There is a lot of life left in lead

Overview on automotive battery market trends, battery field experience & lifetime and future development potential of Start-Stop batteries

AABC Europe 2017

Mainz, Germany

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Johnson Controls Power Solutions EMEA

Electrification of vehicle power train

- Global target: reduction of vehicle CO_2 emissions
- EU Emissions target: Reduce average CO_2 emissions from new cars to 95 g/km from 2020
- This is a 40% reduction from the mandatory 2015 target (130 g/km)

- Possible approaches:
  - Improvements in engine efficiency
  - Lighter, smaller vehicles
  - Alternative fuels
  - Electrification of power train (all levels of hybridization)

Battery performance is one key factor for CO_2 reduction

Focus on Start-Stop applications and 12 V starter batteries

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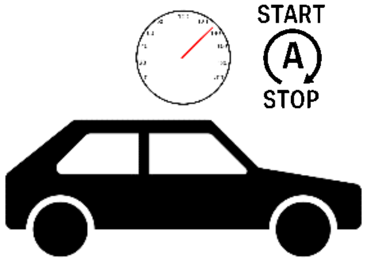
Requirements for 12 V starter batteries

Main tasks of 12V starter batteries:

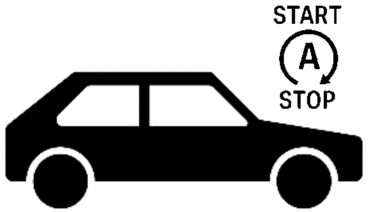
Hybrid electric vehicles

- Engine crank, at least cold start
- Regeneration of braking energy



Start-Stop Coasting / Stop-in-motion

- Even more engine starts
- Supply electrical system frequently
- Recover energy, quick recharge



Start-Stop vehicles

- More frequent engine starts
- Supply electrical system
- Regeneration of braking energy

Conventional vehicles

- Engine start

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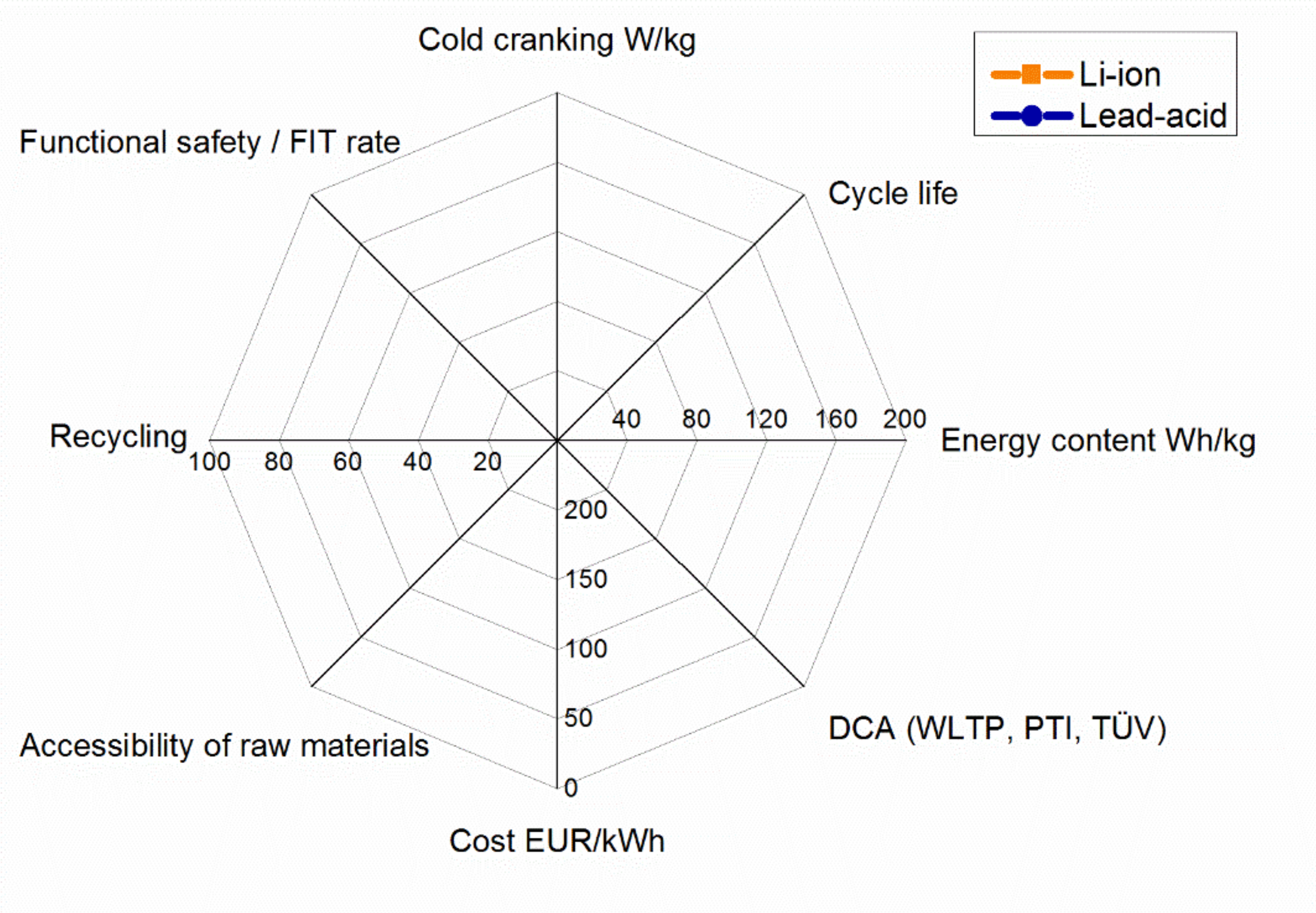
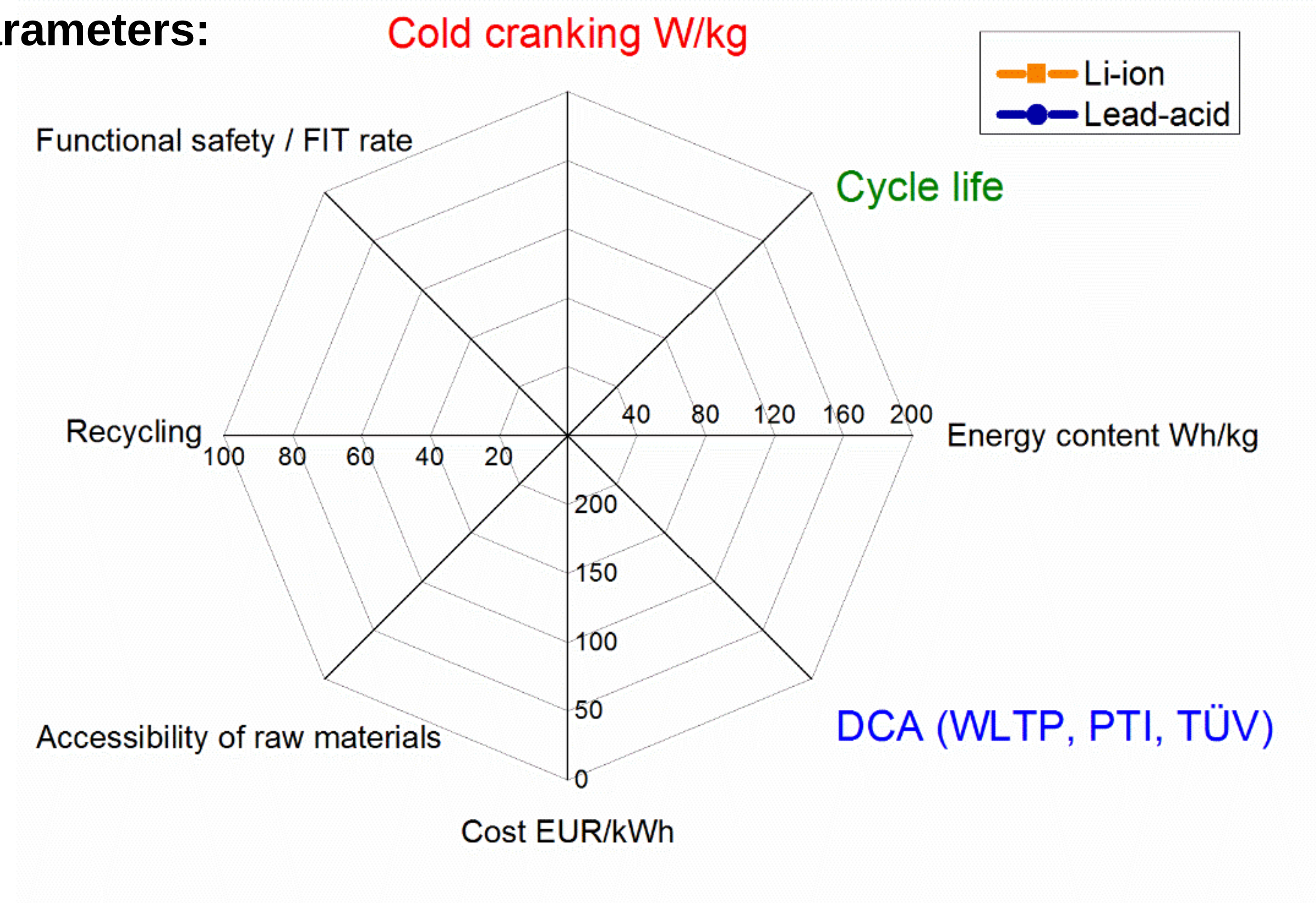
Requirements for 12 V starter batteries



Requirements for 12 V starter batteries

Focus on three parameters:



12V Lead-acid batteries in vehicle applications today

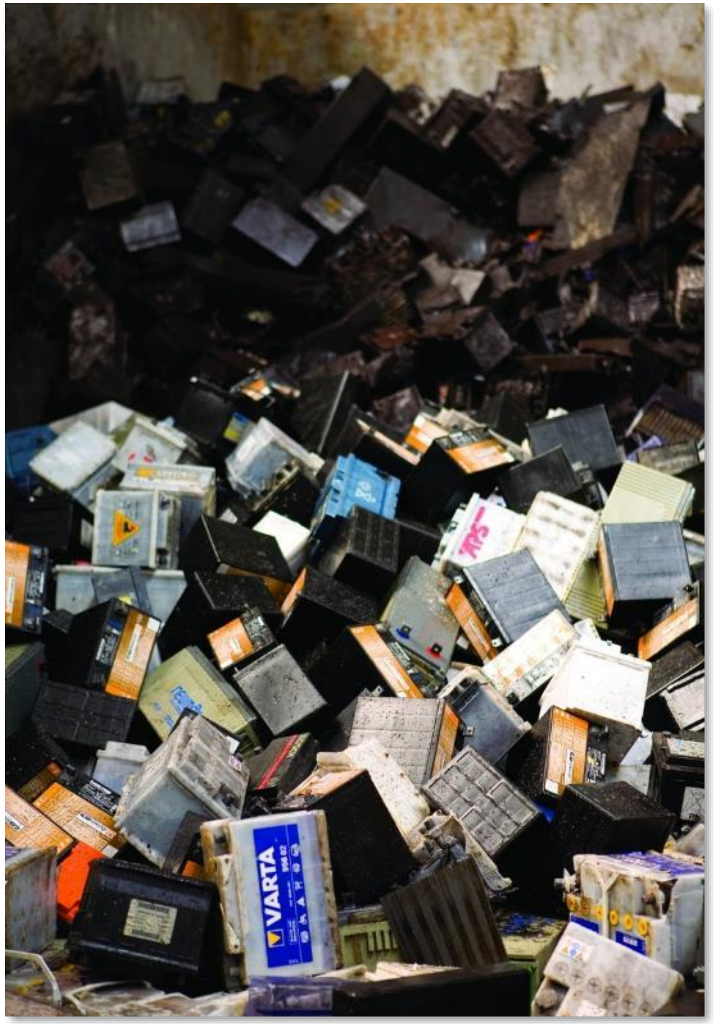
Requirements for 12V starter batteries:

- Crank combustion engine ("power")
- Supply vehicle electrical system ("energy")
- Capability of quick recharge ("dynamic charge acceptance")

↔

End of battery life mainly is determined from:

- High internal resistance
- Capacity loss due to deterioration of active masses
- Low DCA due to sulfation



How do real-world lead-acid AGM batteries look like at the end of service life?

12V Lead-acid batteries in vehicle applications today

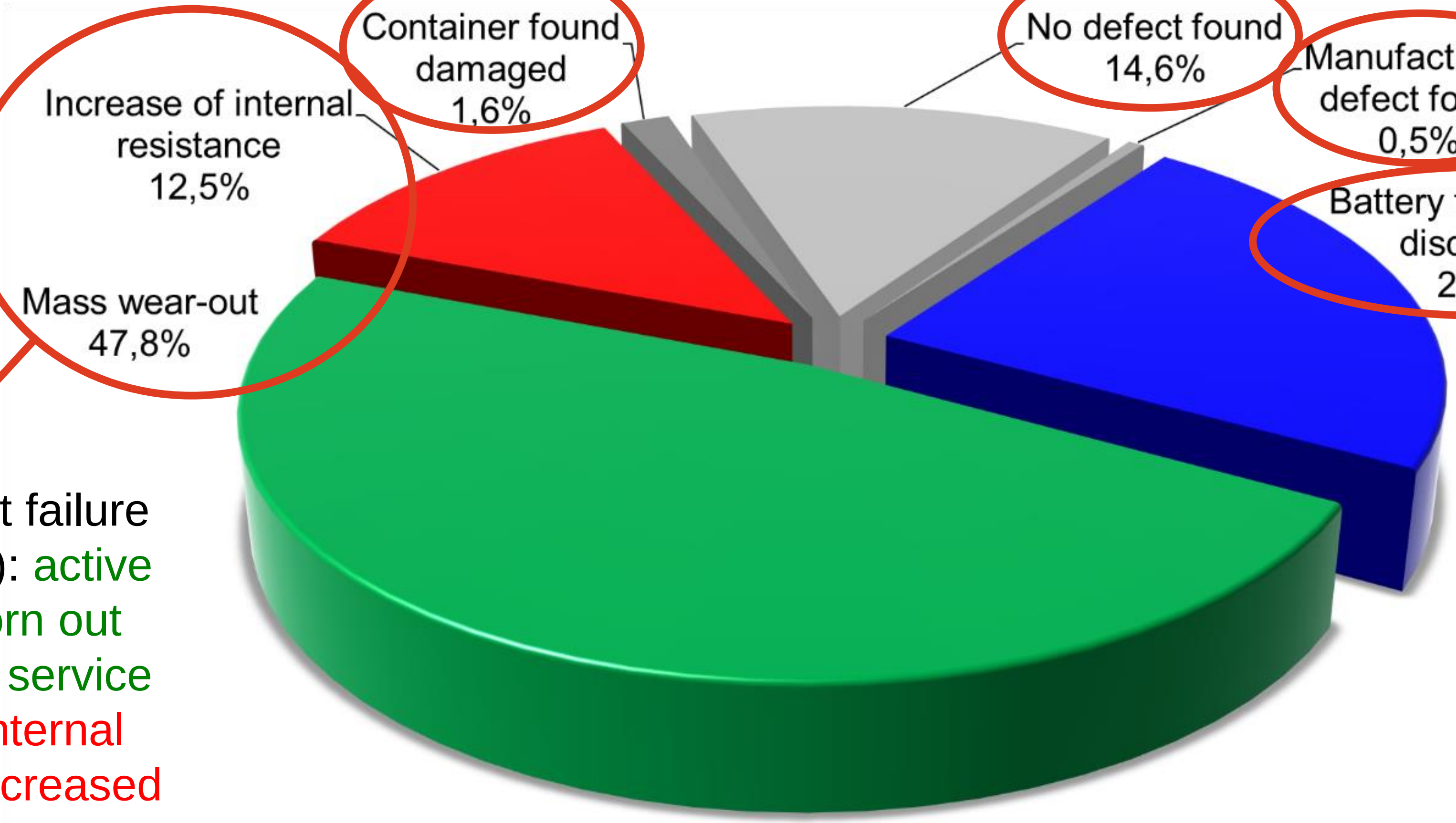
More than 800 AGM batteries investigated after end of service life

Remarkable 14.6% of all batteries are still working

During shipment

Failure mode distribution:

Life time of up to four years despite of defects



Deep-discharge occurred during vehicle operation

Most significant failure modes (60.3%): active masses are worn out (regular end of service life reached), internal resistance is increased

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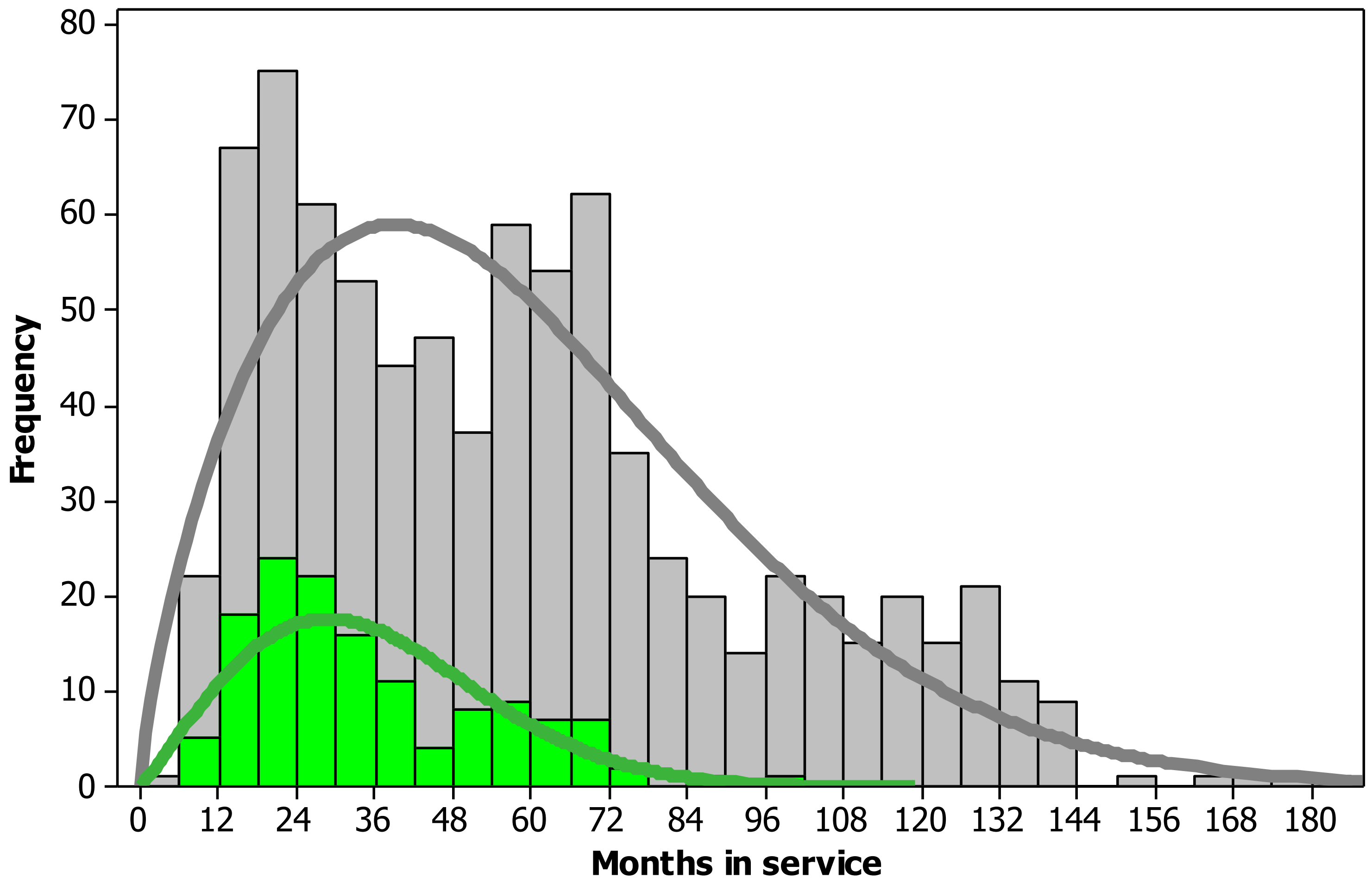
12V Lead-acid batteries in vehicle applications today

Age of AGM batteries returned from field:



- Battery lifetime up to 15 years found
- Average lifetime of approximately 6 years
- 14.6% of batteries still usable (green color), average age of 2 years

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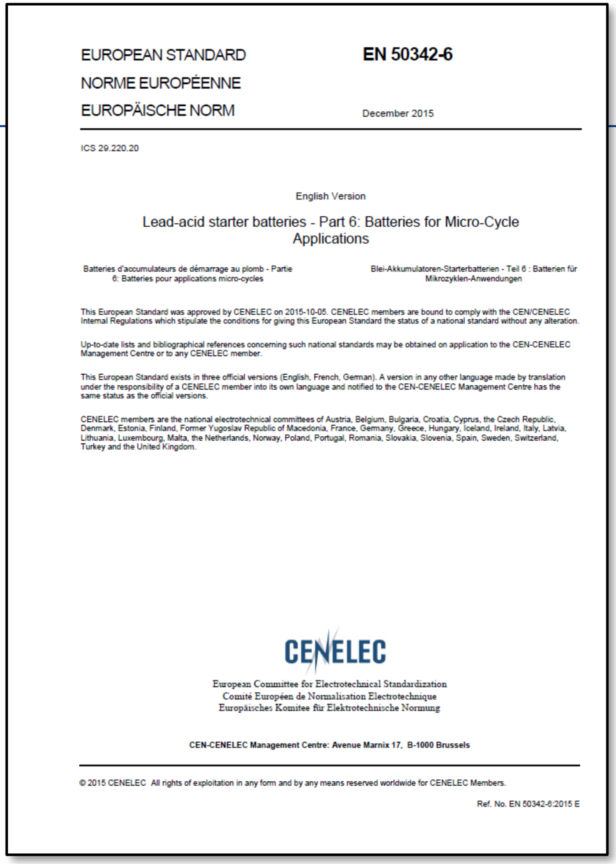
Battery test procedures for Start-Stop applications

Correlation of real-world performance and lab tests

New European standard EN 50342-6:2015

- MHT ("Micro-Hybrid Test")
  - → Covers Start-Stop operation
- Cycling endurance tests (17.5% DoD, 50% DoD)
  - → Cover cycling performance
  - → Also cover deep-discharge
- DCA ("Dynamic Charge Acceptance")
  - → Covers DCA (in "run-in" battery state)



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 50342-6

December 2015

ICS 29.220.20

English Version

Lead-acid starter batteries - Part 6: Batteries for Micro-Cycle Applications

Batteries d'accumulateurs de démarrage au plomb - Partie 6: Batteries pour applications micro-cycles

Blei-Akkumulatoren-Starterbatterien - Teil 6 : Batterien für Mikrozyklen-Anwendungen

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Ref. No. EN 50342-6:2015 E

EN 50342-6 offers battery tests correlating to battery performance requirements as well as field failure modes:

a) Engine cranking ⟷ High internal resistance ⟷ MHT

b) Power supply ⟷ Mass wear out ⟷ 17.5% and 50% DoD test

c) Quick recharge ⟷ Plate sulfation ⟷ DCA test

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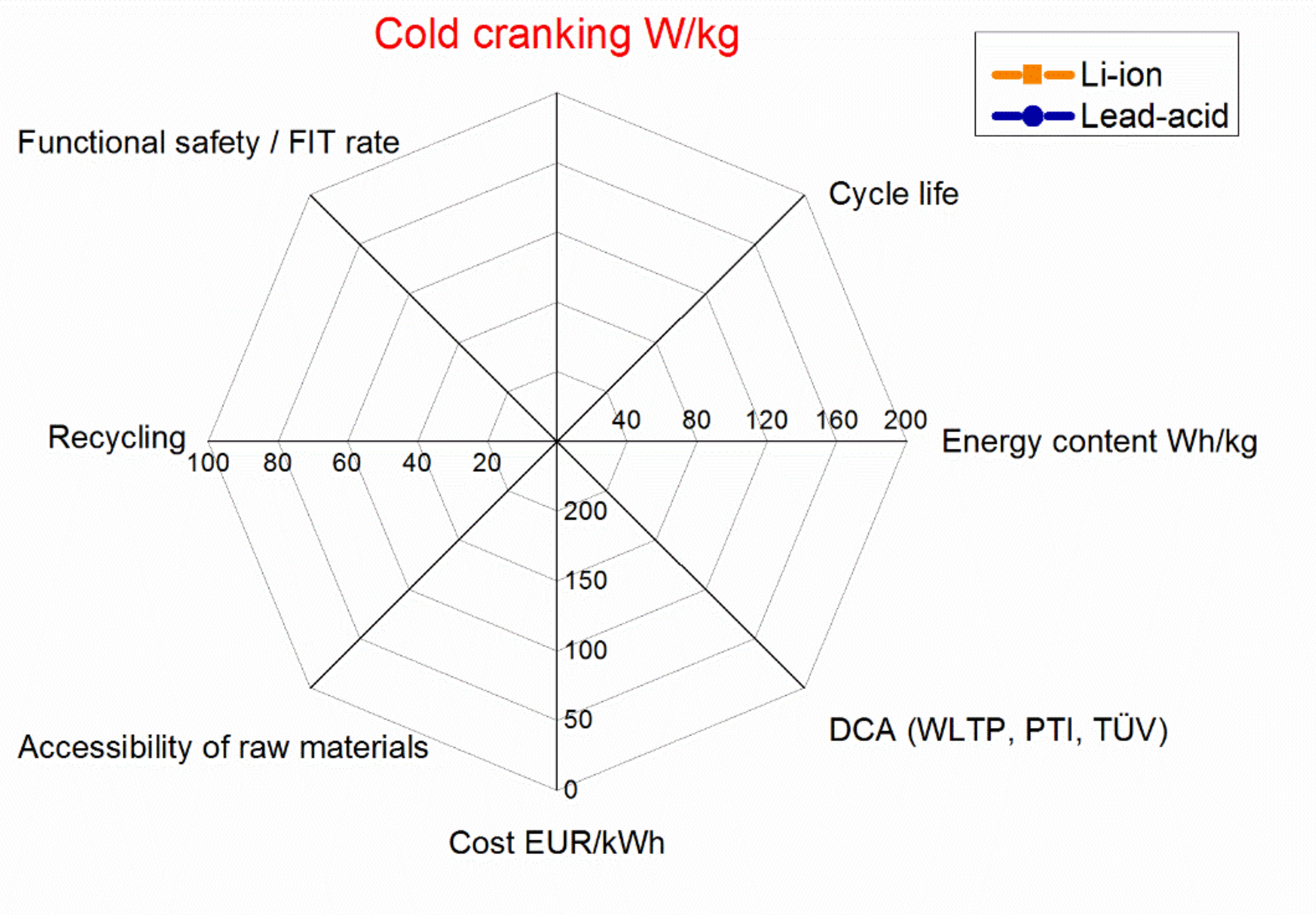
Requirements for 12 V starter batteries: **Cold cranking / internal resistance**

1



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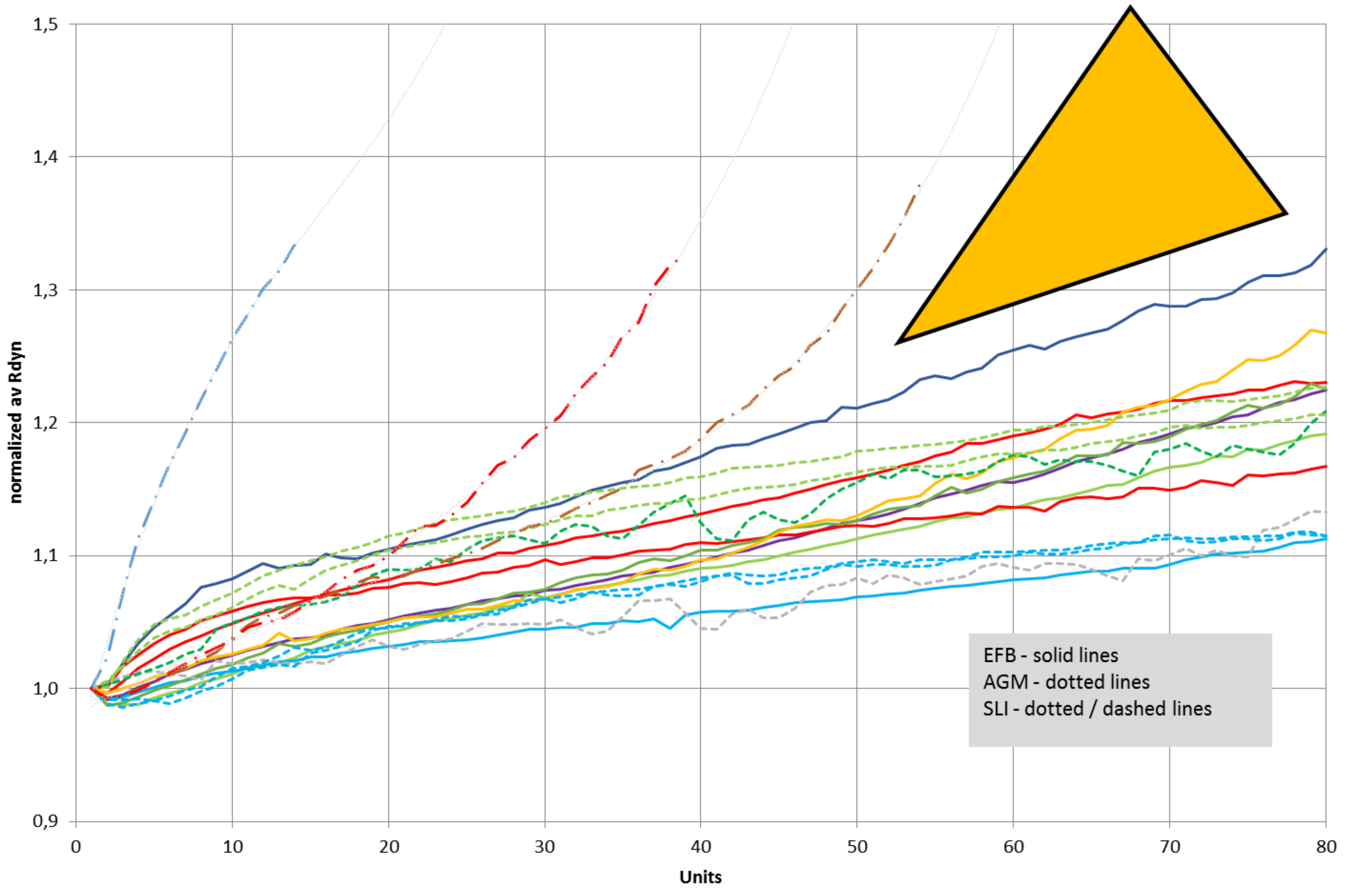
Requirements for 12 V starter batteries: Cold cranking / internal resistance

1 Micro-Hybrid Test MHT



MHT represents Start-Stop application:

- Increase of internal resistance
- Decrease of voltage level during high-rate discharge
- Capacity decrease

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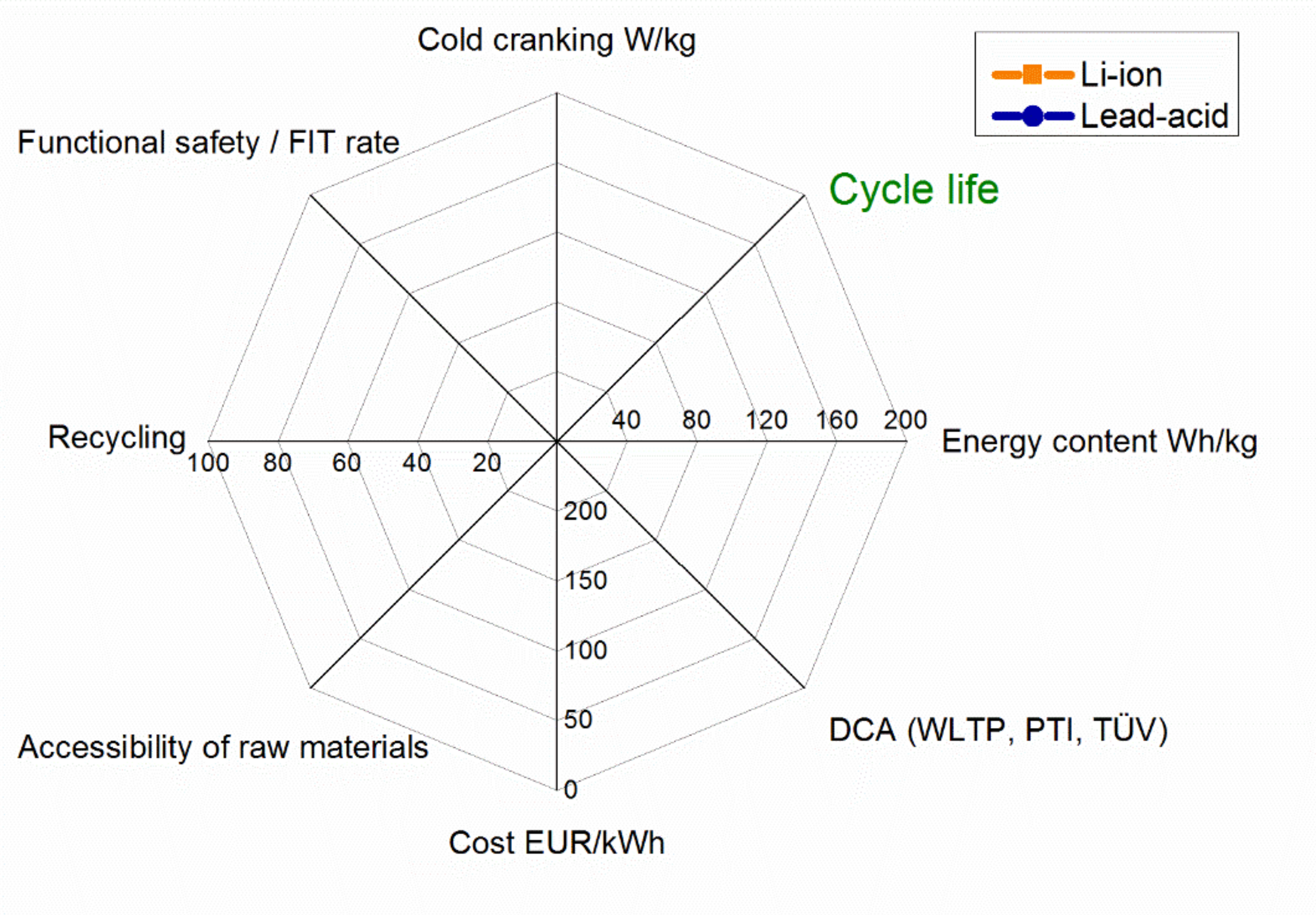
Requirements for 12 V starter batteries: **Cycle life**

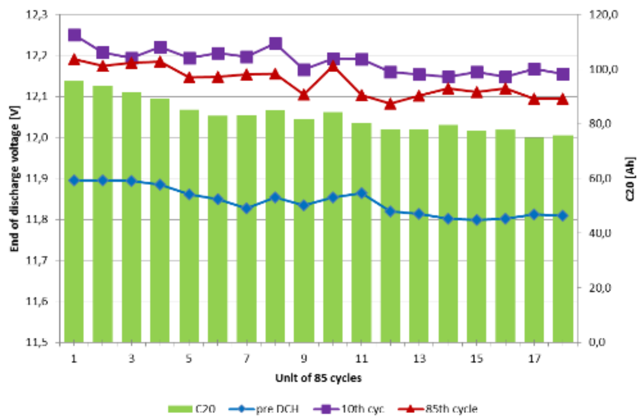
2



Requirements for 12 V starter batteries: **Cycle life**

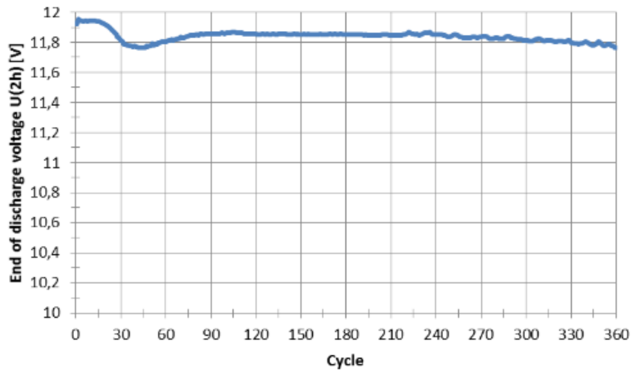
❷ Cycling endurance tests:

17.5% DoD



25°C

50% DoD (deep-discharge test included)



40°C

Cycling endurance tests show aging effects also known from real-world operation:

- Mass degradation (positive electrodes)
- Sulfation (negative electrodes)
- Deterioration after deep-discharge/misuse

Accelerated life tests do not try to simulate real-world operation, but represent know failure modes.

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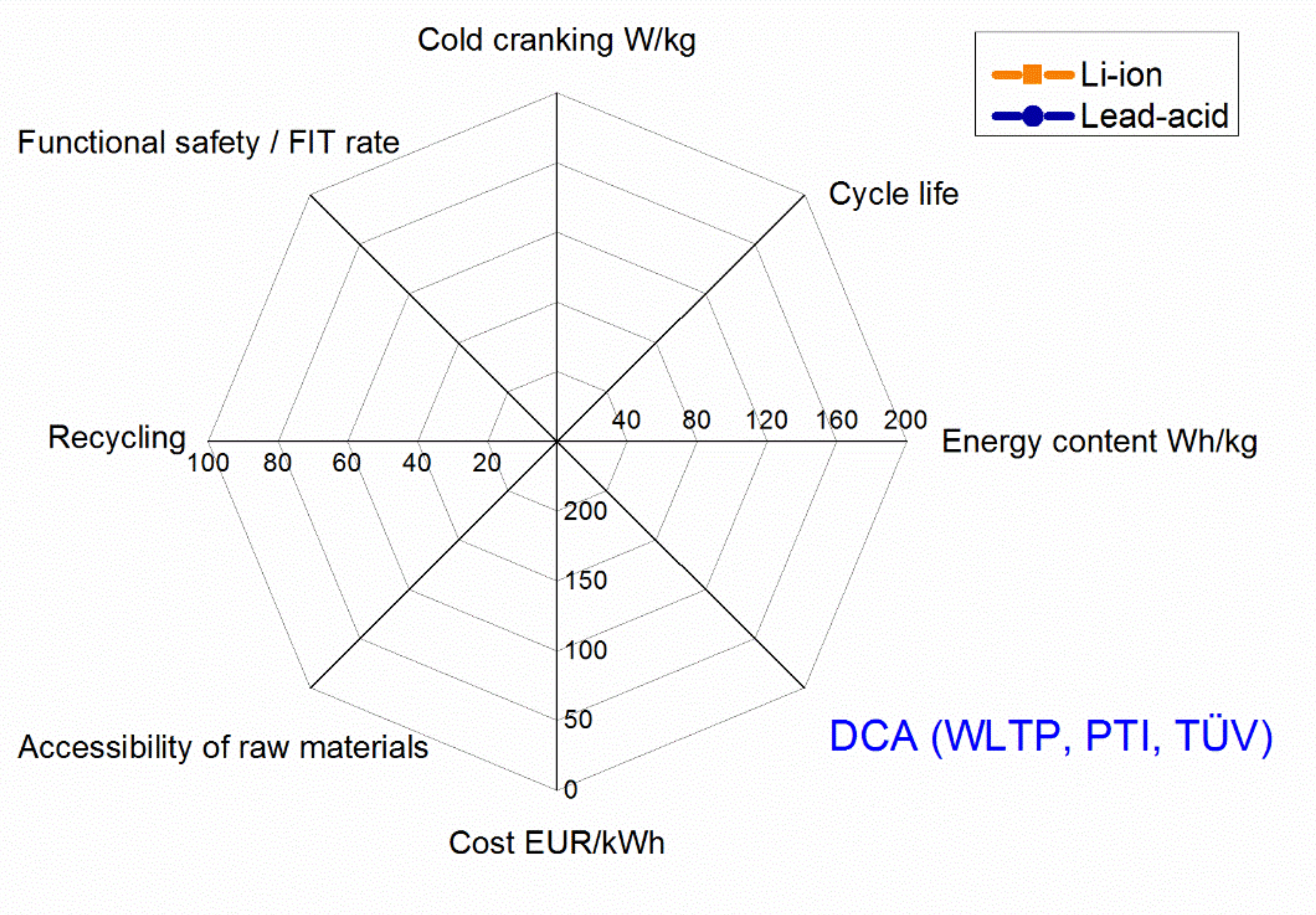
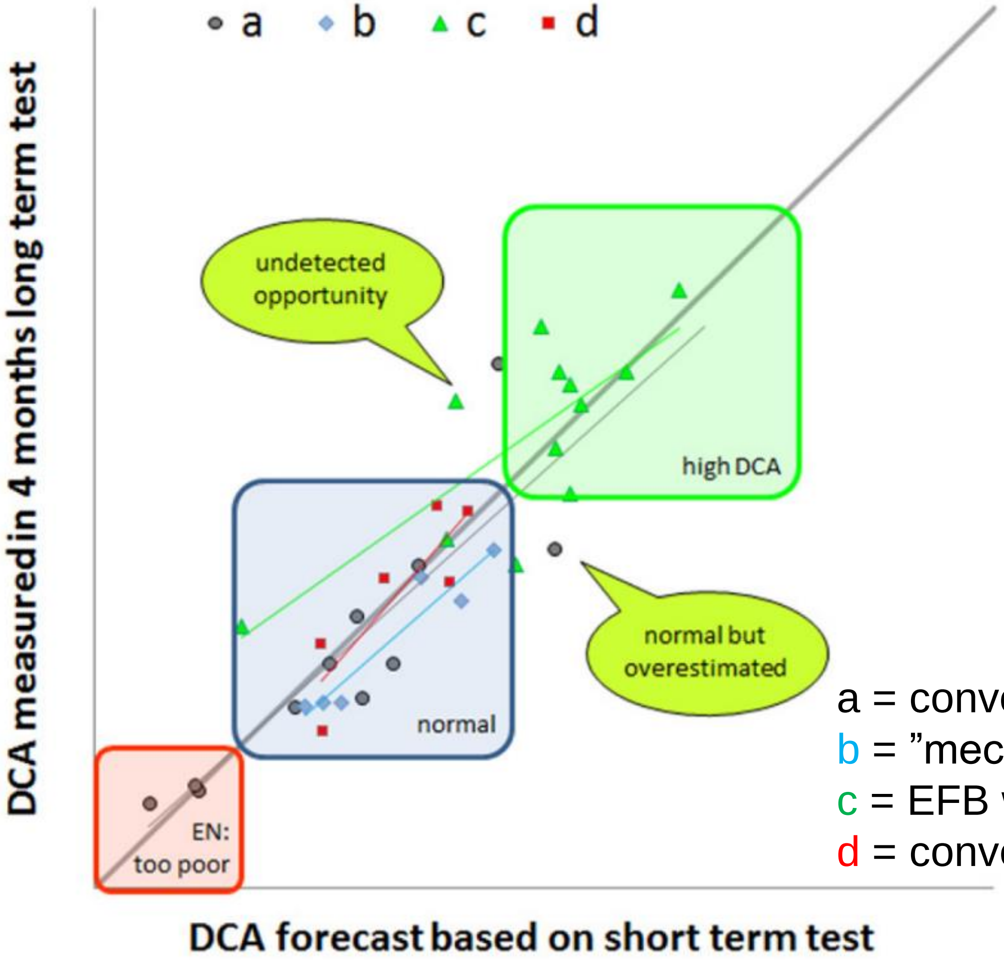
Requirements for 12 V starter batteries: **Dynamic charge acceptance**

3



Requirements for 12 V starter batteries: **Dynamic charge acceptance**

❸ Dynamic Charge Acceptance (DCA)



DCA test predicts long-term charge acceptance level in a two-weeks test

Levels of DCA performance:

- "Too poor" for Start-Stop
- "Normal" level, suitable for Start-Stop
- "High DCA" level (batteries with additives)

a = conventional flooded
b = "mechanically" enhanced flooded (EFB)
c = EFB with innovative negative electrodes
d = conventional AGM

Source: E. Karden, 13 ELBC Paris 2012

Requirements for 12 V starter batteries: **Dynamic charge acceptance**

Does a battery with improved DCA performance necessarily have a higher water consumption?

	Water consumption in lab test		**Real-world water consumption**
Battery usage:	Artificial: continuous overcharge	⟷	Operating strategy (conventional / Start-Stop)
Temperature:	60°C	⟷	Dependent on ambient conditions
Battery state:	No rest time, no discharge	⟷	Overcharge, discharge, rest
Duration:	6 or 12 weeks	⟷	Battery life time (up to 15 years)

→ Are the test conditions (representing conv. cars) in lab still comparable to real world (Start-Stop) applications?

Yesterday's workshop tried to coordinate all research activities in this topic!

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High DCA battery in vehicle test - first experiences

Johnson Controls City Cycle determines real world Start-Stop performance:

- 30 km round trip in Hannover downtown
- Stronger emphasis on urban driving to force Start-Stop opportunities

Former comparison of Start-Stop availability:

- Car with AGM battery exhibited lower number of missing engine stop opportunities compared to EFB
- Eberhard Meissner, 14 ELBC (Edinburgh 2014)

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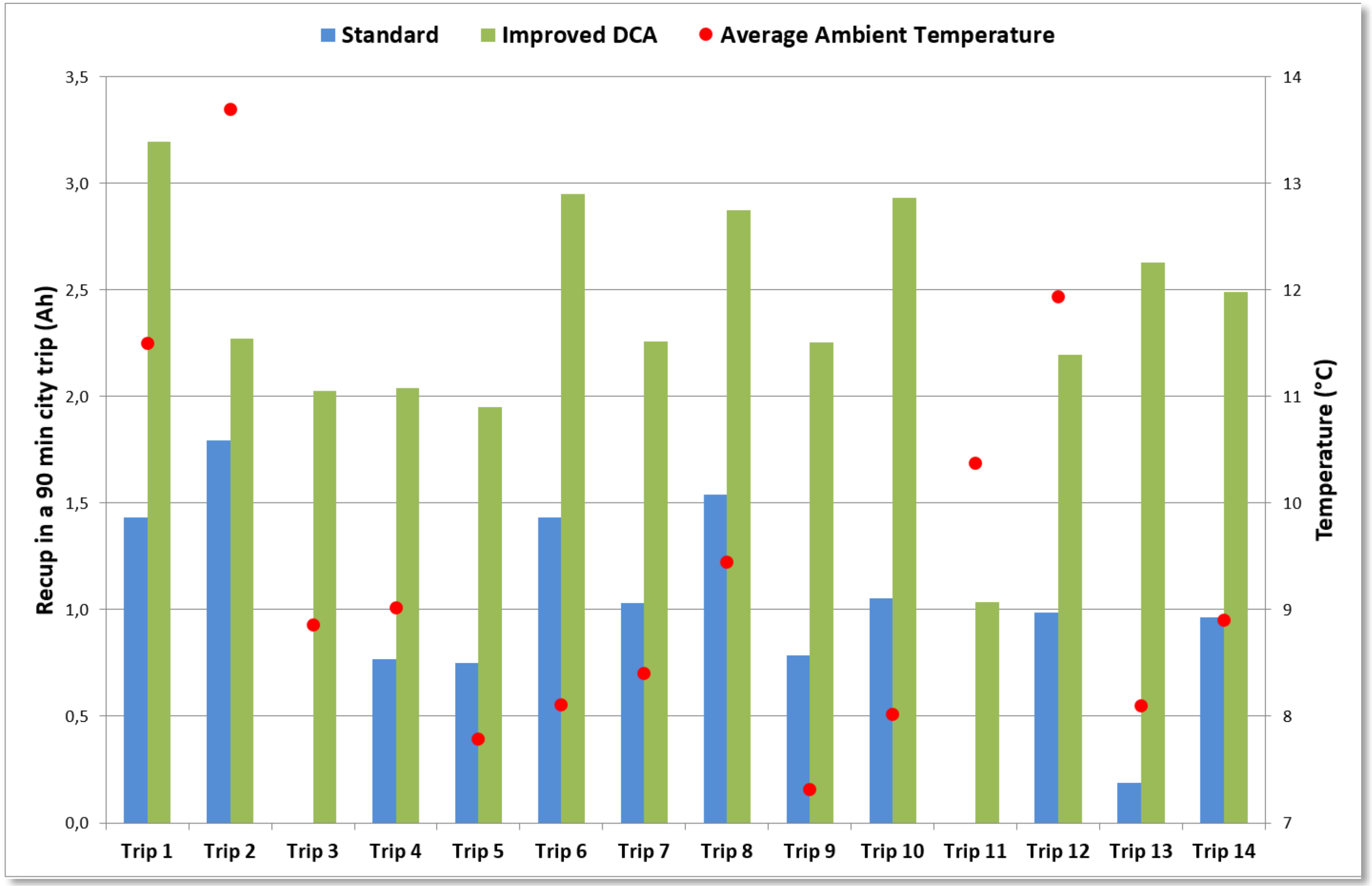
High DCA battery in vehicle test - first experiences

Johnson Controls City Cycle:

- Platoon of two Ford Focus Start-Stop cars (same engine, equipment), ambient temperature 7…14 °C
- Batteries:
  - (1) EFB “standard” design
  - (2) EFB “high DCA” design



Analysis of braking energy recovery:

2.5 x higher amount of charge recovered by recuperation with (2) EFB “high DCA” design

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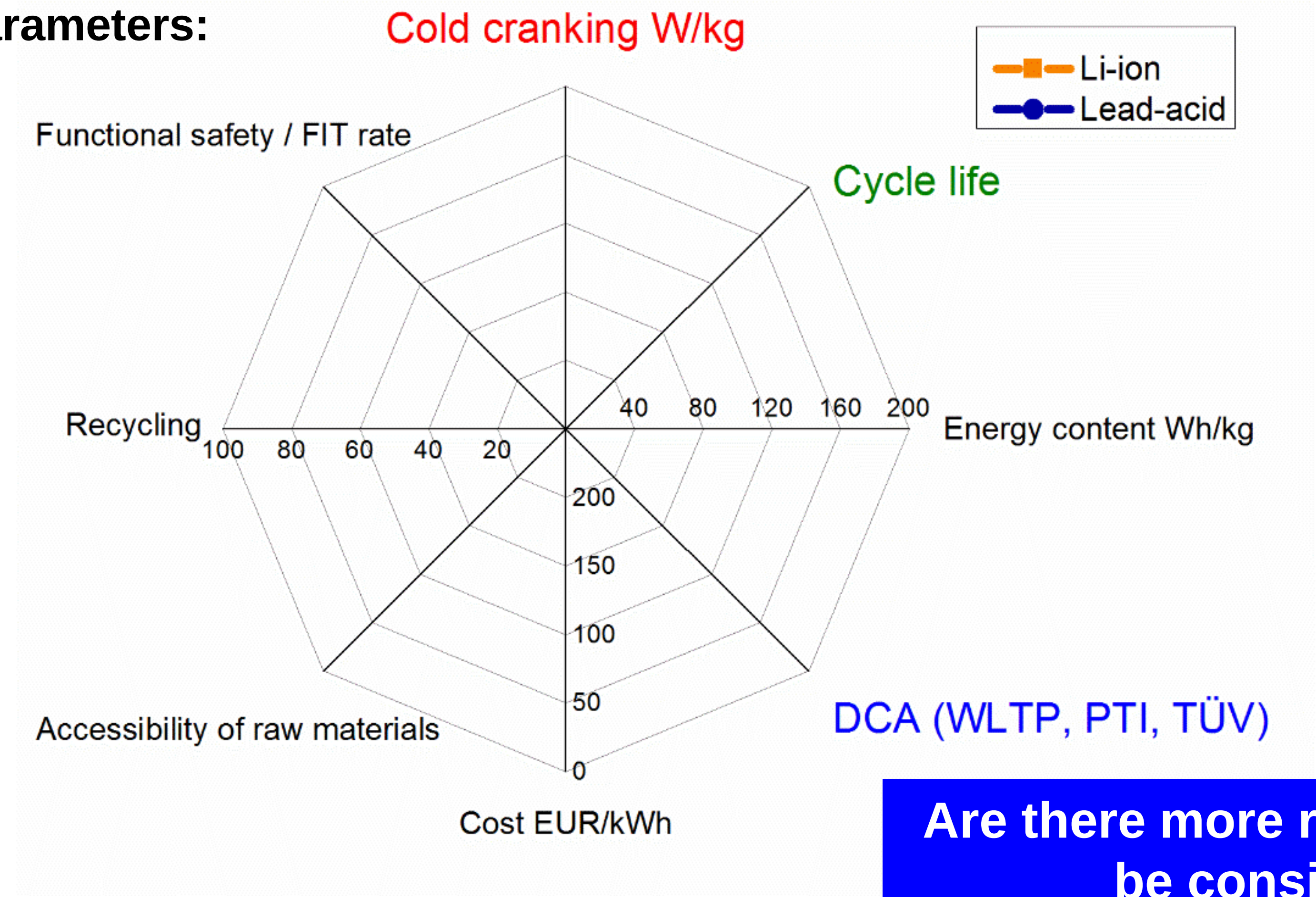
Requirements for 12 V starter batteries

Focus on three parameters:



Are there more requirements to be considered?

Future vehicle applications – a challenge for the battery

Future vehicle concepts:

- Higher fuel efficiency needed!
  - Still need engine crank, if not fully electric (internal resistance)
  - More electrification (cycling capability needed)
  - Use braking energy (high DCA needed)

→ Same battery requirements as today, but **increased expectations**!

- Route to autonomous driving:
  - Highly reliable electrical systems required
  - Battery reliability and battery diagnostics are key factors
  - Functional safety of vehicle and battery system

→ New requirements: **Reliability and battery diagnostics**

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Development potential of lead-acid batteries

Engine cranking performance / Internal resistance

- No increased requirements expected
- Low temperature cranking performance of lead-acid batteries has been proven

Reliability

- Battery reliability of lead-acid is even higher compared to Li-ion (no active components like switches)

Battery diagnostics

- Very high precision in lead-acid battery diagnostics, proven for many years
- Data available for aged batteries, field returns, etc.

Cycling performance

- Improvements possible (even for AGM)
- If even more cycling performance needed → Combined energy storage system (Lead-acid + Li-ion)

Dynamic charge acceptance

- Improvements possible (even for AGM)
- If even more charge acceptance needed → Combined energy storage system (Lead-acid + Li-ion)

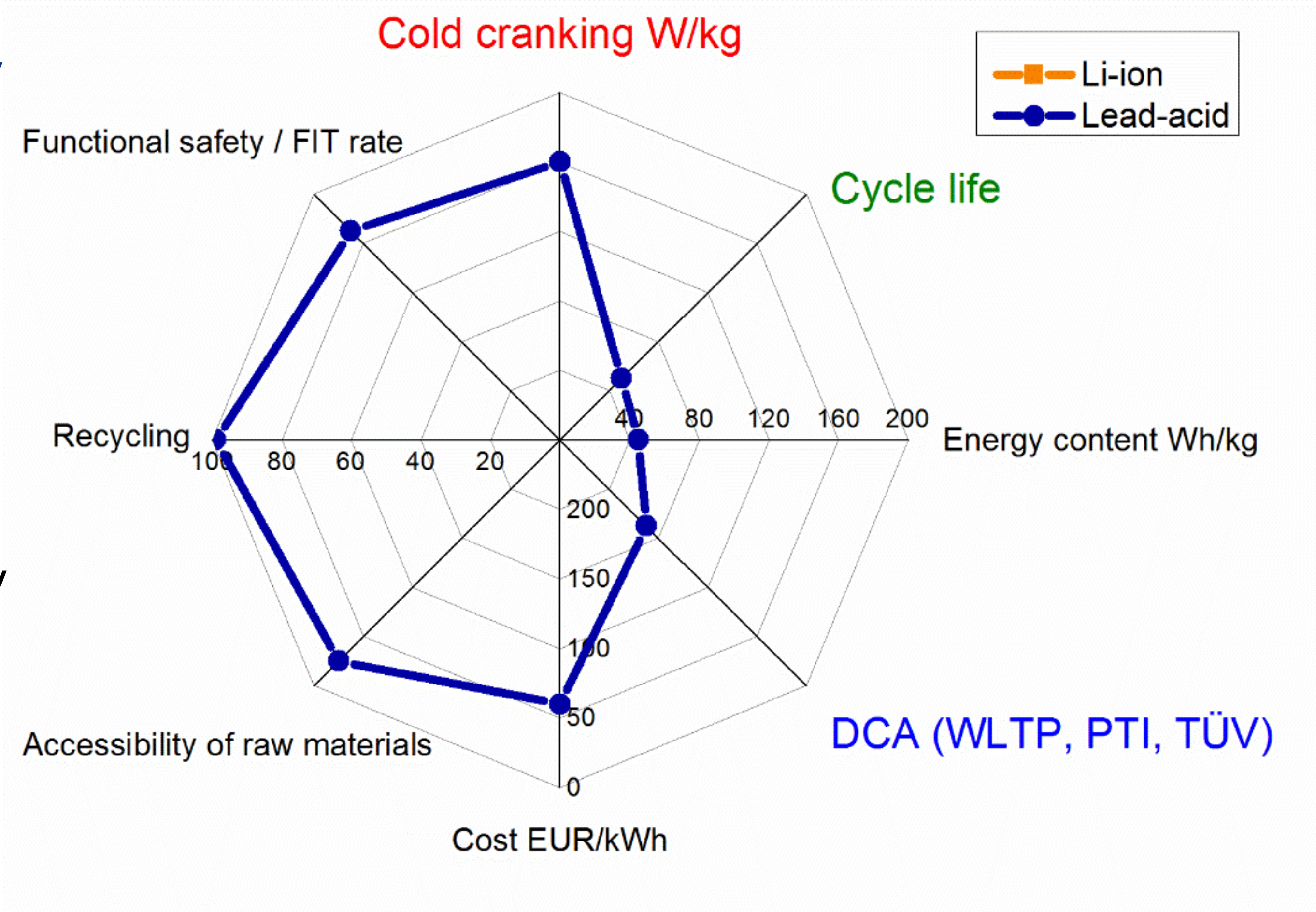
We focused on three parameters. However, many more are essential!

Technology comparison of 12V batteries: Lead-acid and Li-ion

Lead-acid battery 12V

Advantages:

- Cold cranking
- High reliability
- Recycling > 99%
- Raw materials easily accessible
- Cost advantage



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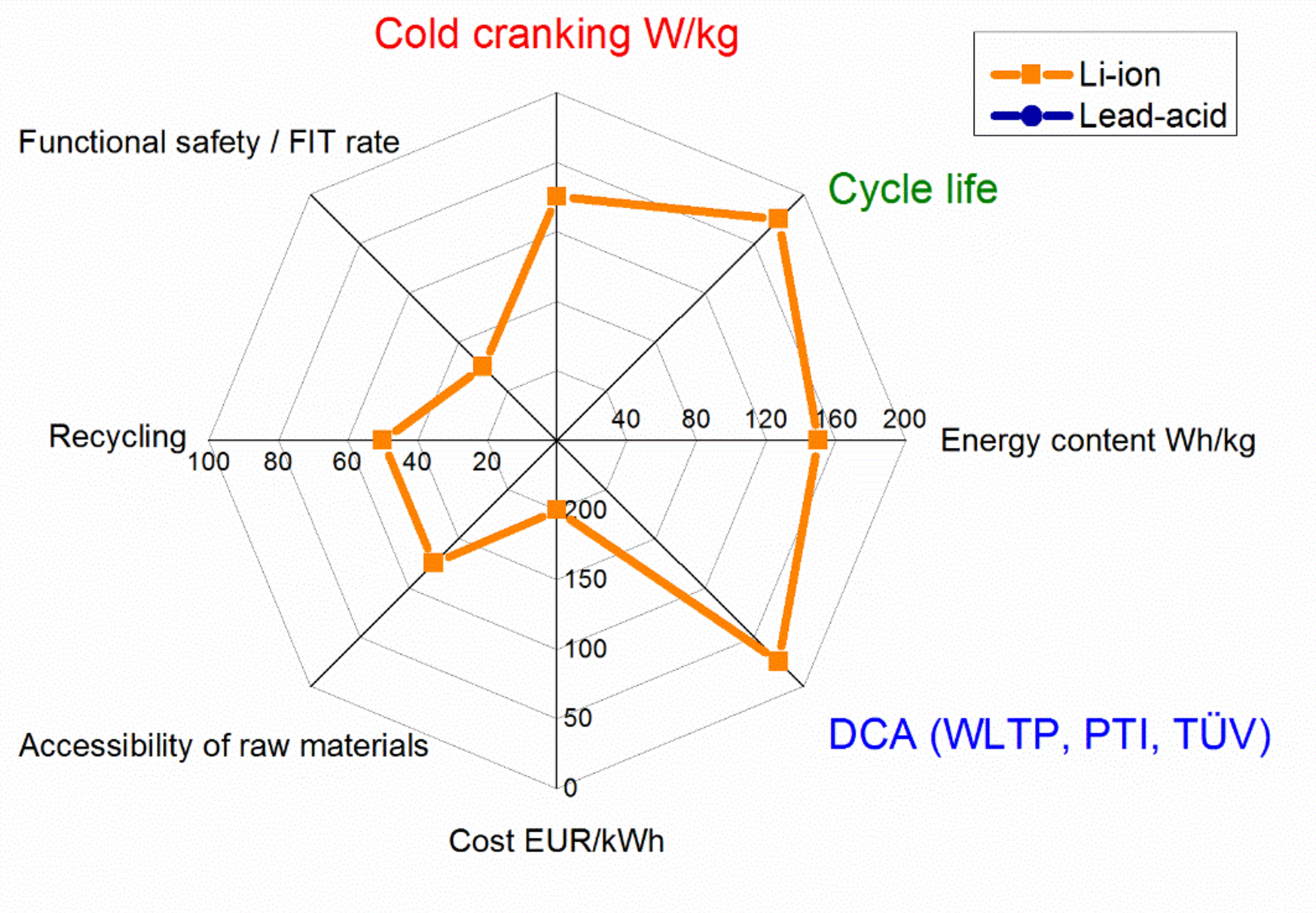
Technology comparison of 12V batteries: Lead-acid and Li-ion



Li-ion battery 12V

Advantages:

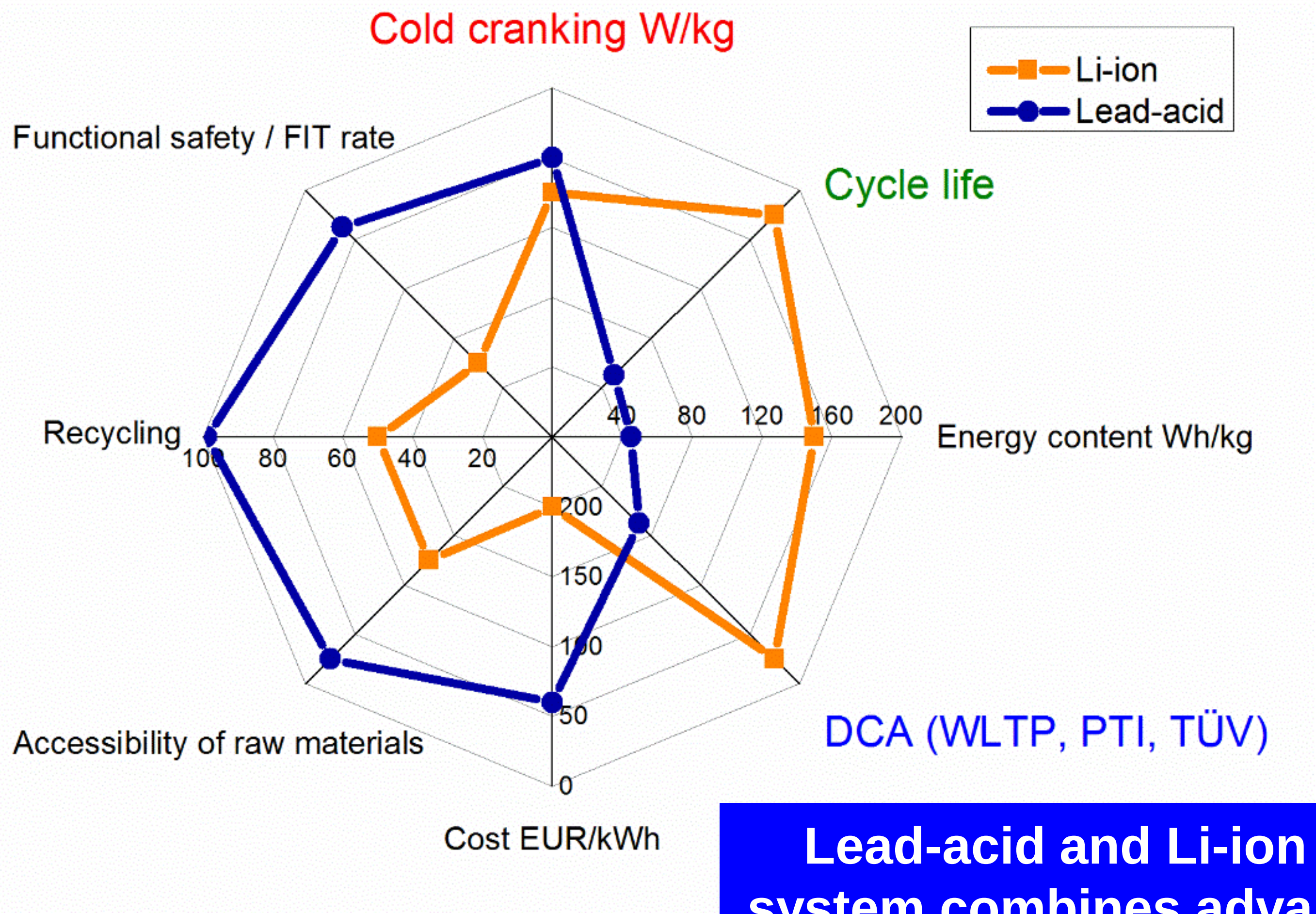
- Cycle life
- Energy content
- Dynamic charge acceptance

Technology comparison of 12V batteries: Lead-acid and Li-ion

Lead-acid battery 12V

Advantages:

- Cold cranking
- High reliability
- Recycling > 99%
- Raw materials easily accessible
- Cost advantage



Li-ion battery 12V

Advantages:

- Cycle life
- Energy content
- Dynamic charge acceptance

Lead-acid and Li-ion dual battery system combines advantages of both

Dual battery system – Lead-acid and Li-ion

- **Combination of two battery chemistries** can be advantageous:
  - Reasonable cost level
  - High reliability and redundancy
  - High cycling ability
  - High dynamic charge acceptance
  - Engine cold crank is ensured
  - Excellent lifetime expected for both batteries

- Johnson Controls **test vehicle** with **dual battery system** already in use to prove fuel efficiency benefits

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Conclusions

- CO_2 emission goals (EU: 95 g/km) require electrification of vehicles
- Start-Stop battery requirements: power, energy, DCA
- End of life determined from:
  - High internal resistance
  - Active mass wear-out
  - Low DCA
- Requirements and failure modes are linked – and are represented by lab tests published in EN 50342-6:2015
- DCA improvements possible, increased real-life performance proven in Start-Stop road test (improvement factor of 2.5)
- New requirements: reliability and battery diagnostics
- Lead-acid is well suited to fulfil future vehicle requirements
- Next step of performance: dual battery system lead-acid / Li-ion

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Thank you for your attention!

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