ELBC, Milan, Italy, September 2024

Market and technology trends for 12V batteries in electrified vehicles

19 September 2024

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Eckhard Karden

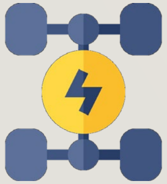
- Technology Consultant in the field of lead-acid batteries and their applications
- Jul 2002 – Nov 2023: Ford Motor Company, European Research and Innovation Center in Aachen, Germany: technology assessment, advanced engineering, system integration of
  - stop-start batteries (EFB),
  - microhybrid batteries with enhanced charge acceptance (EFB+C),
  - auxiliary batteries with Functional Safety requirements (mostly AGM),
  - battery monitoring systems for the above applications.
- 1994 – 2002: Researcher and Senior Engineer
  at the Institute for Power Electronics and Electrical Drives (ISEA) of RWTH Aachen University,
  where he previously had obtained a Ph.D. in Electrical Engineering and a diploma in Physics.
- research career focusing on application-related aspects of lead-acid batteries, including modelling, state detection, impedance spectroscopy and charging performance.
- fostering application-driven innovation at the supply base by involvement in German, European and International standardization groups and other pre-competitive industry working groups.
- cooperating with the Consortium for Battery Innovation (CBI), initiated and technically leads a series of technical expert workshops since 2017 (Automotive Lead Battery Advancements, ALBA).
- International Lead Award 2022

Content

Lead batteries – essential for every car?

- Automotive absorbs half of global lead battery production
- OEM expert survey – expert views on lead battery use

Global automotive industry trends and their implications for 12V batteries



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4. ... or alternative architectures may provide ASIL without 12V (lead) battery

5. OEMs will need stronger & pro-active support from lead battery supply base

Discussion & Outlook

Automotive ≅ 49% of global lead/acid GWh production

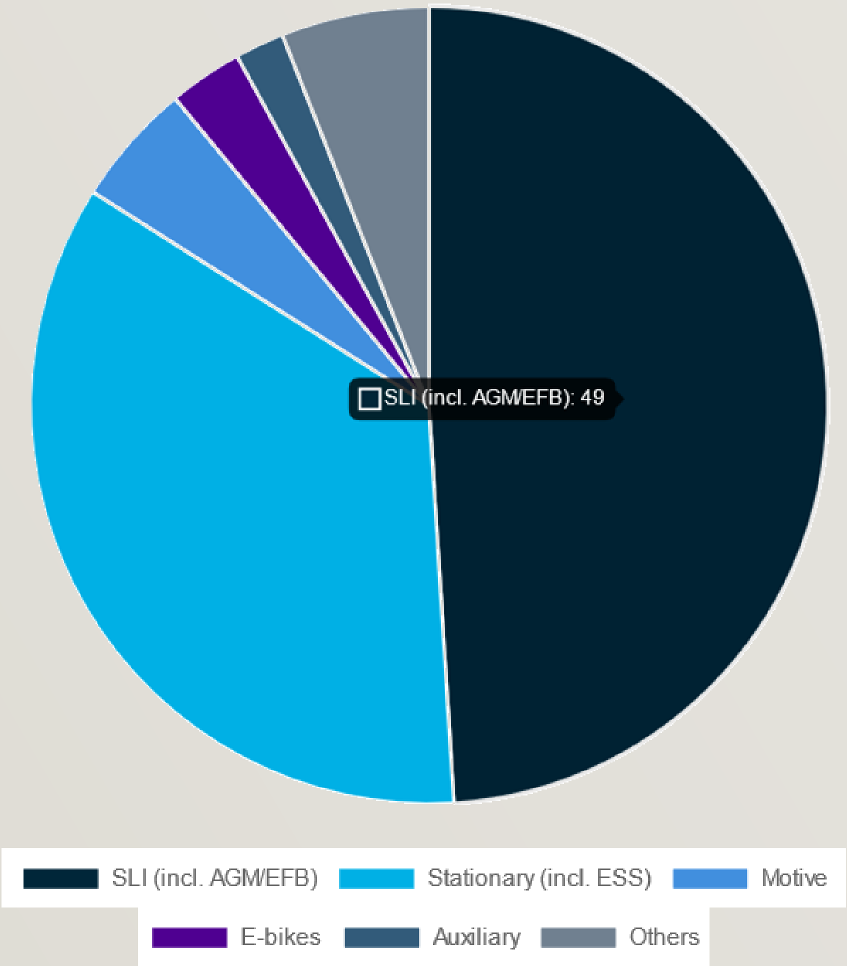
CBI aims to understand customer / OEM needs

- downsizing (Ah·12V = Wh per vehicle)
  - diesel phase-out (EU)
  - BEV: no starter, recharge while parked
- alternatives discussed
  - 48V only distribution system
  - battery-less 12V from dc/dc converter?
  - 12V Li-ion
- technology challenged
  - lead ban? (EU)
  - diagnostics for ASIL?

pre-competitive cooperation opportunities in a mature commodity industry

- standardization: sizes, terminals, test procedures, …
- research collaboration (CBI), technology workshops (ALBA)
- OEM guidelines (e.g., sizing & charging in BEV)
- CBI SSOF WG: generic methodology and documentation for Functional Safety assessment

2022: 590 GWh (percentage segments)



source: Avicenne Energy
https://batteryinnovation.org/resources/lead-battery-market-data/

CBI OEM expert survey

… in 2 parts, June/July 2024

- OEM experts were approached by suppliers
- most participants from China, Europe, Japan
- responses are strictly anonymous

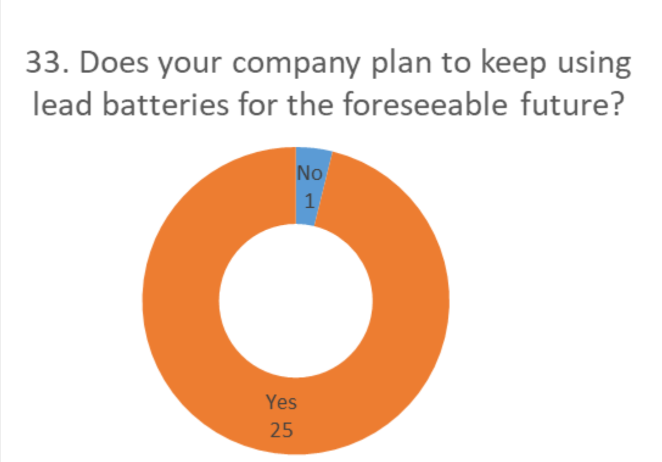
26 **battery experts (power supply)**

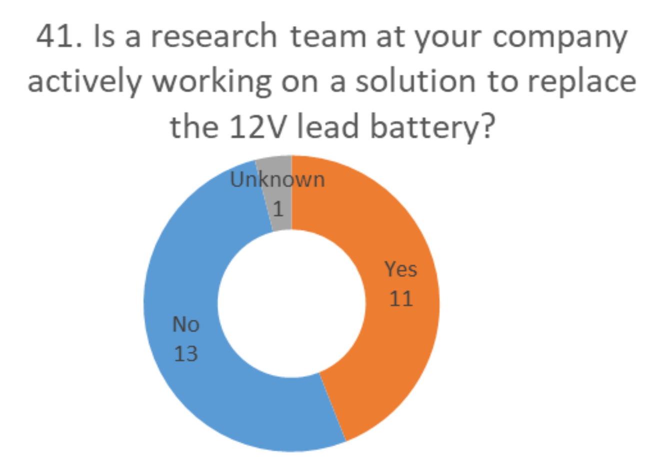
- Most OEMs expect lead batteries to stay …
- … yet half of them are exploring alternatives (not necessarily for full volume & model range)
- highest confidence for ICE cars and 24V truck
- coexistence / competition for BEV

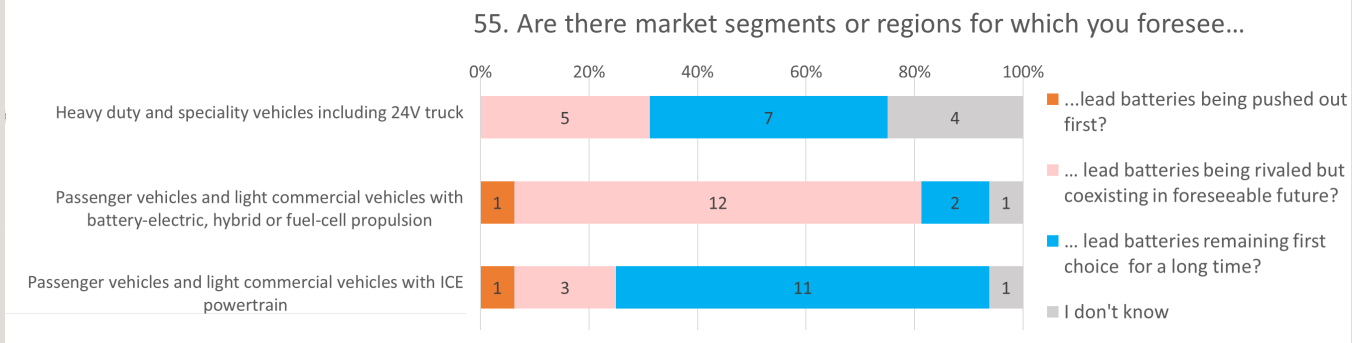
14 **ASIL/BMS experts (architecture etc.)**

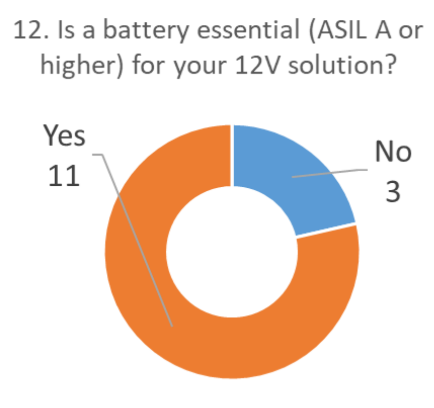
- most safety concepts use 12V battery for ASIL
- most of these use lead battery (not only AGM)

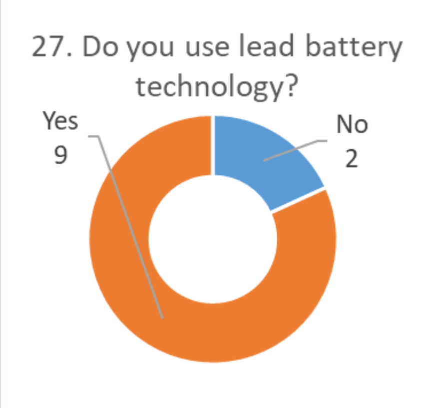
More results: CBI webinar in October

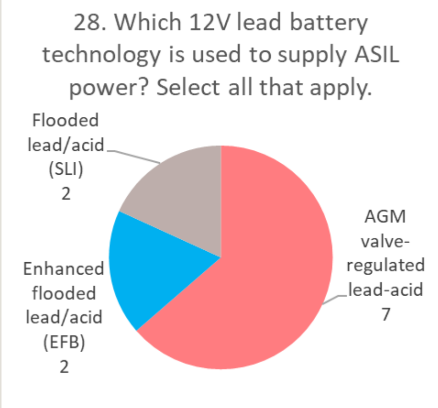












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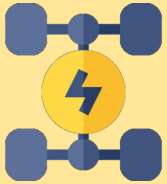

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Discussion & Outlook

❶ Micro-hybrid: shallow cycling and DCA

micro-hybrid = stop/start and regenerative braking <u>for 12V loads</u>

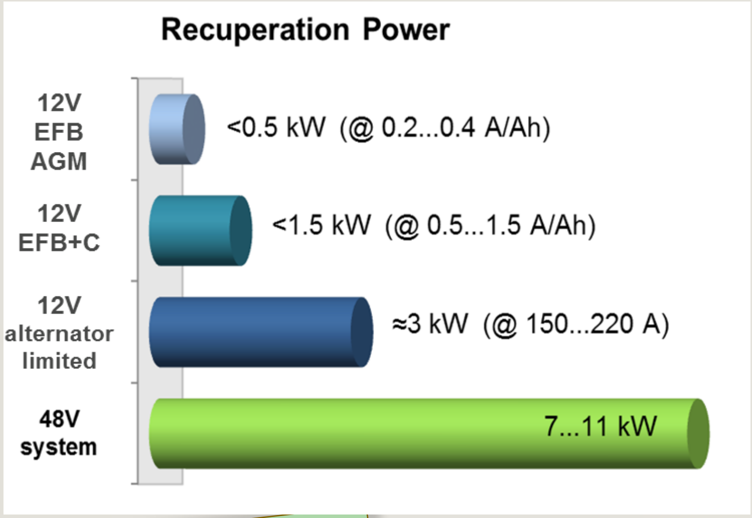
- **emerging markets at least:** CAFE or CO_2 mandates will require low level hybridization for entry-level (and mass market?) vehicles for quite a while
  - mandates, criteria, incentives vary by country or region → technical solutions (el. machine, strategy, storage system) to be optimized!
  - 12V micro-hybrid is offers limited fuel & CO_2 savings at lowest cost per gCO_2/km

background on 12V brake energy recuperation

- ❑ 1 g/km per approx. 5A average alternator load at 14V (rule of thumb). engine-native loads (NEDC, WLTP) 15±3 A → saving potential 3 gCO2/km. (actual savings only 0.8...1.5 gCO2/km, limited by DCA, alternator, kinematics).
- ❑ real-world loads typically 25...60 A → savings realistically 3...5 gCO2/km
- ❑ With 150A alternator and perfect storage device, an average 12V load of 14...27 A is supplied CO_2-free (for deceleration 8...15% of trip time → avg load 8:92...15:85 = 0.09...0.18fold avg recup. current)
- ❑ for higher 12V loads additional savings may be achieved by scheduled generation (min incremental CO_2)
- ❑ kinematics: alternator torque has to be limited at low (engine or vehicle) speed

EFB+C = <u>E</u>nhanced <u>F</u>looded <u>B</u>attery <u>with</u> high Dynamic <u>C</u>harge Acceptance (DCA)

- technology available, proven in EU mass market and hot climate taxi fleets
- may be improved further toward 2-3 A/Ah?



E. Karden, LABAT 2021

What is the value of CO_2 savings?
OEM may accept marginal cost rather than paying the penalty:
EU 95€ per gCO_2/km
India ₹25,000 (≃270€) up to 4.7 gCO_2/km

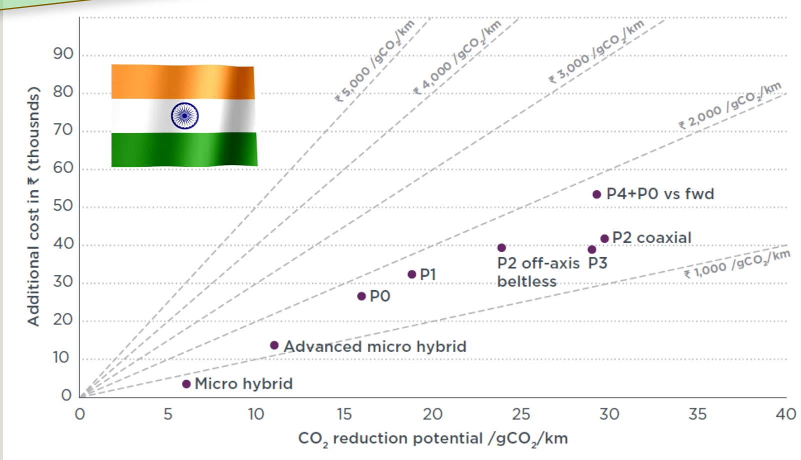


Figure 6. DMC cost of 48V hybrids with respect to total CO_2 reduction potential for a gasoline vehicle in 2025 on the NEDC cycle. All systems use 15 kW motors except micro and advanced micro hybrids.

Deo, German, Bandivadekar, ICCT White Paper, July 2022

❷ What is different for 12V batteries in BEV?

no more engine start required	**cold-cranking current (CCA)** test & sizing methods become obsolete	**pulse-power characterization (PPC)** test & PPC-based sizing, **battery design** for 9-10 V_{peak}
no more alternator but dc/dc: recharge possible at any time	"airport parking" etc. use cases & **capacity** sizing methods become obsolete	optimize **charge recovery** (to be defined and tested – IEC), revise OEM **charging strategy**
no more engine-bay packaging	heat exposure (slightly) reduced → **high temp durability** requirements may be relaxed?	water loss, corrosion, 75°C: cf. trunk installations
functional safety requirements (even for modern ICE vehicles)	hardware **reliability** & battery **monitoring** gain relevance	update supplier **FMEA**, **SSOF** monitoring & verification, revise **service** strategy
battery downsizing, while loads often increased	expect **early failures** due to high throughput and/or undercharge/sulfation	realistic throughput-based **sizing**, **energy management**: reduce loads and/or supply out of dc/dc

❷ Requirements for auxiliary & backup batteries

peak loads: typical values	chassis loads	cold cranking
current	70 … 200 A	300 … 1000 A
(test) duration	1 … 5 s	30 … 150 s
min. battery voltage	8 … 10.5 V	6 … 7.2 V
SOC	full operating range	high (test at 100%)

performance

- pulse power: PSOC, U_{min} ~9 V, peaks 0.2 … 0.5 CCA
- charge recovery: downsizing, recharge in key-off, ASIL
- energy: downsizing 60…80 Ah → 30…60 Ah → 15…40 Ah ?

durability

- auxiliary: cyclic & PSOC (variable per application – often demanding)
- backup: high SOC, cycling only comparable to classic SLI
- high temperature: comparable to classic SLI in trunk

system integration

- low-cost part but sizing, charging, load mgmt., monitoring need attention

Standardization can enable efficient commodity solutions

- IEC 60095-8 (CD): new tests for pulse-power characterization (PPC), charge recovery (CR), may become a template for OEM specifications and guide product design for 9V, CR, …
- sizing tools and charging recommendations may be added as informative annexes
- Should sub-30Ah sizes be standardized?

Automotive mass products do not require the best technical solution.

They require an affordable solution that is **good enough**.

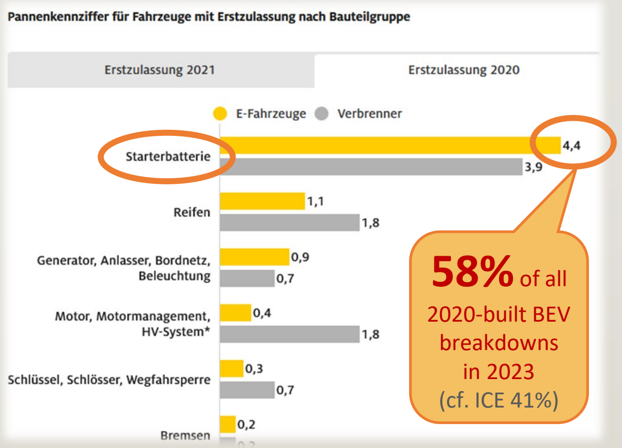
ALBA 2024 recap

❷ How (early) 12V batteries in XEV fail

ADAC

12V battery: no.1 breakdown "cause" in BEV

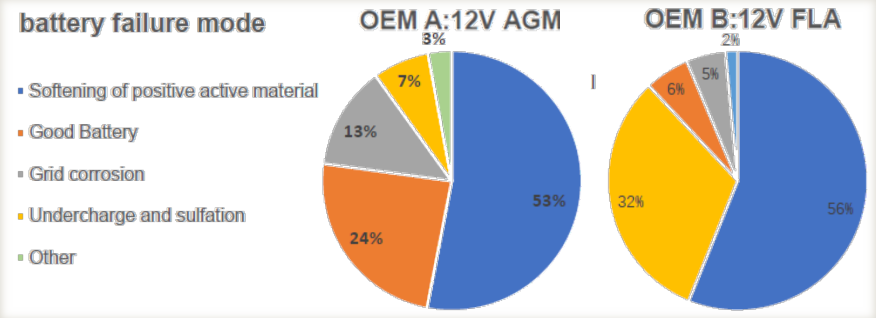
- German ADAC roadside-assistance statistics for 2~3 years old vehicles
- similar R/1000 due to (flat or defect) 12V battery in BEV as in ICE, while overall R/1000 (including powertrain, tires etc.) are lower for BEV



Leoch

Teardown analysis of >1100 field-returned BEV 12V batteries

- OEM A: AGM JIS B21 (mostly in trunk, mostly central China, built 2019-22) – 341#
- OEM B: FLA JIS B20 (mostly underhood, mostly southern China, b. 2020-23) – 794#
- PAM softening dominates in both populations



Camel

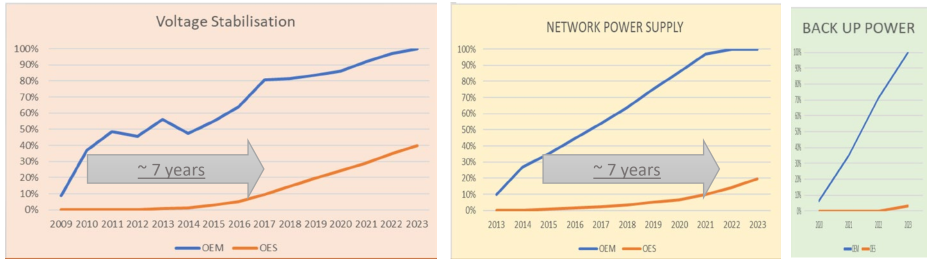
AUX battery failure mode analysis for NEV (new energy vehicles)

- passenger car BEV: (1) misjudgement, (2) sulfation
- electric bus: (1) PAM softening and wear

EastPenn

OEM vs. OES sales for 3 auxiliary & backup AGM applications

- good energy management can achieve >5~7 years field life (insignificant OES sales)



Summary

AUX batteries too often fail by undercharge or undersizing

- sulfation dominates despite dc/dc recharge would always be available
- PAM wear indicates excessive cycling – often battery downsized & loads high
- OEM engineers overestimate effects of corrosion and water loss

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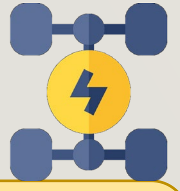

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Discussion & Outlook

❸ Lead batteries can support Functional Safety.

The challenge

- Failure of a 12V battery to provide power may affect safety of vehicle operation.
- Vehicle manufacturer performs systematic safety analysis (ISO 26262: Automotive Safety Integrity Level = **ASIL** A/B/C/D).
- Depending on power-supply topology & strategy, battery contributes to back-to-safe scenario.

Lead batteries are in a good position

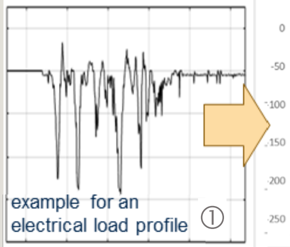
- mature technology, proven in use (>100 years mass production for SLI), cost-efficient
- very reliable, abuse-tolerant, no cascading failure mechanisms, other technology than traction

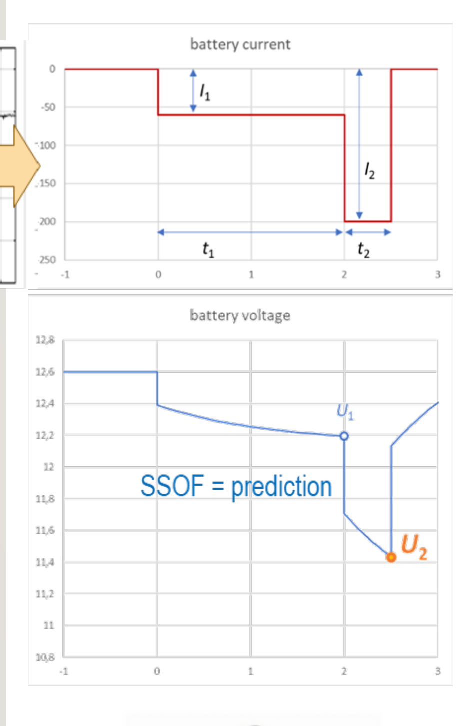
Supply base to provide highly standardized off-the-shelf solutions!

- lead battery (cell stack): mostly documentation needed – low probability of sudden faults
- monitoring: OEMs need (make or buy) robust indication of SSOF = safety state of function

Collaboration is key – facilitated by pre-competitive CBI SSOF working group

- battery specification & quality: coordinated with IEC TC21 (60095-8)
- battery monitoring system (BMS): together with sensor suppliers and vehicle OEMs
- documenting the state of the art, providing application guidelines





① Courtesy of Ford Motor Company (see publications at AABC Mainz 2022, Haus der Technik eehe 2023)

❸ Transient SOF Recovery: Open for research (ALBA 24→25)

observations

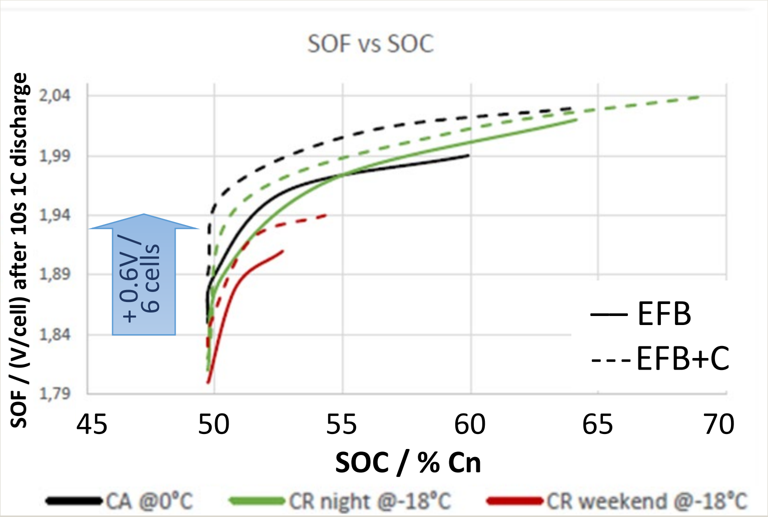
- SOF recovers to nominal or better performance when only few% C_n recharged – at all temperatures
- NAM variation (high DCA) may accelerate this initial SOF recovery
- initial voltage slope: pseudo-capacitive pos electrode polarization
- pos electrode potential after dch duration ~10s (~0.3% C_n) is still elevated as a function of recharged Ah

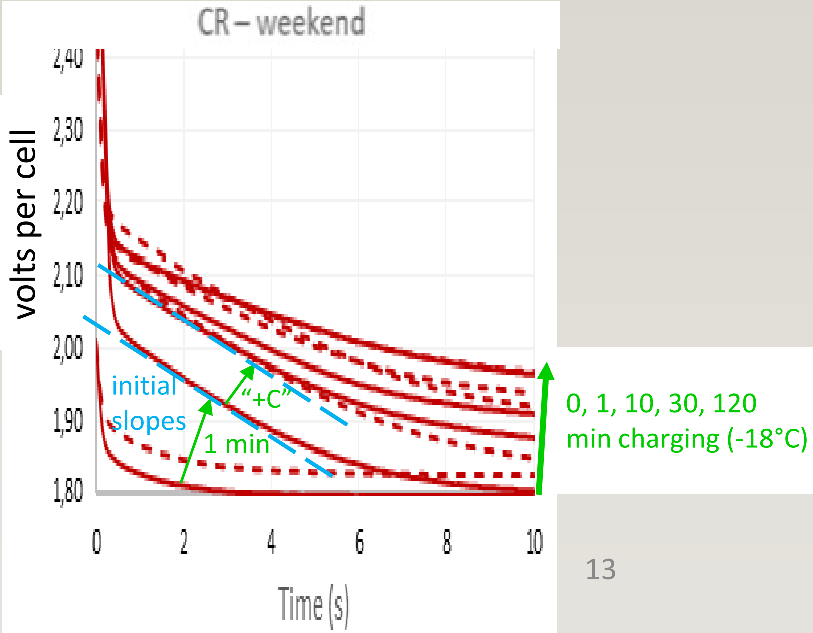
more data / systematic characterization needed

- hysteresis: SOF “decay” during rest, low-rate discharge, microcycling?
- quantitative description: what determines initial slope and later plateau?
- prediction model & observer for in-trip short-term SSOF monitoring

dedicated optimization of recipes and designs

- accelerate initial SOF rise (similar changes as for DCA? start at NAM?)
- maximize SOF after rest or pre-discharge (start at PAM?)
  – NB: many ASIL cases require 2-step profiles = base load + peaks(s)





figures after: G. Rocha, ALBA 2024

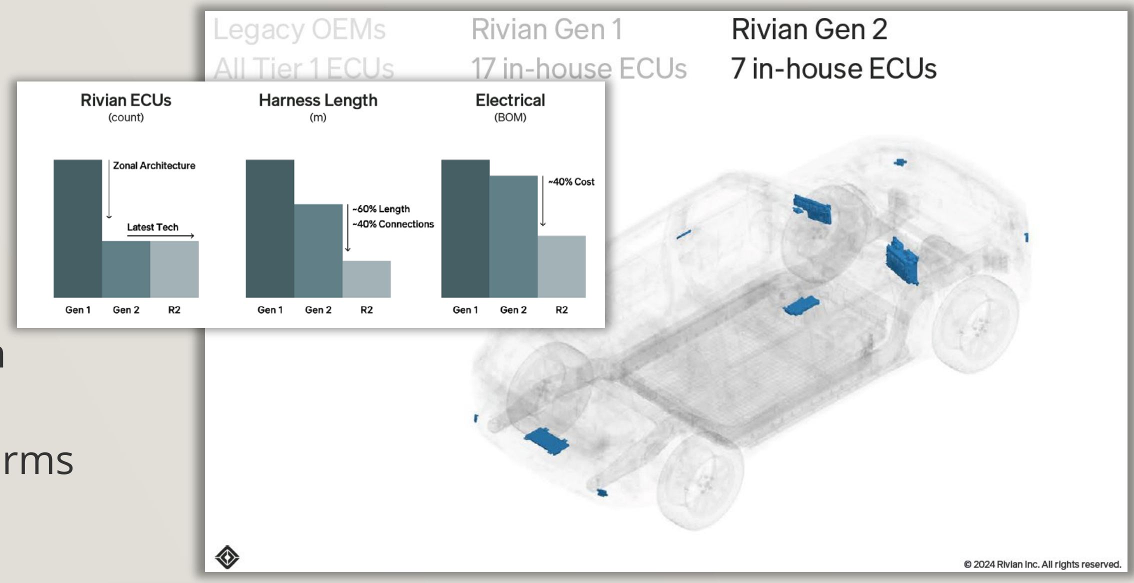
❹ Power supply without 12V (lead) battery?

Zonal architectures – proposed for "software defined vehicles" (SDV)

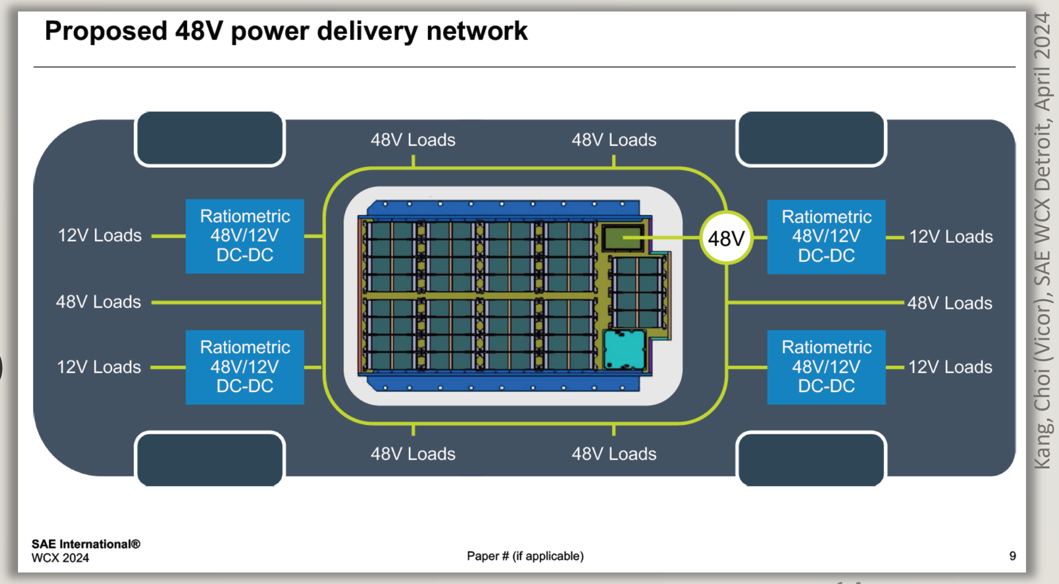
- all software runs on a few, OEM-owned central controllers
- announced by Tesla (CyberTruck) and Rivian
- may go along with 48V-only distribution and zonal step-down conversion to any voltage as needed: no more 12V batteries?
- Such 48V-only architectures are an option for BEV-only platforms
- Next 3-5 years: Will mainstream BEV flip to 48V-only? Platform decisions will not depend on battery technology.

Other options for 12V batteries

- entry & volume segments: likely to stay lead (flooded, EFB or AGM) for auxiliary, but may not always supply ASIL functions from it.
- Li-ion (most likely, LFP) 12V? – not an attractive business proposition to traction battery makers (<0.5 vs. >50 kWh per car)
- Na-ion may be competing in the long term (again, for traction first)
- redundant dc/dc converters without 12V storage? – most OEMs see reliability issues (vehicle access etc.)



Rivian Investor Day 2024



Kang, Choi (Vicor), SAE WCX Detroit, April 2024

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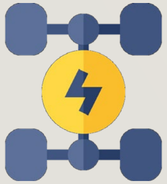

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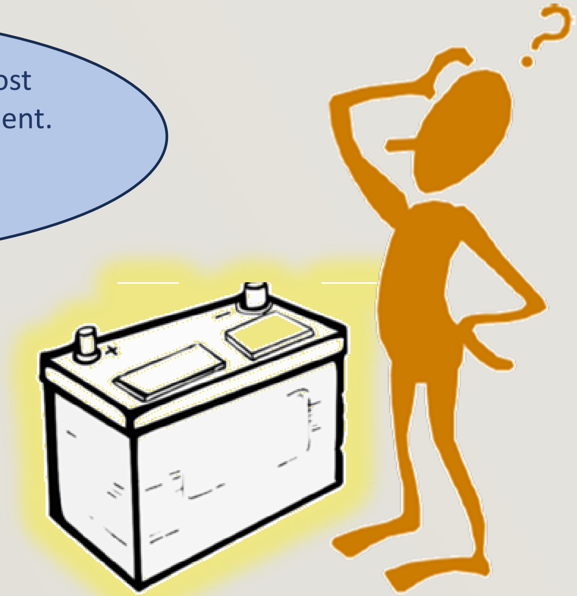
❺ OEM support

Our technology comes at lowest cost
but demands some smart management.
We will help you on that –
or go away and pay more.

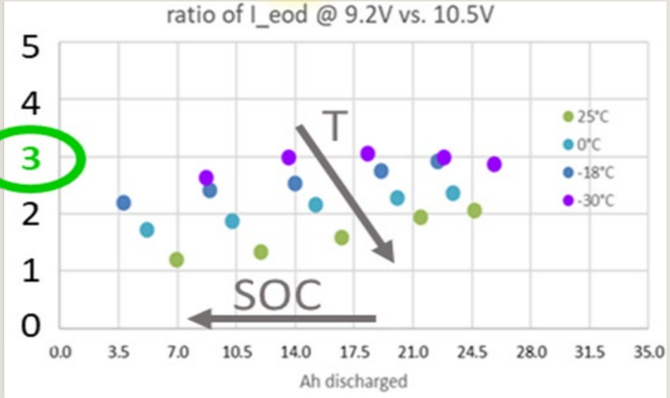


Lead battery expertise at OEMs

- new BEV-only companies do not have decades of “starter” experience
- legacy OEMs tend to sideline classic power-supply departments during BEV and ASIL decisions, lead battery expert positions are not backfilled
- ➢ Expect OEMs to be(come) receptive for advice and technological solutions!

Examples for pre-competitive support areas

- CAE tool: PPC-based sizing (CCA, capacity) based on (SOC, T) ranges → min. voltage allowance is much more sensitive than max. current!
- CAE tool: realistic throughput estimation for battery selection & sizing
- charging guidelines based on experience and experimentation: float or charge-as-needed? optimize voltage transients (slow ramps)? …
- other guidelines for battery and 12V-system operation specifically for BEV: load control & supply, minimize time at low SOC, …
- robust SSOF monitoring: proof of concept for short-term observers



example: same 35 Ah battery delivers 2-3x higher current at 9.2V compared to 10.5V (low SOC, low temp)

Lead battery suppliers should pro-actively support battery application and system integration at OEMs. Standardization and pre-competitive industry working groups can be instrumental.

Discussion & Outlook

Automotive industry mega trends

- Powertrain electrification:
  DCA for emerging markets! Charge recovery and design-for-9V for BEV! Optimize auxiliary and backup battery designs!
- Driver assistance, autonomous driving, software-defined vehicle:
  Demonstrate feasibility of ASIL compliance! Let's not make 48V-only a self-fulfilling prophecy.
- OEM lead battery expertise, on average, is dwindling:
  Assume a pro-active role as technology supplier! Offer "authoritative" design tools & guidelines!

Collaboration is key for a mature commodity industry facing technology challenges

- Standards should guide OEM specifications. New application-driven test methods are underway: High-Temperature Endurance HTE (EN 50342-1), Pulse-power characterization PPC & Charge Recovery CR (IEC 60095-8).
- Standardization of sub-30Ah auxiliary & backup battery sizes should be addressed next.
- Industry working groups should collect application rules and develop engineering tools for power supply engineers. CBI can provide a pre-competitive framework.
- Battery monitoring for Functional Safety should be demonstrated (proof-of-concept) to guide OEM demand.
  CBI SSOF database with logged battery data under realistic operating conditions is a bootcamp.