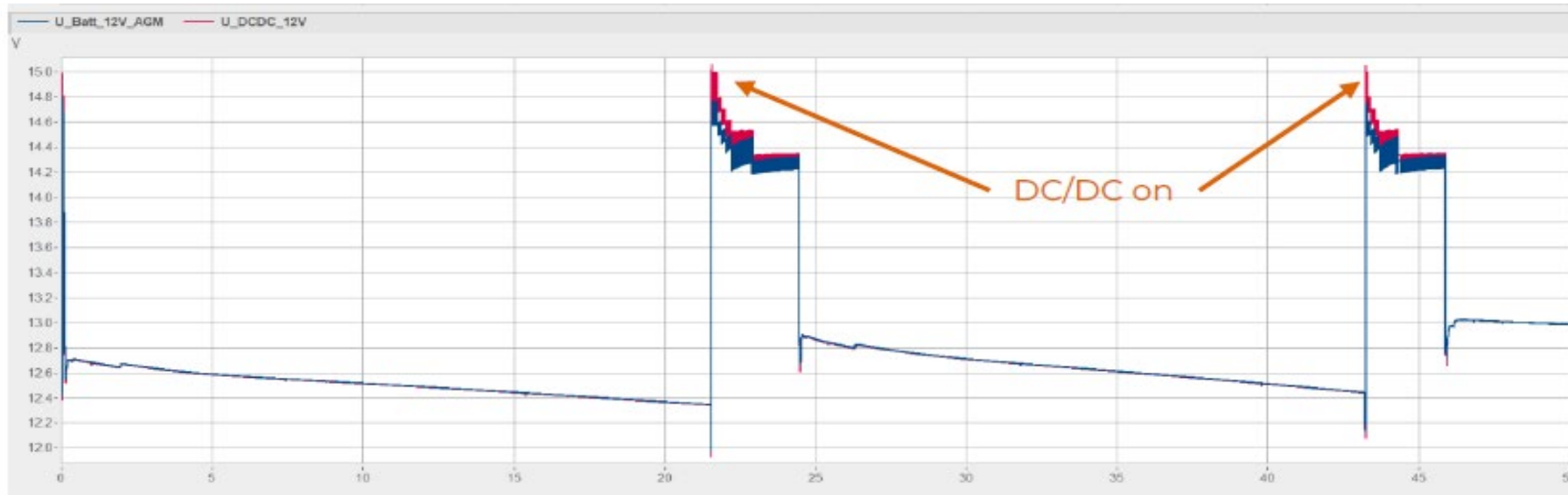
# Case Studies: Observations in OEM strategies

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## 5) One good example

- parking lights supplied out of 12V battery
- 12V battery replenished regularly

## Vehicle 3 – Power Net Investigation



- First discharge interval:
  - Discharge for ~6h (~15 Ah)
  - ~2.5 A
  - HV battery not active
- First charge interval:
  - 12 V AGM charged from HV battery over DC/DC
  - 14.19 V – 14.77 V battery voltage
  - Charge for 48 min (~15.8 Ah)
  - $\sigma$  ~19.8 A (peak: ~188 A; ~2.7 kW)
- Second discharge interval:
  - Discharge for ~5h (~13 Ah)
  - ~2.5 A
  - HV battery not active
- Second charge interval:
  - 12 V AGM charged from HV battery over DC/DC
  - 14.19 V – 14.77 V battery voltage
  - Charge for 44 min (~13 Ah)
  - $\sigma$  ~17.5 A (peak: ~186 A; ~2.6 kW)

ALBA 2025: CSO2, Michael Gossner / Clarios

🤖 **Vehicle 3:** Primary usage of 12V Lead Battery with frequent recharge by HV System (via DC/DC): Low overall energy consumption + protection of 12V battery

# Field data analysis: How 12V batteries fail in HEV and BEV

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## 1) HEV in Japan

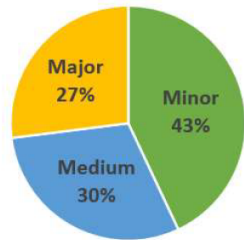
ALBA 2025: AUX5, Kohei Koga / Battery Association of Japan

### AUX Battery Investigation on HEV in JP Market

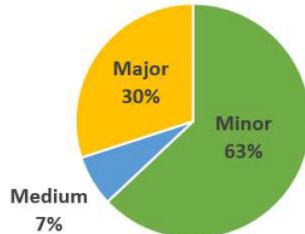
#### Positive Plate Deterioration

- Grid Corrosion
  - ✓ Minor level:43%, Medium level:30%, Major level:27%
  - ✓ Correlated with temperature/period of use
- PAM Softening
  - ✓ Minor level:63%, Medium level:7%, Major level:30%
  - ✓ Affected by vehicle control system
  - ✓ Commonly used under shallow charge/discharge cycles

Grid Corrosion



PAM Softening



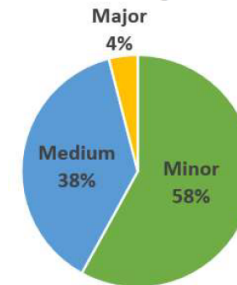
一般電池工業会  
社団法人  
BATTERY ASSOCIATION OF JAPAN

### AUX Battery Investigation on HEV in JP Market

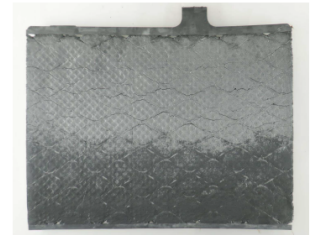
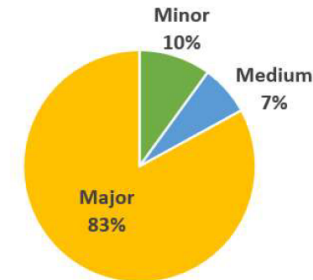
#### Negative Plate Deterioration

- NAM Shrinkage
  - ✓ Minor level:58%, Medium level:38%, Major level:4%
  - ✓ Affected by shallow charge/discharge cycles
  - ✓ Thinner plate – Easier to shrink
- NAM Sulfation
  - ✓ Minor level:10%, Medium level:7%, Major level:83%
  - ✓ Correlated with period of use
  - ✓ Affected by acid stratification

NAM Shrinkage



NAM Sulfation



一般電池工業会  
社団法人  
BATTERY ASSOCIATION OF JAPAN

**Undercharge and sulfation dominate AUX field battery failures.  
So far, OEMs tend to optimize strategies to avoid overcharge and corrosion.**

# Field data analysis: How 12V batteries fail in HEV and BEV

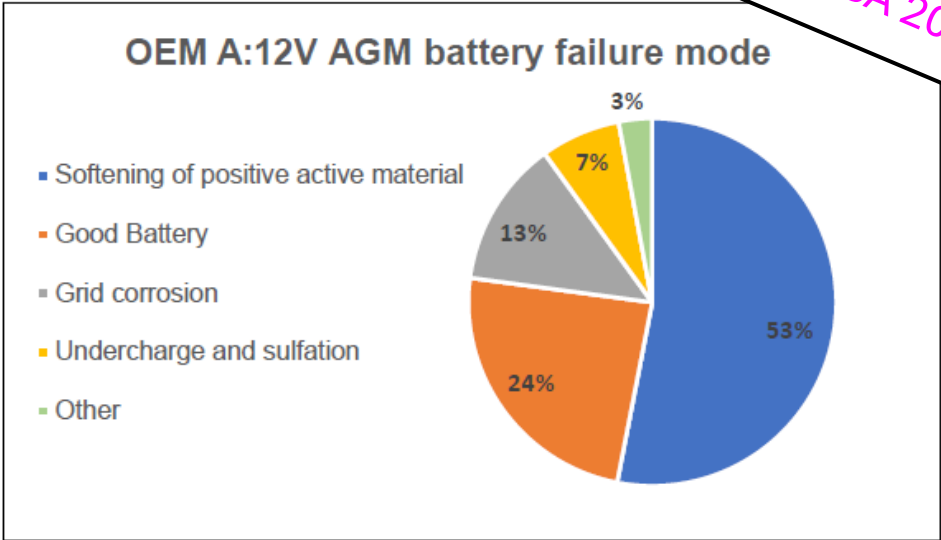
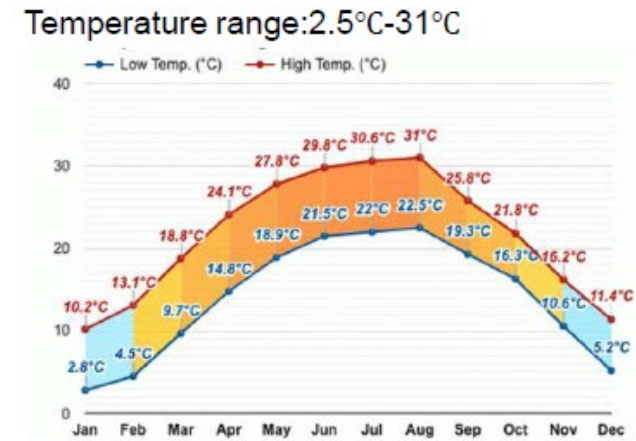
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ALBA 2024: AUX02.2, Mike Miao / Leoch

## 2) AGM in BEV, central China

- AGM JIS B21, 40 Ah
- OEM A: 3 models, usually installed in trunk
- sample size: 341 pcs (from 2019-2022)
- **cyclic wear dominates – despite AGM**

OEM A's main sales area



| Type                | Failure mode                          | Qty | Rate |
|---------------------|---------------------------------------|-----|------|
| AGM<br>JIS B21 40Ah | Softening of positive active material | 181 | 53%  |
|                     | Good Battery                          | 82  | 24%  |
|                     | Grid corrosion                        | 44  | 13%  |
|                     | Undercharge and sulfation             | 24  | 7%   |
|                     | Other                                 | 10  | 3%   |
|                     | Total                                 | 341 | 100% |

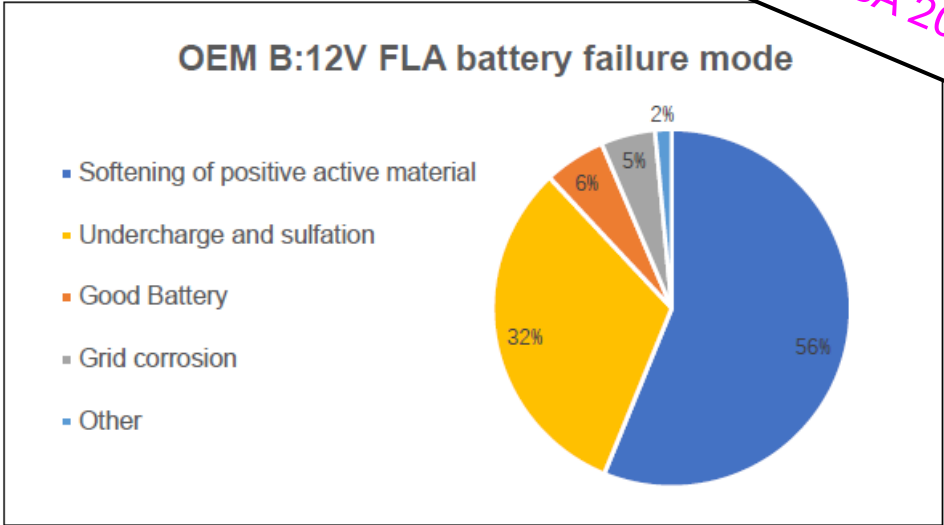
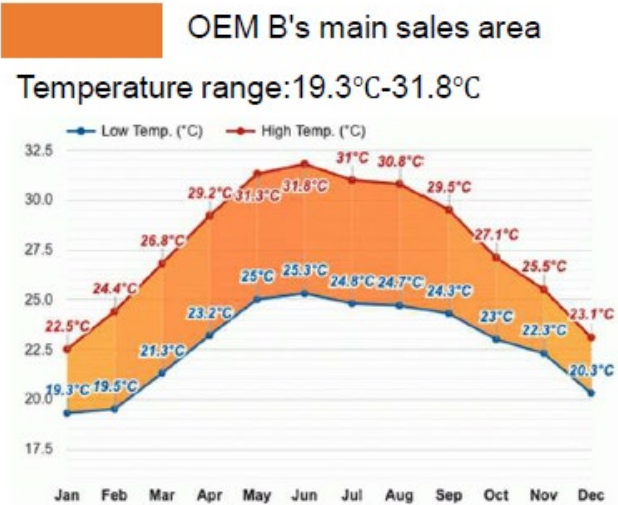
# Field data analysis: How 12V batteries fail in HEV and BEV

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ALBA 2024: AUX02.2, Mike Miao / Leoch

## 3) Flooded in BEV, southern China

- FLA JIS B20, 36 Ah
- OEM B: 5 models, usually installed under hood
- sample size: 794 pcs (from 2020-2023)
- **cyclic wear and sulfation dominate – despite hot climate**



| Type         | Failure mode                          | Qty | Rate |
|--------------|---------------------------------------|-----|------|
| JIS B20 36Ah | Softening of positive active material | 446 | 56%  |
|              | Undercharge and sulfation             | 253 | 32%  |
|              | Good Battery                          | 44  | 6%   |
|              | Grid corrosion                        | 39  | 5%   |
|              | Other                                 | 12  | 2%   |
|              | Total                                 | 794 | 100% |

# Field data analysis: How 12V batteries fail in HEV and BEV

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ALBA 2024: AUX02.3, Gao Guoxing / Camel

## 4) Flooded in BEV, China

- wrong judgement from handheld tester is no.1 warranty cause for BEV still (like for ICE cars)
- **sulfation dominates – mainly caused by**
  - quiescent drain (measured  $>150\text{mA}$  as opposed to normal  $10\sim30\text{mA}$ )
  - low charging voltage  $13.8\text{V}\sim14.0\text{V}$ ;
  - long storage after battery and vehicle production;
  - short charging duration (city commuter during trips only)



# Field data analysis: How 12V batteries fail in HEV and BEV

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ALBA 2024: AUX02.3, Gao Guoxing / Camel

## 5) Flooded in electric bus, China

### ▪ PAM softening / cyclic wear dominates – mainly caused by

- deep cycling when high-volt system is shut down during stand-by operation at terminals/stops
- high-volt system does not recharge 12V battery timely



# Field data analysis: How 12V batteries fail in HEV and BEV

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ALBA 2024: AUX02.3, Gao Guoxing / Camel

## 6) Flooded in electric bus, China

### ▪ PAM softening / cyclic wear dominates – mainly caused by

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- high-volt system does not recharge 12V battery timely



# Field data analysis: How 12V batteries fail in HEV and BEV

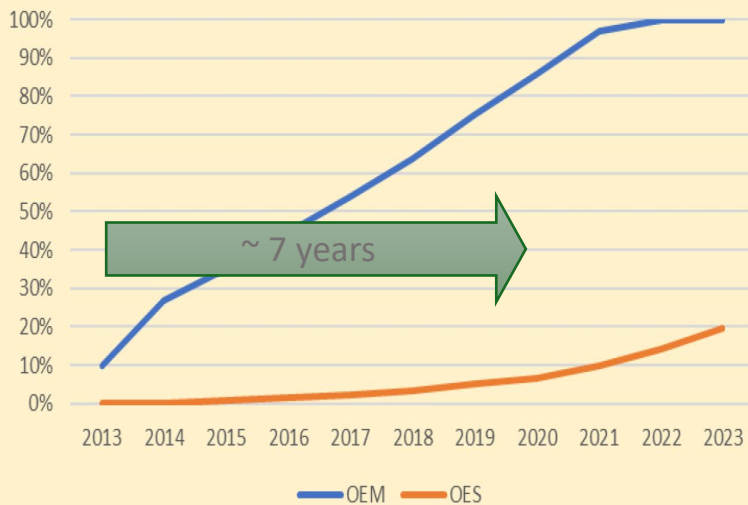
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ALBA 2024: AUX02.4, Bernd Engwicht / East Penn \*)

## 7) good field durability proven with 3 auxiliary & backup battery applications

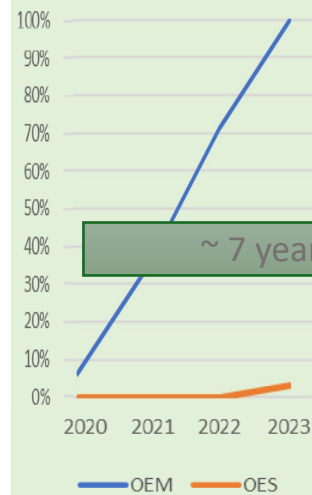
- no compatible replacement battery was available from third parties / independent aftermarket, but only OES
- cumulated aftermarket sales versus OEM (normalized 2023=100%)

NETWORK POWER SUPPLY



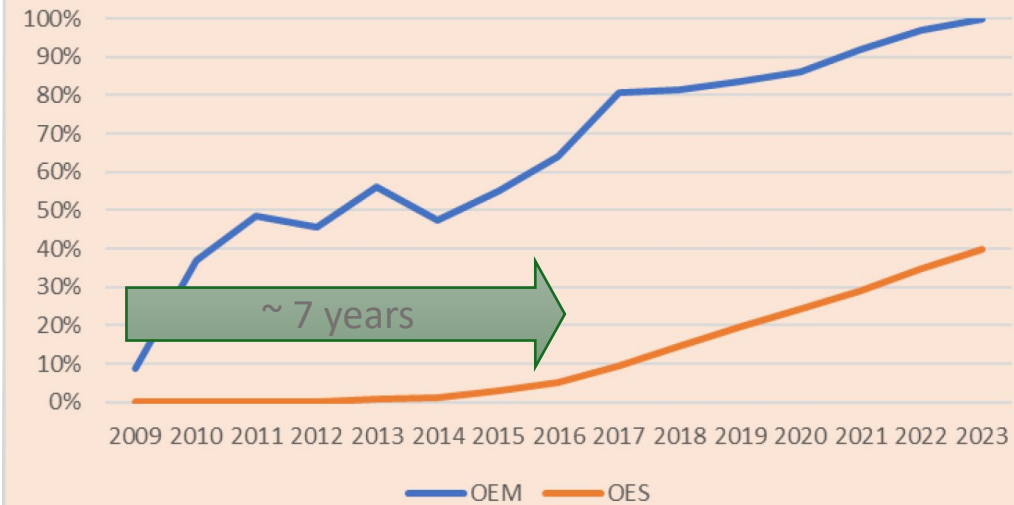
**BEV full Auxiliary battery** (IEC category 1C)  
vehicle SOP 2013  
After 10 years, ~20% of all batteries replaced

BACK UP POWER



**Backup battery** (IEC category 2)  
vehicle SOP 2020 (OES sales include inventory filling)  
After 3 years, <<5% of all batteries replaced

Voltage Stabilisation



**stop/start voltage stabilization** (IEC category 3)  
vehicle SOP 2009  
After 10 years, ~25% of all batteries replaced

coordination 2025-2026 :

Roger Zimmermann, combatec

Eckhard Karden, Consultant

\*) diagrams rescaled by E. Karden for ALBA Asia 2025, A41

# Scope for using lead batteries in BEVs

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## BEV: Distinction to ICE

- no engine bay “hot” location, but comparable to trunk in ICE car (temperature mostly < 60°C)
- more 12V “on” time (on-plug traction battery charging, high-volt-to-low-volt charge transfer while parking)
- dc/dc converter (rather than alternator: faster response, no compromise with powertrain controls)
- recharge possible in parking vehicle (HV-to-12V transfer is only limited by dc/dc conversion losses)
- higher maximum charging voltage (~15.5V) may be allowed due to fast dc/dc response in load-dump case
- advanced topologies may allow for continuous HV-to-12V transfer (with very high efficiency at low power)
- Established battery sizing rules for capacity (drain while parking) and power (engine start) are obsolete, new rules not broadly established yet. System design and component sizing are not subject of this document.

## OEM platforms use different 12V power-supply topologies → role of battery?

- **AUXiliary** = main 12V battery that just does not start an engine but supplies other loads and may be subjected to significant cyclic throughput (e.g., over-the-air updates, parking lights, electric tailgates etc.)
- **Backup** battery, not discharged into loads regularly
- either way, some peak-power loads may be safety-relevant: **ASIL functions**  
(ASIL = automotive safety integrity level: typically B, sometimes C per sub-net supplied by one battery)

# Application categories IEC 60095-8

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Auxiliary

Backup

ICE

### 3.1 Categories

Batteries defined for auxiliary or backup purposes relate to vehicle applications which are very diverse and undergo fast technical changes. However, they can typically be associated with one of the following three categories:

- Category (1):** 12V central-storage (main) battery, with most functions of modern automotive batteries except engine starting. These functions typically include: power supply during parking, vehicle activation and after-run, over-the air update and as well transient power delivery and absorption, along with voltage stabilization, during normal vehicle operation.

Such batteries are typically sized for energy or capacity (e.g., to support parking loads for a certain duration) *and* power or high-rate discharge current (e.g., powering electric chassis actuators) simultaneously. As 12 V batteries in electric vehicles can be recharged out of the traction battery while parking, and as cold-cranking performance is not a requirement, they are often downsized and then subjected to higher relative cyclic throughput at greater depth-of-discharge, compared to a starter or micro-hybrid battery in an ICE vehicle with otherwise identical electrical loads.

Emergency power support might be required in system architectures where such functionality is not supported by any additional dedicated energy and power source

Three requirement levels (1A), (1B), (1C) for endurance shall take into account different capacity throughput as predicted by the OEM for specific applications and system designs.

- Category (2):** 12 V backup battery that is stabilizing voltage and providing emergency power for a sensitive – often safety relevant – electrical component or sub-net of the power supply system. Such batteries are often disconnected from the 12 V loads when alternator or dc/dc converter are not feeding the 12 V system, protecting them from discharge while parking etc. In such cases the operating state-of-charge (SOC) range may be narrow (and close to fully charged)

Requirements for category (2) will take into account limited capacity throughput during life and appropriate voltage response when supporting high-rate discharge currents.

Note: this document doesn't provide safety requirements

- Category (3):** 12 V auxiliary batteries in stop/start or micro-hybrid vehicles that stabilize system voltage during engine restart, which would be powered out of the 12 V starter battery. This application is similar to the backup case described above, but battery discharge occurs frequently during normal operation, and is not safety relevant. Requirements for category (3) shall take into account limited capacity throughput and power.

### IEC 60095-8 Categories and durability levels

| category                                  | 1                                                                                                                    |                |                | 2                                                                                                    | 3                                                                                                                        |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------|----------------|----------------|------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| application:<br>high-level<br>description | 12 V central-storage (main) battery:<br>with most functions of modern automotive<br>batteries except engine starting |                |                | 12 V backup battery:<br>stabilizing voltage,<br>providing emergency power<br>(often safety-relevant) | 12 V auxiliary batteries in<br>stop/start or micro-hybrid<br>vehicles: stabilize system<br>voltage during engine restart |
| durability<br>level                       | A                                                                                                                    | B              | C              | n/a                                                                                                  | n/a                                                                                                                      |
| equivalent<br>cyclic<br>durability        | M3 of<br>EN 50342-6                                                                                                  | IEC<br>60095-6 | IEC<br>60095-1 |                                                                                                      |                                                                                                                          |

- Categories remain as in the previous draft, moved to clause 3, some text adjustments to descriptions
  - Durability levels were simplified, carrying over from existing standards where possible
- Note for category 3: dedicated to those auxiliary battery for existing ICE S&S/microhybrid stabilization/support (typically sub LN0 sizes), where the testing and requirements are currently not precisely defined for the purpose by a standard or OEM specifications (e.g. Motorcycle size 9 to 14Ah where the IEC 60095-7 applies, basic requirements just for Motorcycle applications)



# Basic 12V storage-system requirements

(assumptions for this document)

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## Unlike “advanced” battery technologies, an automotive lead battery system consists of

- 6-cell block as serviceable standalone part without communications nor electronics
- intelligent battery sensor (IBS) = battery monitoring system (BMS) integrated into battery-minus terminal clamp (stays in the vehicle in case of battery replacement)

### ▪ lead battery specification

- very low water consumption: EN W4 or IEC VL (?)
- AGM or flooded technology (no differentiation recommended for charging strategy & parameters)
- stratification **to be considered**
- Proper battery sizing to be assured by BEV-specific system design processes.

### ▪ intelligent battery sensor (IBS) is used

- internal battery temperature from chip temperature and thermal model
- voltage measured at the battery terminals
- battery current measured (and integrated) continuously
- typically, LIN communication
- higher-level battery state information (state of charge SOC, state of function SOF, state of health SOH, etc.) may be calculated by IBS-internal software (and communicated via LIN) and/or by a central vehicle control unit

# Content

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## Introduction: 12V lead batteries in BEV

- Lead battery basics – key facts
- Case studies: Observations in OEM strategies
- Field data analysis: How 12V batteries fail in real-world HEV and BEV
- Differences versus conventional (ICE) cars, application categories
- Basic requirements to battery and monitoring system
- Use cases for auxiliary and backup batteries

## The core of the strategy: voltage setpoint

- battery-driven requirements to setpoint choice, Z curves, charge modes, ramps
- integration of charge modes with vehicle operating modes, energy management aspects
- IBS-driven requirements to setpoint modulation

## Other system design aspects

- cyclic throughput: prediction and control
- charge recovery: discharge power is restored much faster than state of charge
- relationship to Functional Safety (ASIL functions)
- package location, heat exposure

# Automotive battery charging is controlled by voltage

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## Alternator or dc/dc converter follows a voltage setpoint

- battery and loads are connected in parallel
- load currents change dynamically, source is supposed to follow demand (alternator intentionally slowly to minimize “jerk” interaction with propulsion)
- **battery current cannot be controlled**
- exception: “zero current control” for lead-acid batteries utilizing lead-battery voltage / current characteristics (big voltage drop for small charging current)

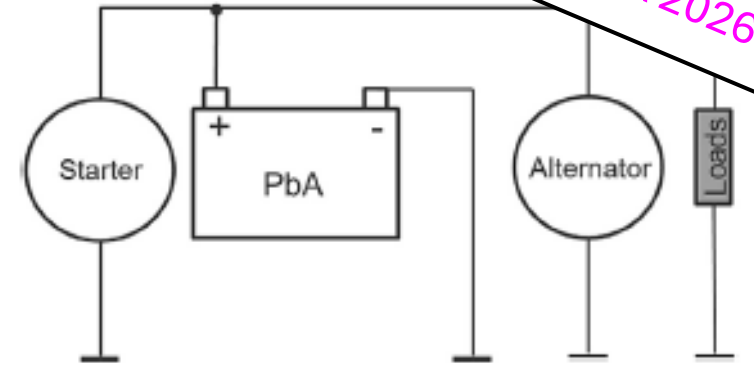


Figure 15.4  
Baseline 12-V topology.

## Voltage setpoint may be modulated

- ripple (inherent for alternator, possible for dc/dc)
- up or down: steps, ramps (fast or slow)
- whenever voltage is stepped down (even to a lower “charging” voltage only), battery will be discharged temporarily: open-circuit voltage after charging would relax to equilibrium very slowly (minutes to days) due to double-layer and pseudo capacitance of positive electrode, as well as acid density gradients

# Normal charge mode

## This single charge mode is sufficient for 12V main battery (AUX) applications

- maybe except some extreme usage profiles like 2-3 shift operation

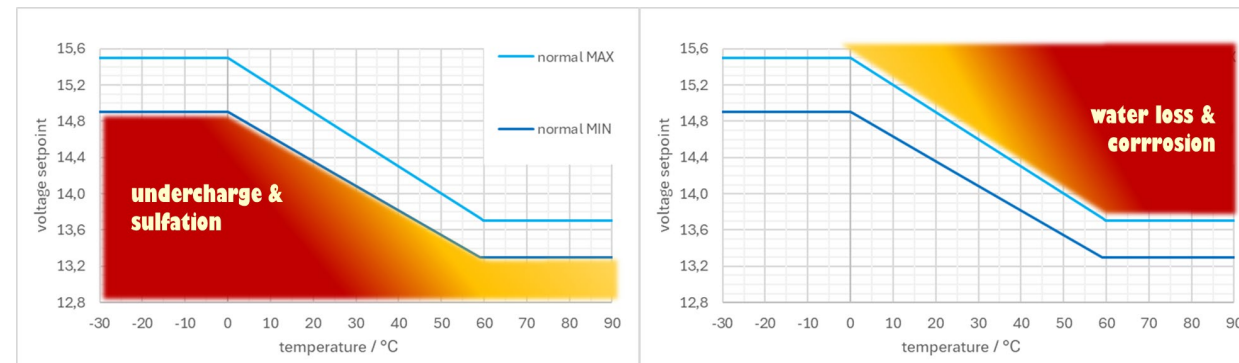
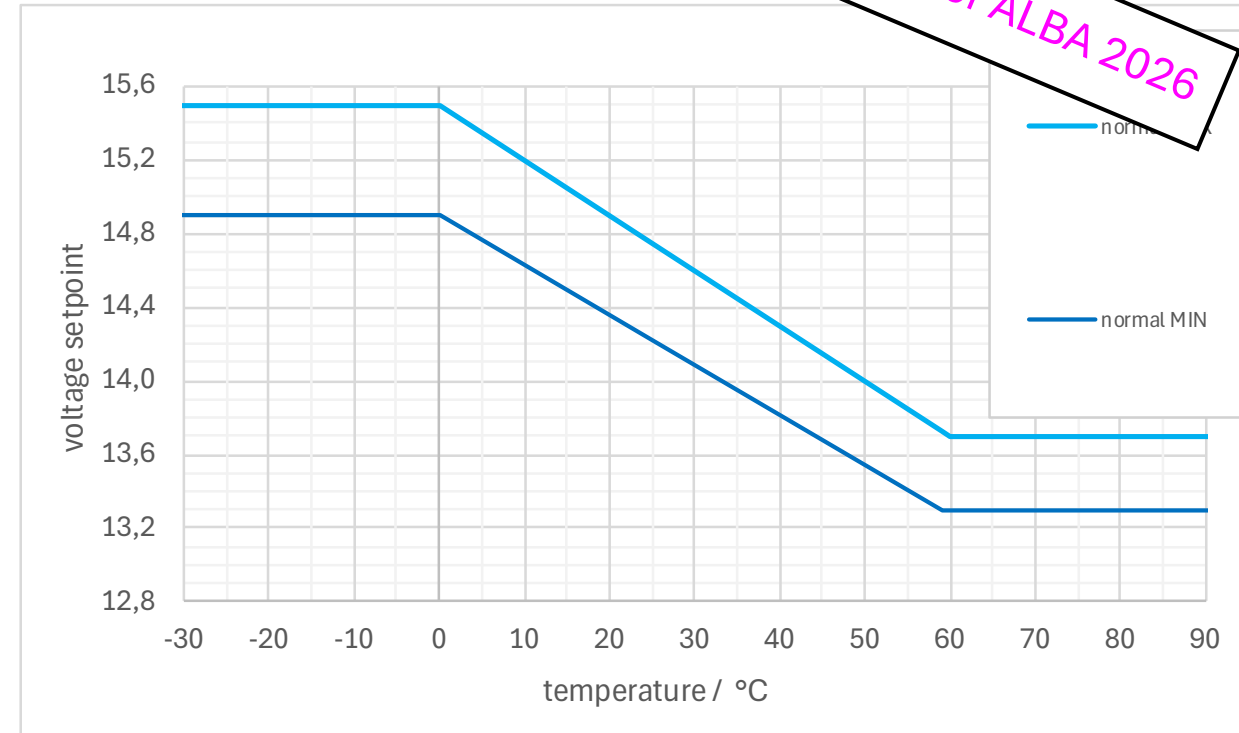
## Key elements: "Z curve"

- temperature compensation (-24 ... -36) mV/K is essential
- minimum voltage cutoff compensates self-discharge
- maximum voltage cutoff only defined by vehicle, not battery
  - load dump: keep system voltage <16V while alternator continues generating excess current for 50~100 ms

## Background

- premature battery failures if voltage below band:
  - undercharge, stratification, sulfation
  - fast dc/dc converter allows higher maximum voltage than with alternator (keep system <16V after load dump)
- premature battery failures if voltage above band:
  - corrosion, water loss, dry-out
- carry over from conventional ICE cars (>100 years experience):
  - typically, 0.5 ... 3 h operation per day, otherwise quiescent drain ~20mA

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# Boost charge mode

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## Rationale / when recommended

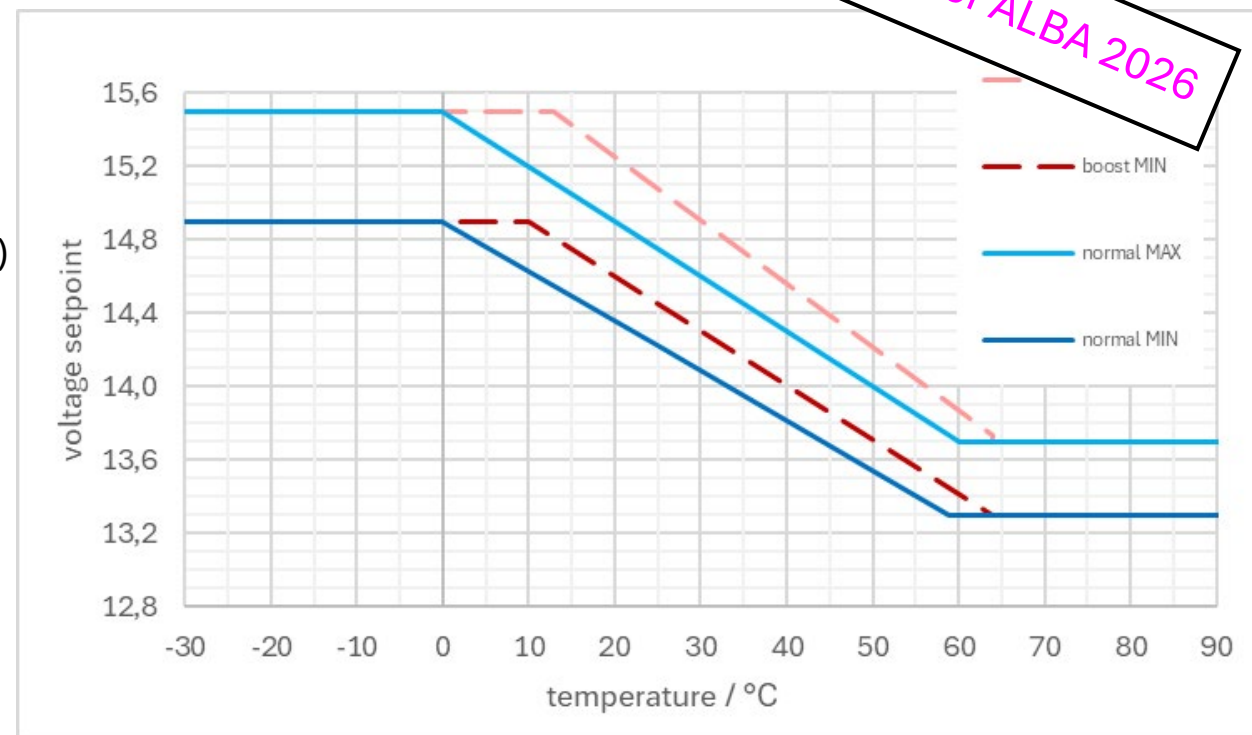
- fast recovery from low SOC or SOF
- equalization / refresh charge (maintenance against sulfation)
- (brake energy recuperation in micro-hybrids = mainstream EU ICE)

## Key elements

- 0.3 ... 0.7 V above normal mode,  $dU/dT$  may be chosen steeper
- maintain MIN and MAX cut-off voltages

## Implementation

- trigger by
  - low SOF (e.g., 0.5V above min. requirement)
  - low SOC (e.g., <60%)
  - calendar time (e.g., every week or every month)
  - throughput, e.g., 3x Cn
- duration should be limited
  - terminate when SOF back >10.0V above requirement or SOC>90%
  - terminate by duration, e.g., 4h total (per event)
  - limit cumulated time per calendar month (e.g., 30 h/month)



# Low charge mode

## Rationale / why OEMs may decide to use it

- vehicle energy management by operating mode: prioritize charging on-plug or while driving – use lower Z curve for low priority charging
  - ❖ range effect is marginal: usable energy (12V bat.) < 1% (traction bat.)
- water consumption “angst”: compensate additional 12V “on” hours in BEV while on-plug charging
  - ❖ despite all field evidence: 12V BEV batteries fail from undercharge, not overcharge
  - ❖ trade-off with water consumption requirement (if high, charge more conservatively)

## Challenges / risks / observed issues

- complexity (software, controls) by using **SOC and SOF** as inputs
- vicious cycle of undercharging and sulfation: **SOC** accuracy is poor, with large positive systematic errors (fooled by low charging current and persistently high OCV after marginal charging)
- More robust is **event or time**-based triggering of equalization charge (whenever plugged in, or every week, every month, ...)

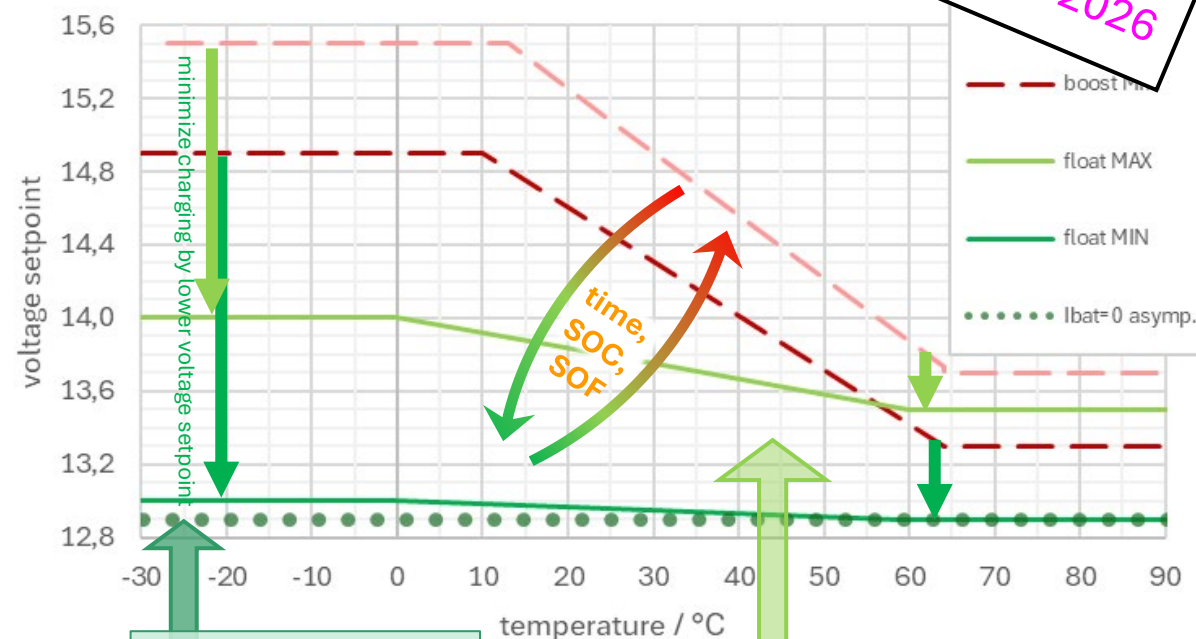
## Implementation

**If a “low” charge mode is added, make sure that equalization charge (rather boost than normal mode) is applied regularly !**

- **Option 1: zero current control** – use battery sensor current signal to dynamically regulate voltage setpoint such that battery current is ~0
- **Option 2: float charging** – apply a Z curve between normal mode and equilibrium voltage, or just clip charging voltage from normal Z curve

Low charge mode alone for AUX & ... will cause frequent premature battery failures due to undercharging.

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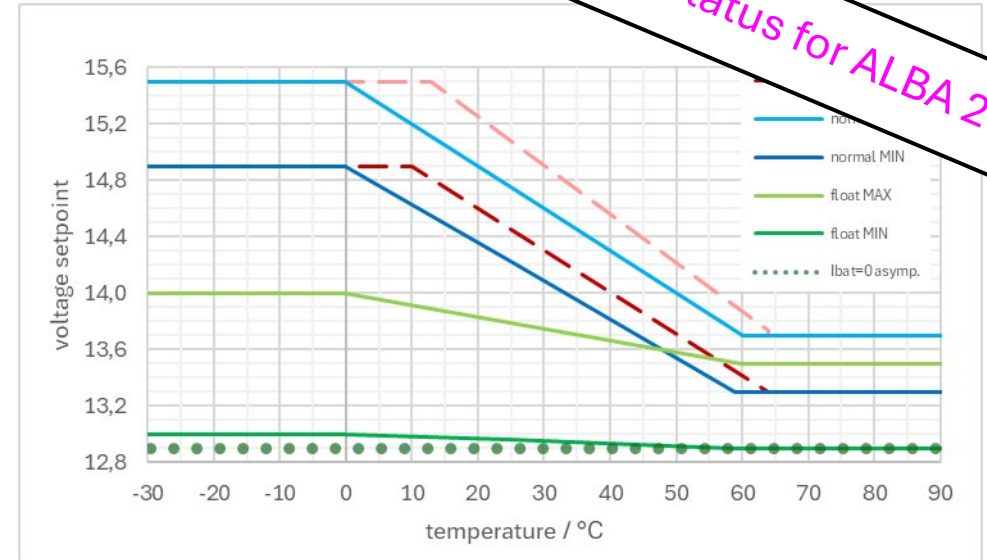
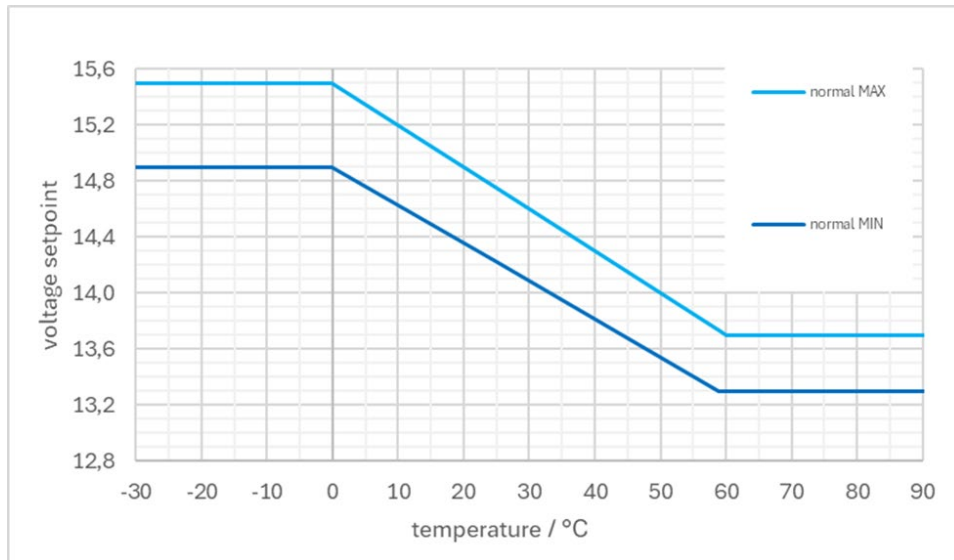


- requires LIN/ CAN communication IBS – dc/dc
- eases OCV-based SOC estimation
- avoids discharge first minutes after charging

- additional Z curve – straightforward implementation
- variant (even more complex): 2D lookup  $U_{setp} = f(\text{temp}, \text{SOC})$
- fast setpoint drop removes 1...3%SOC after each charge

# Discussion: Two extreme use cases and solution

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## main 12V battery

- ❑ dc/dc supply "on": driving / key-on, charging on-plug, replenish 12V battery while parking
- ❑ 12V loads supplied out of battery: over-the-air update, parking lights etc., key-off / quiescent loads (BEV: >>20mA)
- ❑ either out of battery or dc/dc "on": vehicle activation & afterrun

→ Lead **battery** is OK with only **normal mode**

→ OEM may require **low mode** for **other reasons**

## backup battery 24/7

- ❑ assume permanent 12V supply out of HV battery via low-power low-loss dc/dc converter (or normal dc/dc when needed)
- ❑ 12V battery for backup (comfort and/or safety) only
- ❑ additional battery discharge tests may be actively performed for battery monitoring or diagnostic purposes

→ **low mode** may support battery durability

→ **boost mode** equalization is **then** mandatory

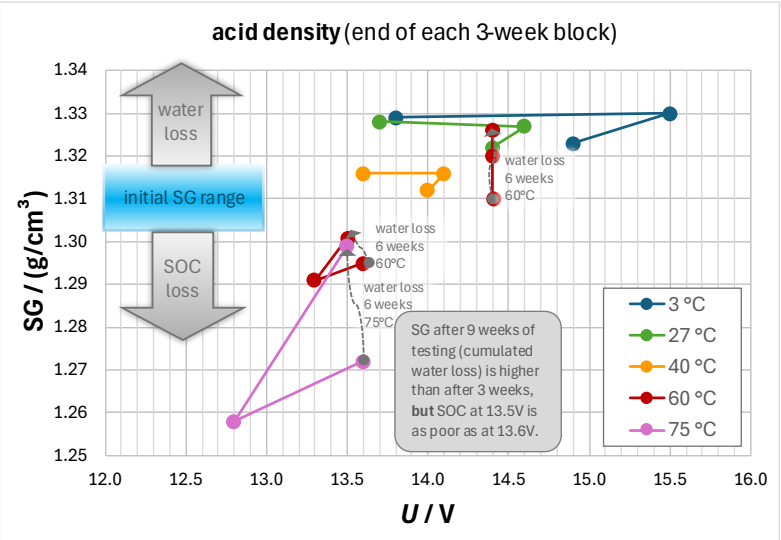
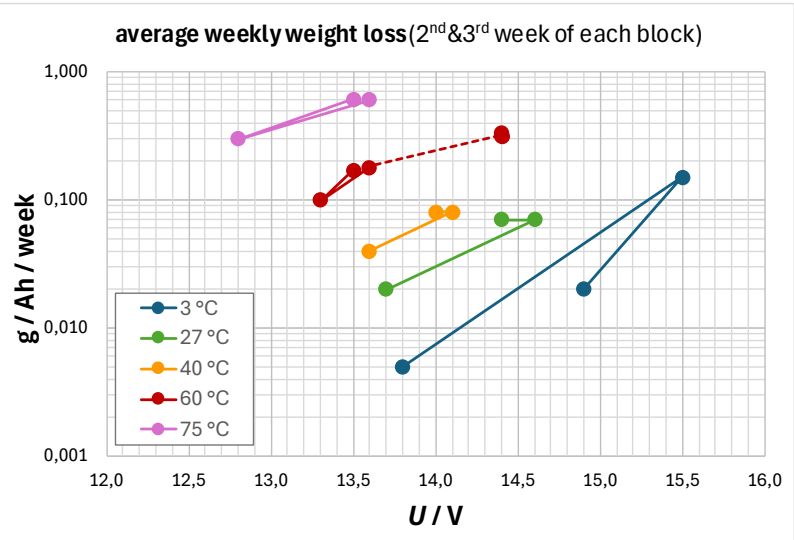
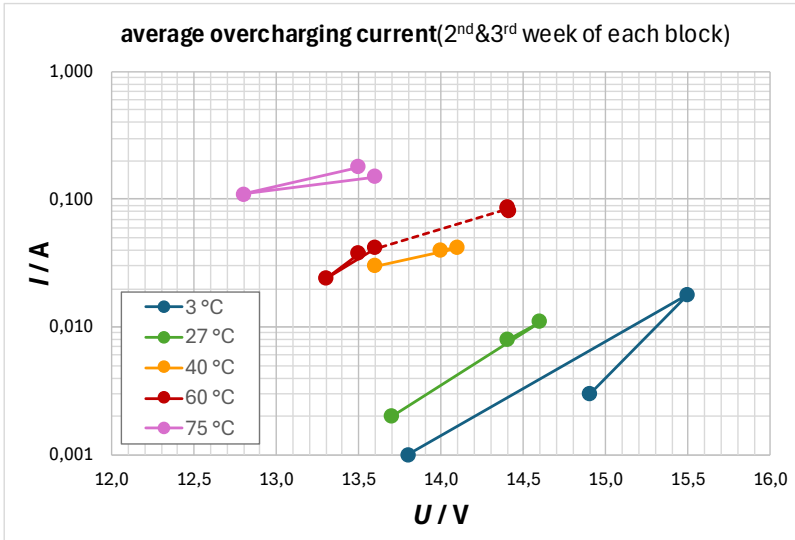
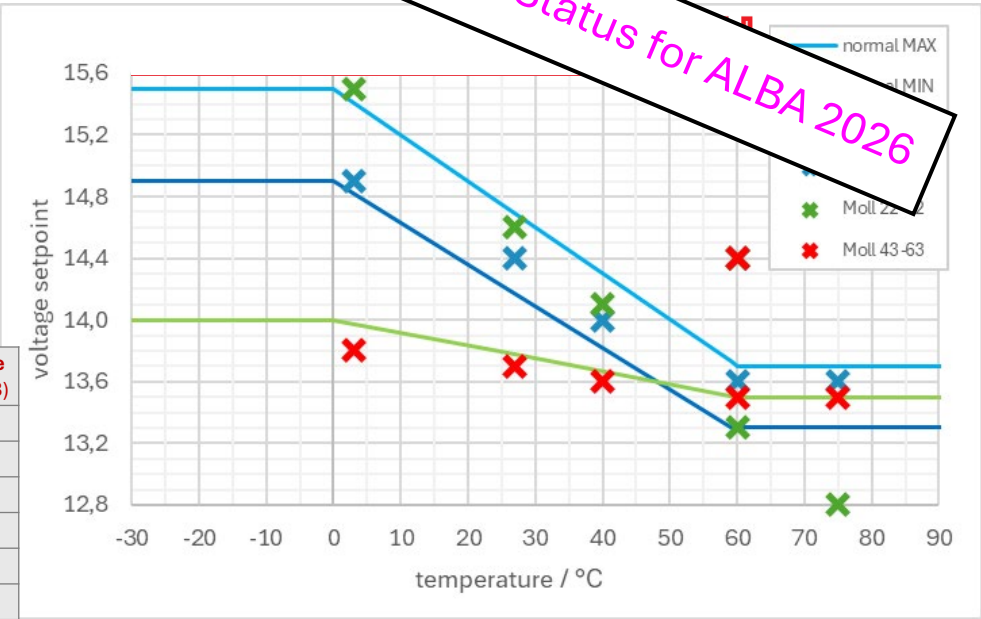
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# Constraints for Z curves – experimental study

## modified “water consumption” test

- ❑ 6 identical samples: Moll EFB (EN W4), after EN initials and fully charged
  - 5 samples, each in one water bath, overcharged at 3 voltages 3 weeks each
  - 1 sample = control: EN/IEC “water consumption” at 60°C for 9 weeks
- ❑ stabilized (over)charging currents and weight loss per week (semi-log plots) reproduce expected “Tafel” behavior
  - water-loss and its reduction at “float” voltage are insignificant at 27 °C and below
- ❑ acid density indicates that SOC cannot be kept “full” even with  $U \approx 13.5V$  at high temperature
  - 2<sup>nd</sup> kink of Z curve provides trade-off with durability

| water bath temperature | base Z curve (days 1...21) | steep Z curve (days 22...42) | float charge (days 43...63) |
|------------------------|----------------------------|------------------------------|-----------------------------|
| 3 °C                   | 14.9 V                     | 15.5 V                       | 13.8 V                      |
| 27 °C                  | 14.4 V                     | 14.6 V                       | 13.7 V                      |
| 40 °C                  | 14.0 V                     | 14.1 V                       | 13.6 V                      |
| 60 °C                  | 13.6 V                     | 13.3 V                       | 13.5 V                      |
| 75 °C                  | 13.6 V                     | 12.8 V                       | 13.5 V                      |
| control: 60°C          | 14.4 V                     | 14.4 V                       | 14.4 V                      |



# Recommendations for Z curves – Discussion

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## Charging voltage setpoints for lead batteries must be adjusted with temperature

- Recommended parameterization (blue curves) in this document represent expert consensus and long (ICE) experience.

## “Normal Mode” voltage control is preferred from LAB perspective

- Evidence-based optimum trade-off between undercharge / sulfation and overcharge / gassing / corrosion
- Charging should be invoked in parking BEVs to avoid deep cycles (→wear) and long periods at low SOC (→sulfation):  
The dc/dc converter should be activated based on high-load condition and 12V-battery SOC.
- Wide field data demonstrate that undercharge, sulfation, and excessive cycling drive 12V battery failures in HEV & BEV, but **not** water consumption and corrosion (not even in hot climate) -
- “Float” voltage 24/7 is insufficient to maintain (or even restore) high SOC and avoid undercharge / sulfation.

## OEMs may still require Low Charge Mode for energy management reasons only.

- examples: brake energy recuperation in 12V micro-hybrid, power consumption of 12V resistive loads
- In such cases, make sure that equalization charge is applied regularly, preferably applying **Boost Charge Mode** !

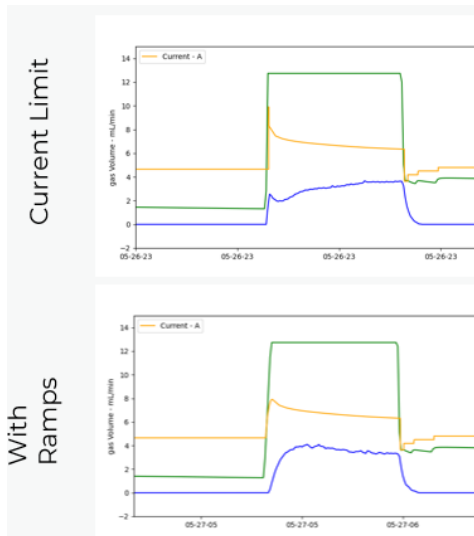
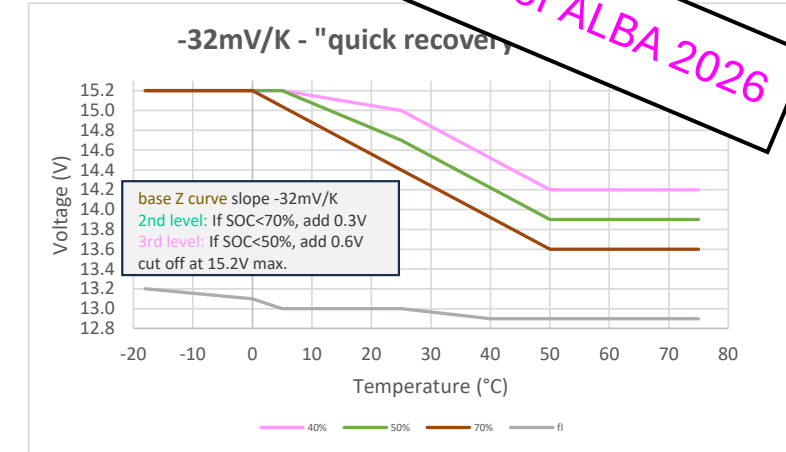
# Further optimizing the Charging Strategy

- Wide field data demonstrate that undercharge, sulfation, and excessive cycling drive 12V battery failures in HEV & BEV, but **not** water consumption and corrosion (not even in hot climate)
- Opportunity for more efficient charging (i.e. higher charging voltages) especially at lower SOC and lower temperatures.
- SOC-dependent charging strategies could replace one traditional Z-Curve charging to reduce/postpone failure mode of undercharged batteries

→ **Set of Z-Curves (to keep T-dependence) for a different SOC.**

- Vehicle implementation should limit the number of Z-Curves to a small number (3-4 different SOC) as the correct SOC determination is challenging.

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- At the beginning of a charging event (or when raising the charging voltage) the negative electrode polarises leading to an initial burst of H<sub>2</sub> evolution (i.e. water consumption). This is even present in AGM batteries as not enough oxygen is present for an effective recombination.
- This initial gas burst can be suppressed by either limiting the charging current (difficult to implement in vehicles) or by ramping up the charging voltage slowly (within 1-5 minutes).

ALBA 2023: XXX Sylvain Angoujard / Clarios  
ALBA 2025: CS05 Jörg Tiburcy / Clarios  
ALBA 2025: CS06 Sebastian Mauer / Moll

# Further optimizing the Charging Strategy

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## Add material from ALBA 2025 / 2026

ALBA 2025: CS05 Jörg Tiburcy / Clarios  
ALBA 2025: CS06 Sebastian Mauer / Moll

ALBA 2026: SO25 Benjamin Hübner / Moll  
ALBA 2026: SO26 Jörg Tiburcy / Clarios  
ALBA 2026: SO27 Sebastian Mauer / Moll

# Setpoint modulation is required for battery monitoring

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## **“Perfect” 12V operation in BEV or PHEV may largely avoid discharging the 12V battery**

- alternator constraints: slow controls, running only with engine-on, regulated down when max torque requested, etc.  
→ discharge 12V battery during vehicle activation, after each trip, by engine stop/start, etc.
- traction battery & dc/dc converter may supply 12V power almost continuously “as required”, leaving the 12V battery for backup functions and rare events (e.g., over-the-air updates that require high-volt system to shut down)

## **... but this takes away important stimulus for battery monitoring & diagnostics**

- internal resistance can be monitored by small-signal voltage modulation (anywhere between 10...1000 Hz)
- short-term discharge performance can be learned during short discharge events while driving
  - example 1: regulate dc/dc setpoint down to 12 ... 12.7 V for a few seconds → battery will (partly) supply 12 V loads during event
  - example 2: regulate dc/dc setpoint up to 15 ... 15.5 V for a few seconds → battery will (partly) supply 12 V loads after event
- significant discharge (current amplitudes and A·s integrals) can be applied as SOF test and for learning
  - vehicle activation: delay dc/dc operation, ideally coinciding with ASIL system test or other high-load use, measures instantaneous SOF
  - vehicle afterrun and plugging in for traction battery charging: opportunity for significant 12V battery discharge with immediate recharge opportunity (which did not exist in ICE vehicles as long as engine off!): detect cell shorts early, assure distance to failure

draft EK:  
we may want to add 2-3  
slides with SSOF evidence!

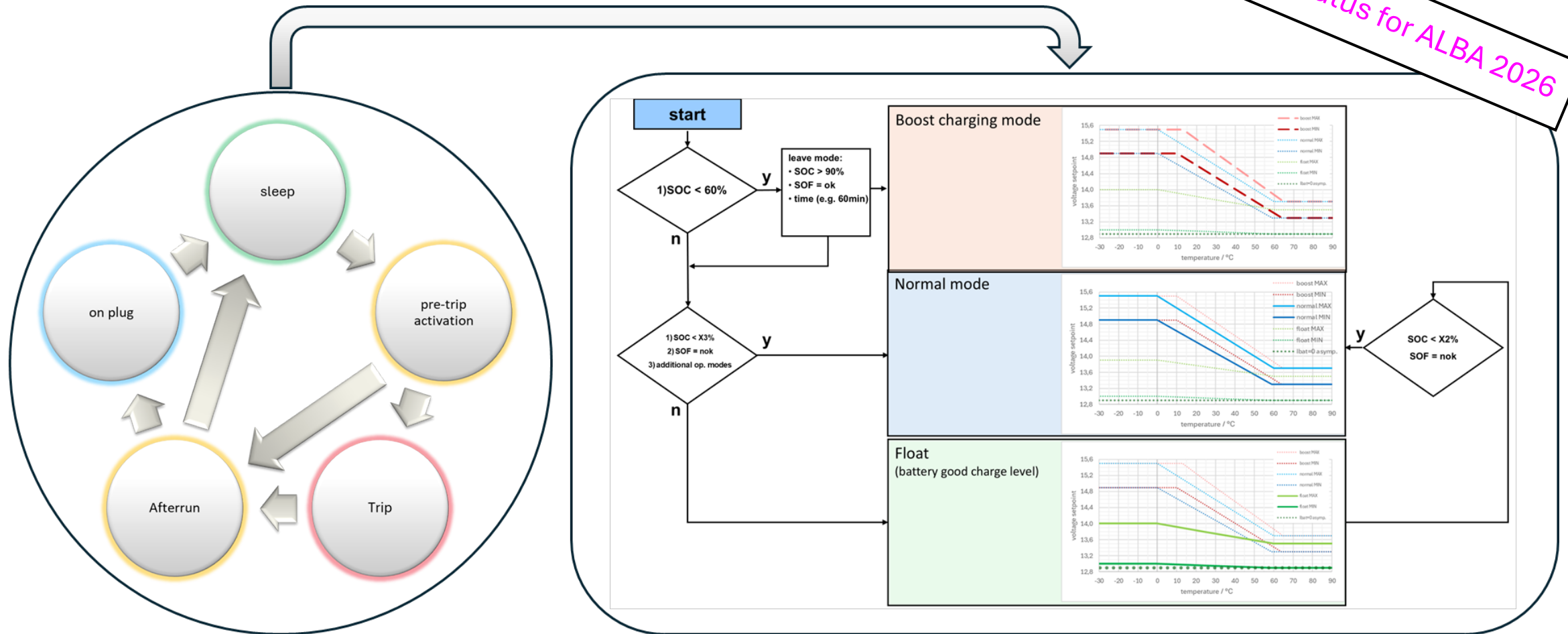
**These BMS functions should be implemented as 12V power-supply system design requirements**  
(dc/dc voltage control and load control)

**and may then be calibrated specifically for each application**

(which amplitude,  $\Delta$ SOC window, how often: depending on load scenarios and ASIL requirements).

# Possible integration into BEV energy management

1/3  
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1) No voltage differentiation between the operating modes

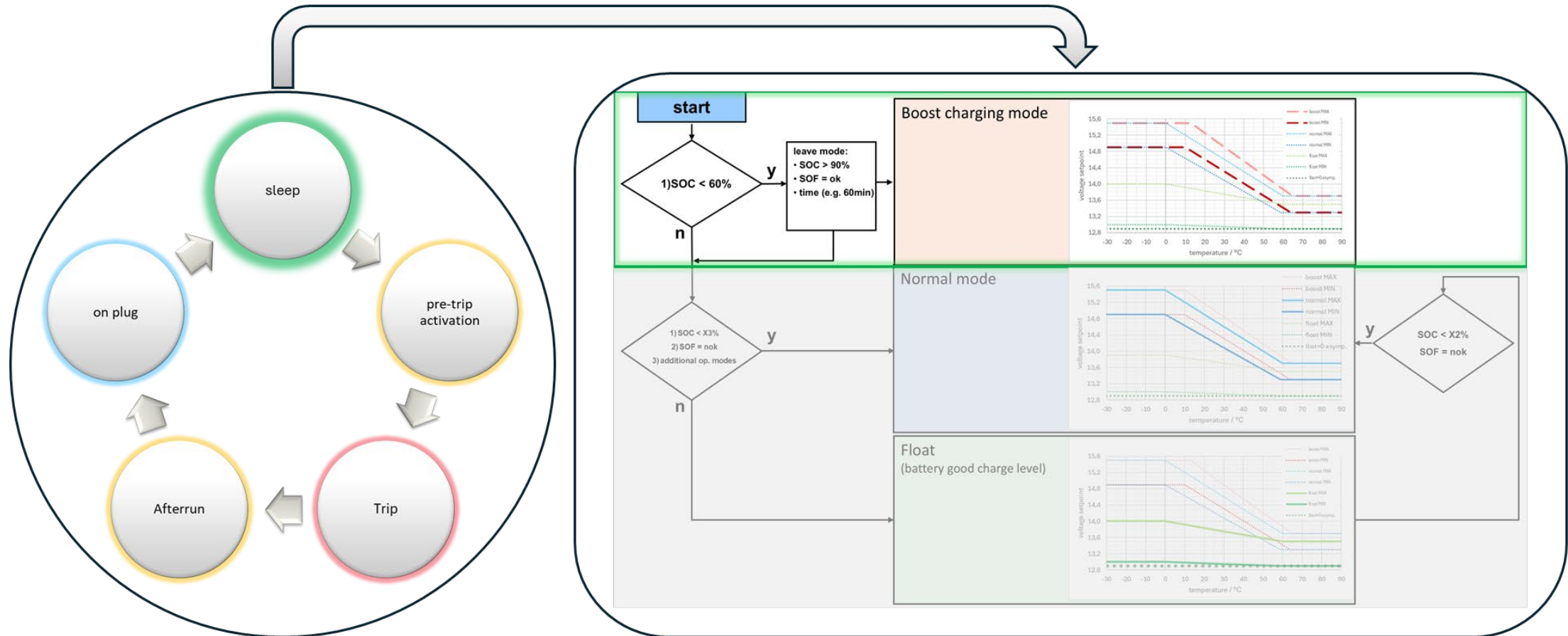
2) OEMs may prioritize charging by calibration of SOC X1% < X2% < X3% per operating mode for energy management reasons

# Possible integration into BEV energy management 2/3

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## Example **sleep** mode:

- During sleep mode with the light on, the SOC drops below 60%
- recharge is requested by the energy management
- boost charging mode is activated until SOC > 90% or a charging time of 60 min is achieved

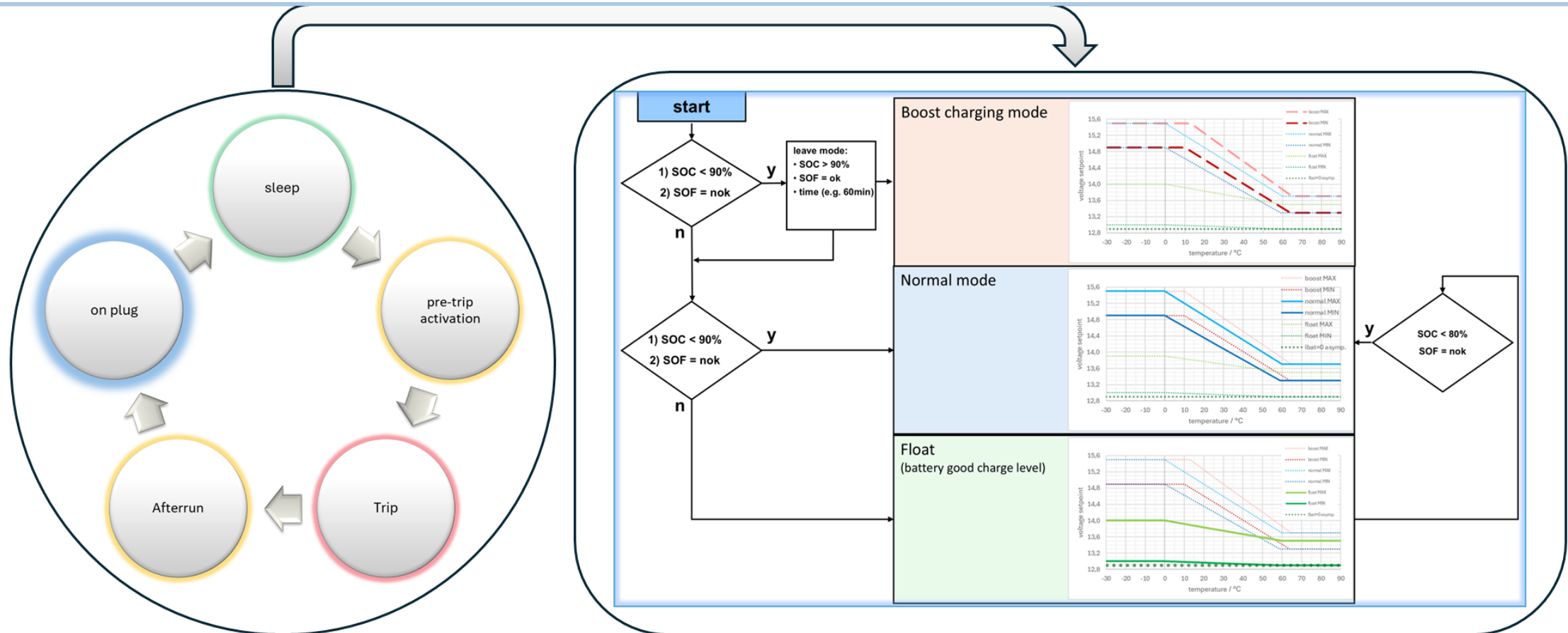


# Possible integration into BEV energy management 2/3

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## Example on plug mode:

- Vehicle is parked after driving with a SOC < 90% and connected to the socket
- recharge is requested by the energy management
- boost charging mode is activated until SOC > 90% or a charging time of 60 min is achieved
- then charge in normal mode or float charge to maintain battery



# Content

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## Introduction: 12V lead batteries in BEV

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- Basic requirements to battery and monitoring system
- Use cases for auxiliary and backup batteries

## The core of the strategy: voltage setpoint

- battery-driven requirements to setpoint choice, Z curves, charge modes, ramps
- IBS-driven requirements to setpoint modulation
- integration of charge modes with vehicle operating modes, energy management aspects

## Other system design aspects

- package location, heat exposure
- cyclic throughput: prediction and control
- CCA sizing for non-cranking applications
- charge recovery: discharge power is restored much faster than state of charge
- relationship to Functional Safety (ASIL functions)

cite/refer to existing documents

diagram cycle life =  
f(DOD)

IEC CR docu., Grace  
plots

from SSOF WG

Team to add  
summaries &  
references from  
existing documents

# Installation of batteries in vehicles (1/3)

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## Packaging

- The battery should be installed on a mechanically stable battery tray enabled to absorb the multiple battery weight resulting from strong vibrations or crashes.
- The battery must be fixed inside the tray by suitable methods like usage of the standardized base hold-down bars on the battery (EN50342-2) or brackets running crossways the battery surface.
- Exactly horizontal orientation of the tray is recommended unless other specified by the manufacturer.

## Degassing

- The battery under all circumstances needs a gas exchange with the surrounding atmosphere as a mixture of hydrogen and oxygen gas is generated even under normal operations. The installation space should be large enough to keep the hydrogen concentration below 4% to avoid a potential ignition. This is typically assured by
  - free ventilation for underhood installation in the engine bay or
  - connection of a venting pipe to the standardized degassing vent of the battery (EN50342-2) for interior battery installations.

## Protection against corrosion caused by battery acid

- The battery contains highly corrosive, diluted acid as electrolyte. Acidic droplets can escape with the charging gases causing corrosion in areas around the battery.
- This risk can be reduced by usage of a venting pipe and by housing the battery in a completely covered compartment.

after: ZVEI information leaflet No. 28e  
Lead-acid starter batteries in systems: Usage information

# Installation of batteries in vehicles (2/3)

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## Electrostatic discharge (ESD)

- The explosive hydrogen/oxygen mixture is present almost always inside the battery's gas compartment and can be ignited by a spark generated from electrostatic discharge. As the battery housing is made of plastic (insulator) it can have a different potential as its surroundings. The potential difference is equalized as electrostatic discharge.
- The electrostatic discharge can be diverted by usage of materials with high conductivity in the immediate surrounding of the battery.

## Splashing water

- Large amount of splashing water can cool down the battery's gas compartment creating low pressure inside the battery that sucks water into the battery. This can ultimately lead to overfilled batteries that leak acid.
- Usage appropriate measure to avoid direct contact with splashing water (installation location, cover hood, sealing the degassing port with a pipe,...)

## Direct light exposure (UV)

- UV components in the sun light cause the battery case to become brittle, potentially resulting in case ruptures and acid leaks.
- Therefore avoid direct, long-term exposure by appropriate measures.

after: ZVEI information leaflet No. 28e  
Lead-acid starter batteries in systems: Usage information

# Installation of batteries in vehicles (3/3)

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## Extreme Temperatures

- Lead acid batteries are generally robust against temperature influence and can be operated in the wide temperature window.
- Battery operating temperature depends on
  - installation location (heat transfer from engine or automatic transmission or exhaust system)
  - thermal insulation (plastic box, foam mats may clip temperature peaks).
- **Optimum operating temperatures** are in the range of +20°C to +40°C. Lower temperatures limit both charge acceptance and discharge performance, while higher temperatures increase self-discharge, water loss and corrosion. The **maximum** (long term) recommended operating temperatures is 60°C for flooded and AGM batteries.
- Avoid large **temperature gradients** over the battery (> 10K) to assure a homogenous usage of the battery and long life.
- Lead acid batteries can be operated at **extremely low temperature** around -40°C – although rechargeability is limited. Maintain a healthy SOC especially at low temperatures. Note that icing of bulk electrolyte may cause mechanical damage to the battery container. As a rule of thumb, at homogenous acid concentration icing sets in at -70°C for 100% SOC to -20°C (around 50% SOC)
  - see following slides for more information on icing.

after: ZVEI information leaflet No. 28e  
Lead-acid starter batteries in systems: Usage information

# Lead battery performance within "icing" area

## Performance is reduced gradually through the „icing“ curve.

- Some textbooks suggest icing would dramatically increase ohmic resistance – and power performance should drop suddenly (phase transition)
- By contrast, IEC TC21 WG2 collected extensive evidence of power performance below the "icing" curve: the trendlines do not change! (-30°C down to <40% SOC, -40°C down to <60% SOC)

- Icing occurs locally first, changing the current distribution over plate area
- At charging, power performance recovers very quickly (thanks to heat generation and thermodynamic properties of freshly charged  $\text{PbO}_2$ )

is consumed during discharge.  
OC, freezing point of (average!)  
from <-60°C to >-30°C

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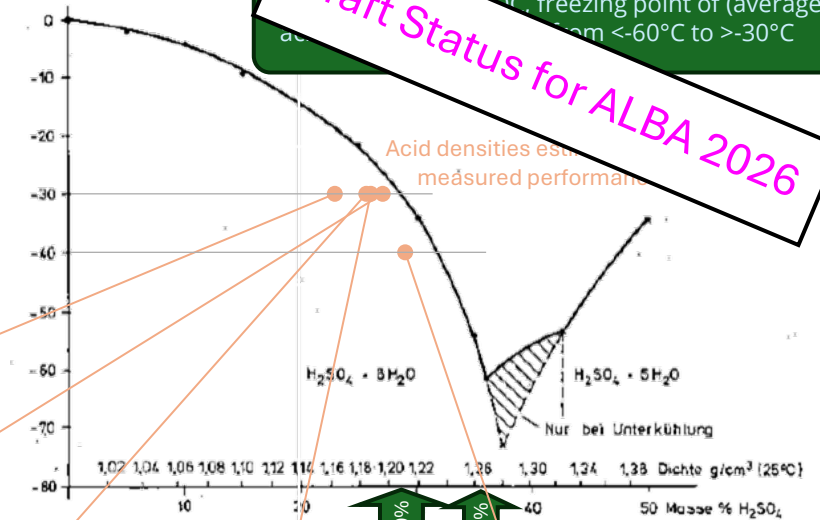
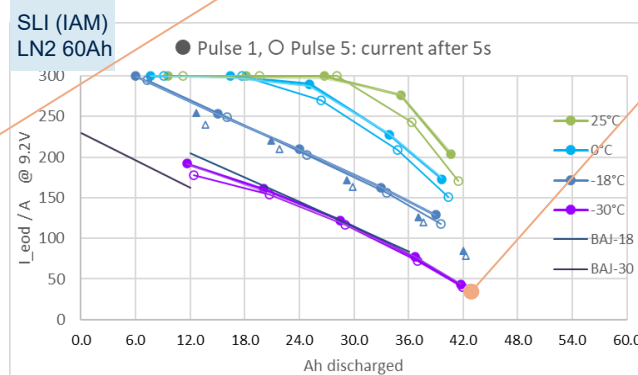
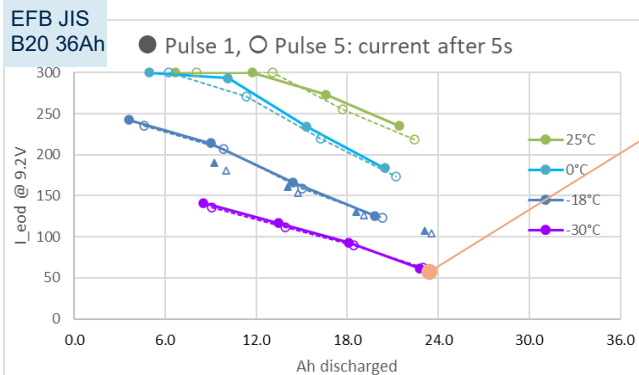
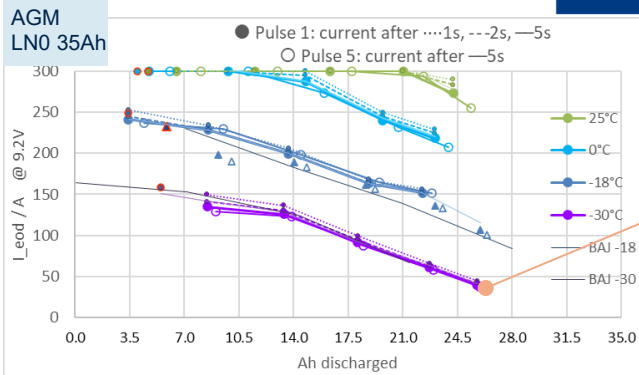


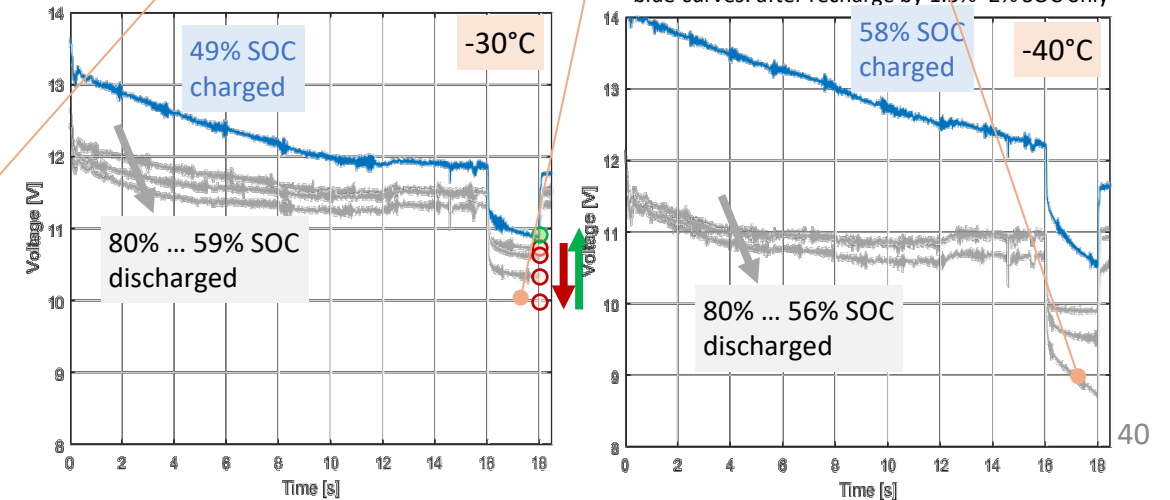
Bild 2/5. Gefrierpunkt verdünnter Schwefelsäure  
D. Berndt et al., Varta AG, Bleiakumulatoren, VDI-Verlag, 1986

SOC ~50%  
SOC ~80%

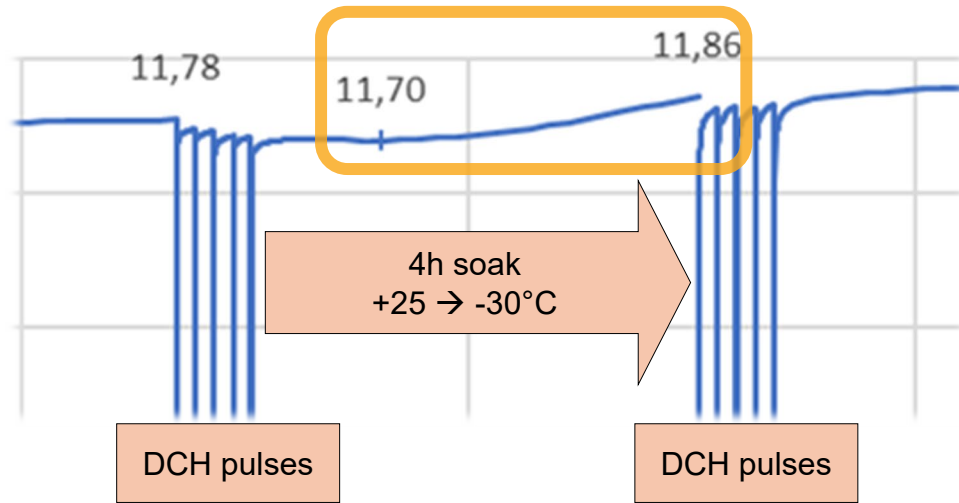
Example maps: current delivered at 9.2V



Experiment at -30 and -40°C: AGM battery 18Ah 280A, power profile 16s DCH ~95W, 2s DCH 320W  
grey curves: gradually discharged from 80% to <50% or <60% SOC, respectively  
blue curves: after recharge by 1.5%~2% SOC only

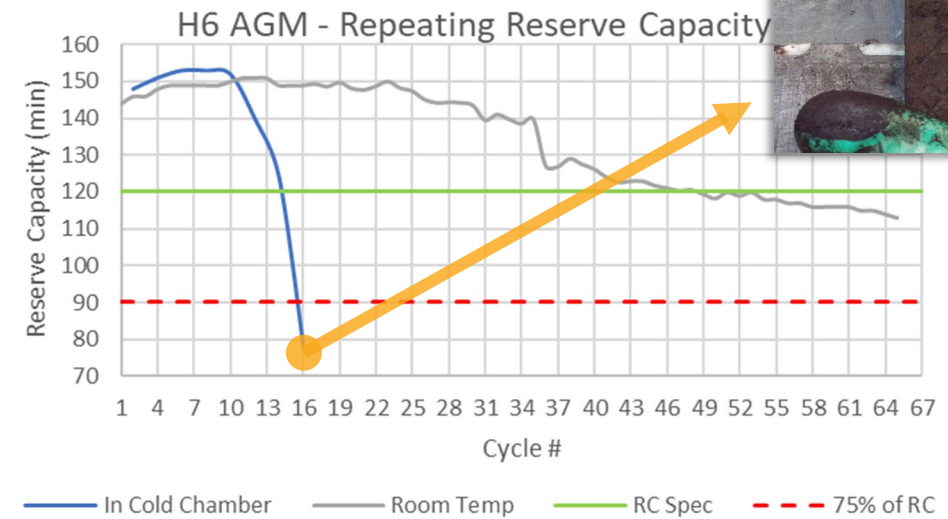


# Ageing test with repetitive icing



## OCV rise while icing

- accidental observation during high-rate discharge & cooling test sequence at low SOC
- time scale: few hours
- $R_i$  increase was also observed and reversible



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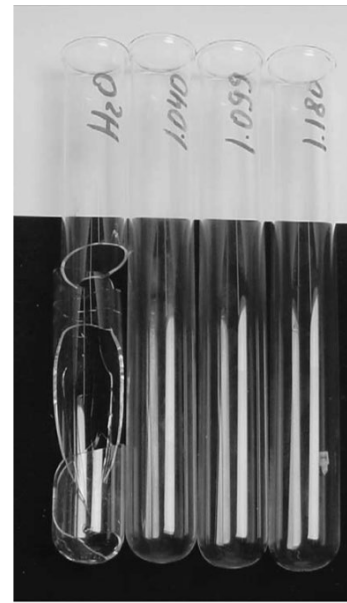
## PAM ageing by icing

- Between RC cycles, while soaking to -30°C, batteries (AGM+EFB) were discharged with 250 A to SOC < 50%
- early failure with PAM degradation (soft over entire height of plates and depth of pellets)

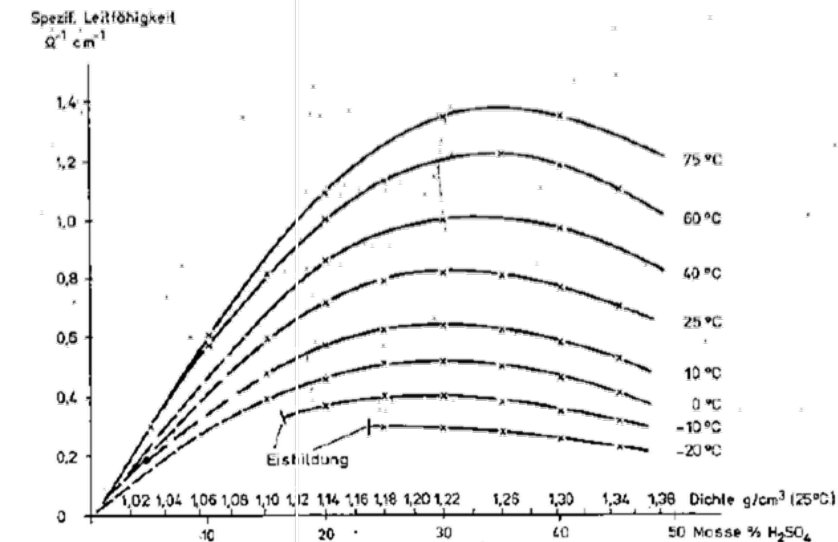
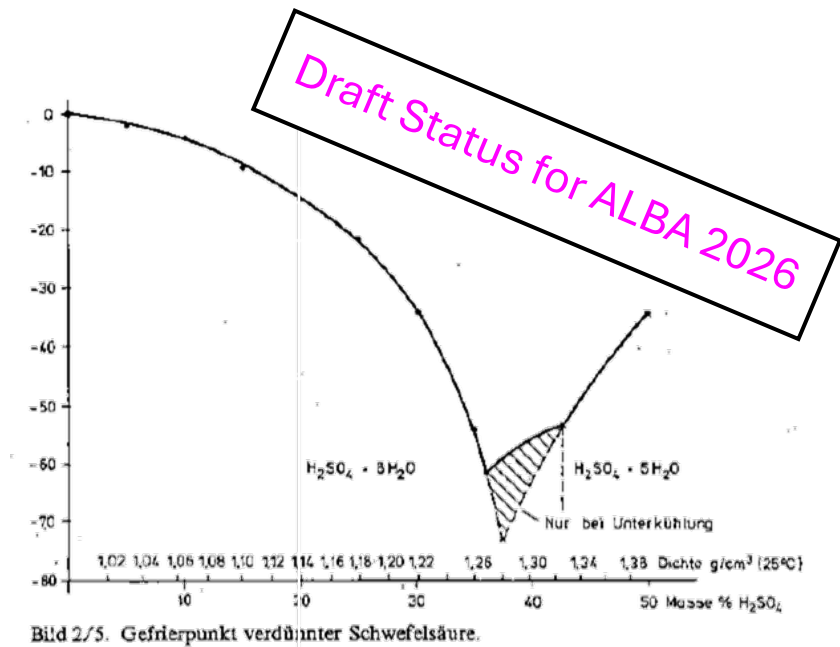
# Icing physics of sulfuric acid

## Lead-acid batteries do not freeze en-bloc.

- Icing means phase separation:  $\text{H}_2\text{O}$  forms small crystals (ice) in liquid acid of increasing density
- OCV will temporarily increase (measurable)
- internal resistance will temporarily increase
- icing will occur first where acid density is minimal, e.g.,
  - after high-rate discharge: in the pos. electrode pores
  - in a stratified battery: in the upper third of (or above) plates
- After repeated high-rate overdischarge at  $-30^\circ\text{C}$ , PAM degradation has been observed (similar as cyclic wear) at 75% remaining capacity.
  - ➔ Icing events cause *incremental* PAM softening but power capability recovers *almost* completely after defrosting.
- Mechanical damage to containers may be caused by water-ice expansion – even though parts of the plate stacks may be still performant.



Icing experiments with sulfuric acid of varying concentrations  
P. Haring, H. Gless, J. Power Sources 116 (2003) 257–262



D. Berndt et al., Varta AG,  
Bleiakkumulatoren, VDI-Verlag, 1986



# Cyclic throughput and durability requirements

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## Ageing in cyclic applications

- PAM wear – for “deep” cycles (norm tests 25%~50% DOD) and/or high temperature (aggravating corrosion, SAE 75°C tests)
- stratification and “bottom part” sulfation (17.5% DOD tests)
- sulfation (primarily neg. electrodes close to geometric surface, stop/start microcycling)
- log-log plot of throughput over DoD works surprisingly well (as if only one mechanism)  
→ deeper cycles exert more stress per Ah!

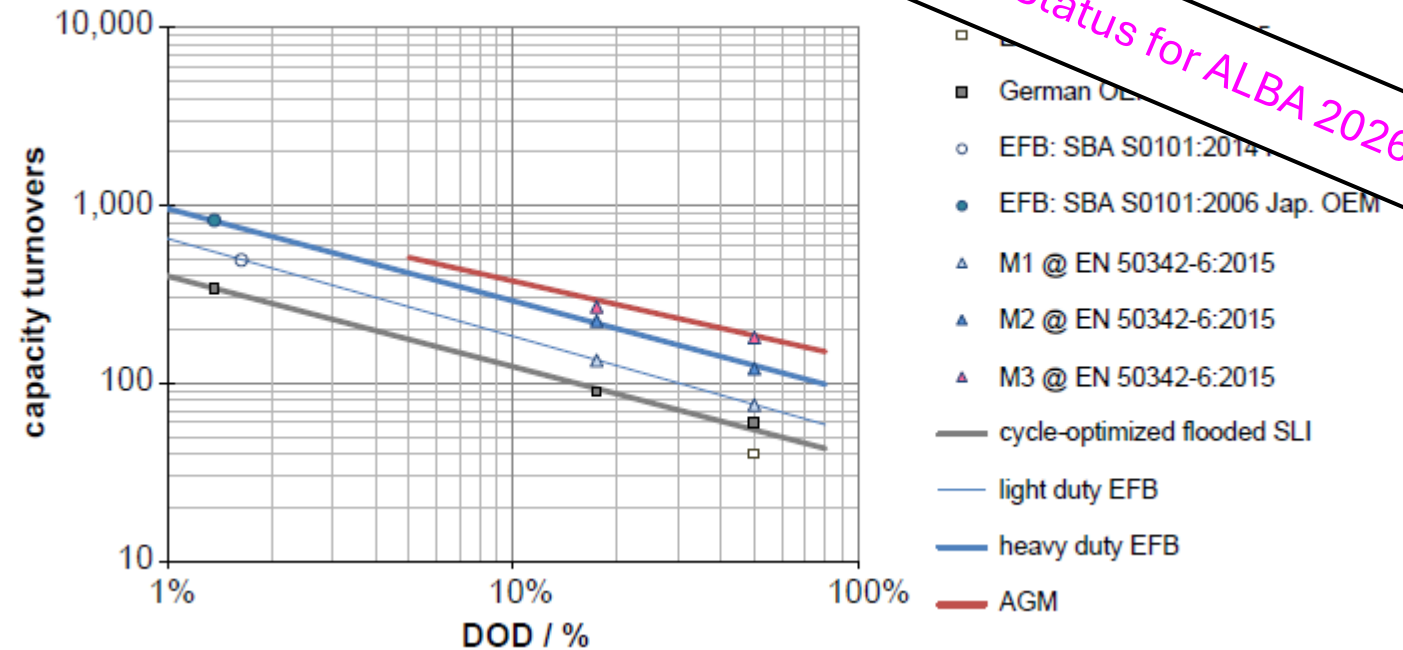


**Figure 1.6**

Battery cycle-life, counted as throughput capability, as a function of micro-cycling depth-of-discharge (DoD). For M1, M2 and M3 durability levels, see Table 5.3, Chapter 5.

## Battery selection

- OEM should have realistic estimate of all load/discharge use cases (DoD in Ah and frequency), particularly for key-off
- DoD (and maybe temp., current, other factors) may generate a penalty factor (how much worse is this event than 1% DoD at RT...)
- Target battery life (e.g., >5 years for 90%ile customer) can hence be translated into cycling-endurance requirements and technology chosen (FLA/EFB/AGM etc.)
- Notice that downsizing increases relative DoD for same event: requires either longer cycle life or modified op. strategy (lower DoD).

E. Karden: Development trends for future automobiles and batteries, in: J. Garche, E. Karden, P.T. Moseley, D.A.J. Rand (eds.): Lead-acid batteries for future automobiles, Elsevier: Amsterdam 2017

# CCA sizing for non-cranking applications

## IEC 60095-8 defines a Pulse Power Characterization test.

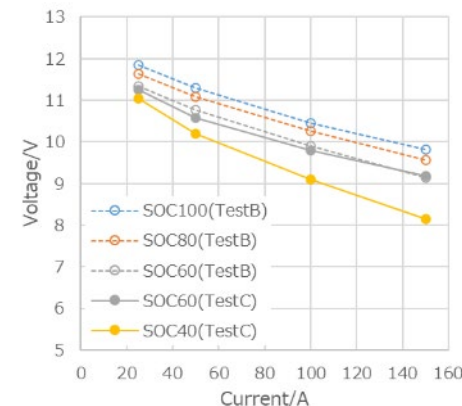
- Legacy cranking test does not represent peak-power requirements in auxiliary & backup applications but it drives battery design, materials etc.
- Test concept: measure 2-seconds voltage at pulse discharge with several current pulses of  $(0.2 \dots 0.5) \cdot \text{CCA}$  at partial SOC, low temp.
- CCA remains "label value" for power performance, PPC requirements scale with CCA rating

## Implications for system design

- Minimum voltage allowance is the most sensitive factor for battery sizing, but usually underestimated at OEMs
- Example: If  $U_{\min}$  for target SOF profile is 10.5V (at battery terminal), battery CCA is required 2.5 ... 3 times larger than for 9.2V !

## CBI & ALBA offer a free CAE sizing tool for these new applications.

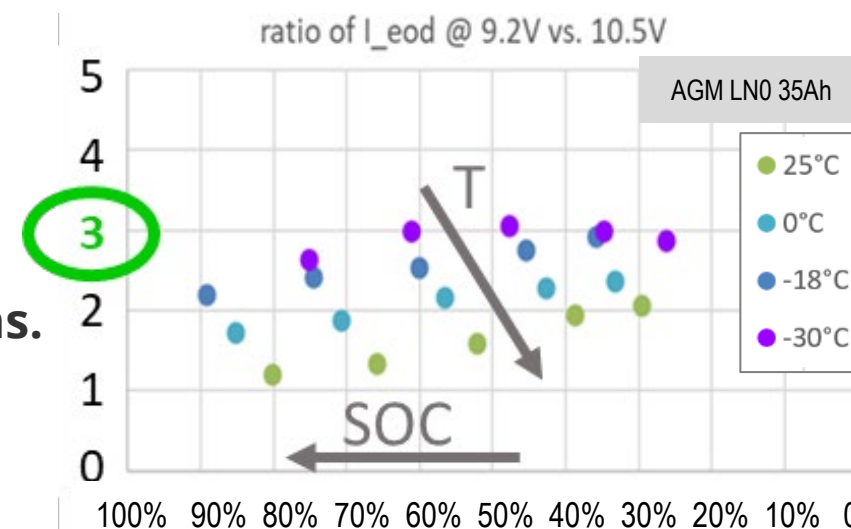
- Please check: <https://ppc.batteryinnovation.org/>



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| pe-<br>typical v        |                         | cold<br>cranking       |
|-------------------------|-------------------------|------------------------|
| current                 | 70 ... 100 A            | 100 A                  |
| (test) duration         | 1 ... 5 s               | 1 s                    |
| min. battery<br>voltage | 8 ... 10.5 V            | 6 ... 7.2 V            |
| SOC                     | full operating<br>range | high<br>(test at 100%) |

| category                       | 1                    | 2,3                  | 1,2,3         |
|--------------------------------|----------------------|----------------------|---------------|
| designed for ...               | partial SOC          | high SOC             | combined test |
| beginning of life (BOL), 25°C  | fully charged        |                      |               |
| beginning of life (BOL), -18°C | 50% $C_n$ below full | 20% $C_n$ below full | both SOC's    |
| end of life (BOL), only -18°C  | 25% $C_n$ below full | 10% $C_n$ below full | both SOC's    |



# Pulse power and its recovery

**Add material from ALBA 2025/26**

Draft Status for ALBA 2026

# relationship to Functional Safety (ASIL)

Draft Status for ALBA 2026

**Add material from SSOF WG**

# Summary: Recommendation for 12V Charging Strategy in BEV

Draft Status for ALBA 2026

**To be developed**

Draft Status for ALBA 2026