Automotive Battery Technology Trends Review

RICARDO

Study commissioners:

European Automobile Manufacturers Association – ACEA
Japan Automobile Manufacturers Association Inc. – JAMA
Korea Automobile Manufacturers Association – KAMA
Association of European Automotive and Industrial Battery Manufacturers – EUROBAT
International Lead Association – ILA

Authors:

Charlie Allen / Ricardo Strategic Consulting (RSC)
Carl Telford / Ricardo Strategic Consulting (RSC)

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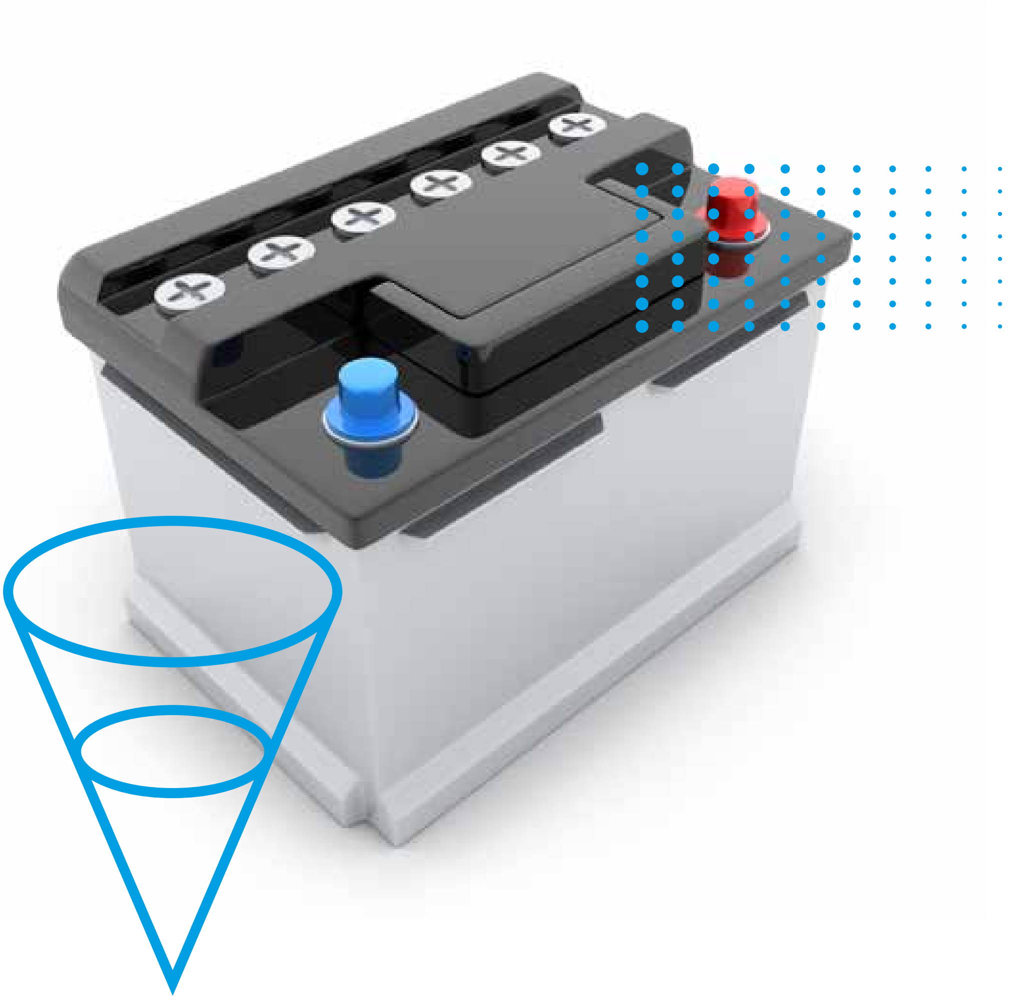

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EXECUTIVE SUMMARY

Automotive Battery Technology Trends Review

The independent consulting firm Ricardo Strategic Consulting (RSC) was requested to assess the short- and medium-term technical requirements for low-voltage batteries utilised in vehicles. The review concluded that 12V batteries will remain a critical technology during the transition to a lower carbon mobility model and that:

"Lead batteries are the only technology capable of fulfilling all the major 12V requirements, from stop-start functions, to reliable auxiliary batteries. No other alternative technology can achieve this functionality at this time"

Introduction

The automotive industry not only faces accelerating pressure to reduce vehicles' environmental impact, but is also experiencing rapid technological change, in the shape of **electrification, connectivity, autonomy, and new business models**. As we enter the 2020s, effective deployment of a suite of suitable battery technologies to support these changes, is paramount.

This study assesses the **short- and medium-term technical requirements for low-voltage batteries**; it provides an independent consideration of the relative merits of key commercial and emerging battery technologies. Using expert workshops, interviews with technical specialists, as well as RSC expertise and experience, the RSC team has conducted an independent review of battery technologies for these low-voltage automotive applications.

The review focused on the consideration of the following interrelated questions:

- **Vehicle mix**: What light-duty vehicles and vehicle categories will be most important in the European light-duty vehicle parc from today through 2030?
- **Battery technology:** What battery technologies are available today, and will emerge commercially, through 2030? What are the relative merits of each battery technology?
- **Technical requirements**: Where are batteries located in existing vehicles; what future requirements will need to be met?

Key Findings

Vehicle mix

The future European parc will comprise a complex suite of partially and fully electrified products, including micro-hybrids, mild hybrids, full-hybrids and plug-in hybrids, and battery electric vehicles (figure 1). Through 2030, almost all light-duty vehicles are likely to feature a 12V board net, and thus require either a 12V Starting Lighting Ignition (SLI) battery, or a 12V auxiliary battery.

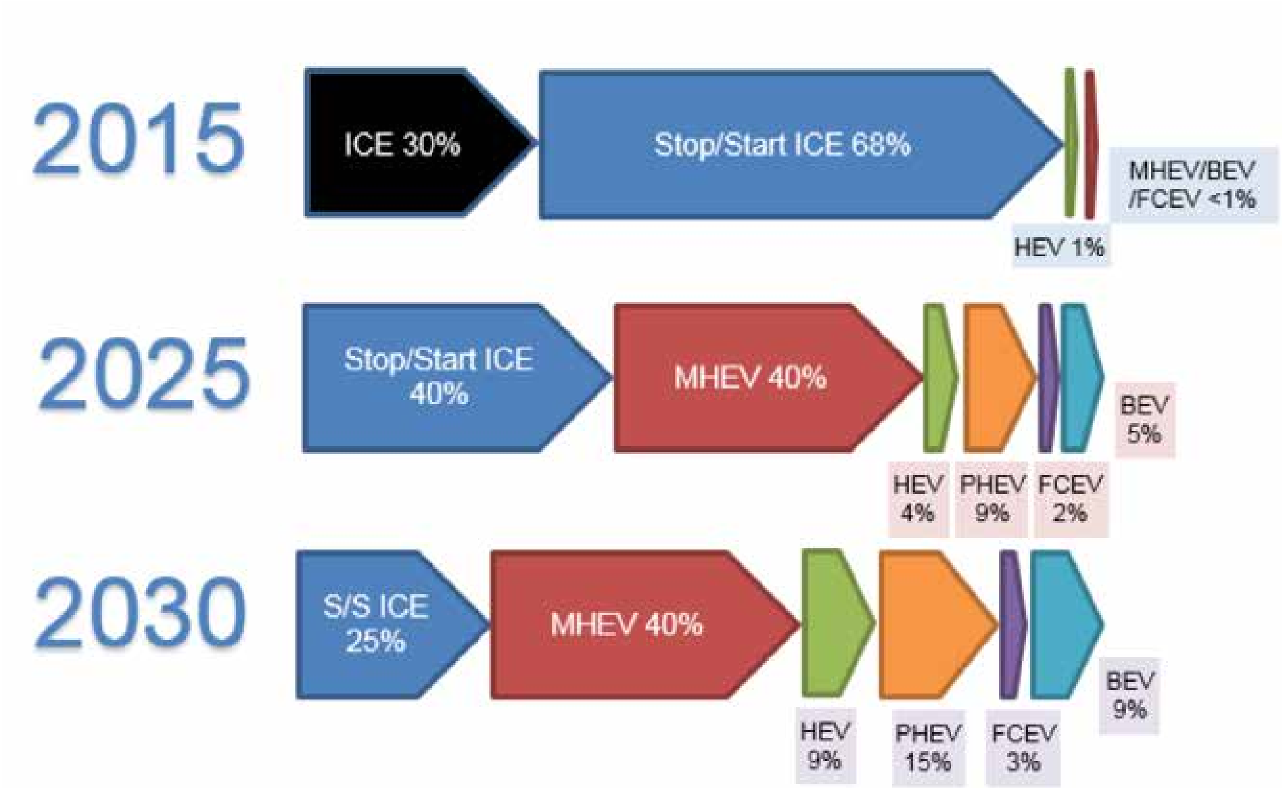


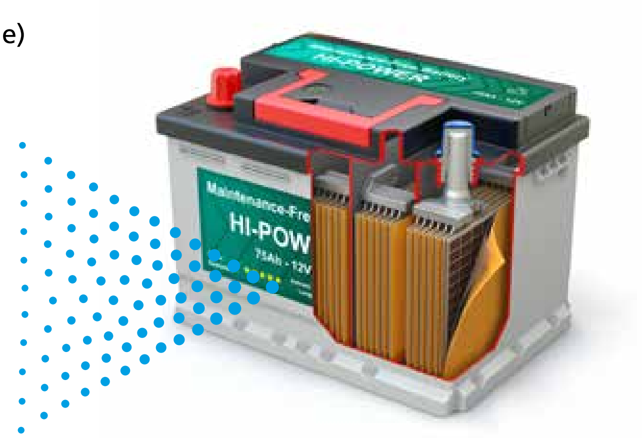
Figure 1 European Light Duty Powertrain Mix for 2015, 2025 and 2030

***ICE**:Internal Combustion Engine / **MHEV**: Mild Hybrid Electrical Vehicle / **BEV**: Battery Electric Vehicle / **FCEV**: Fuel Cell Electric Vehicle / **HEV**: Hybrid Electric Vehicle / **PHEV**: Plug in Hybrid Electric Vehicle*

Battery Technology:

The study focused on the relative merits of battery technologies commercially significant in 12V applications through 2030. To assess these batteries, we considered their attributes across a number of categories:

- Performance (e.g. cold cranking, dynamic charge acceptance (DCA))
- Durability (e.g. high-temperature durability)
- Battery safety
- Functional safety (safety of a component in a vehicle)
- Recycling and sustainability
- Cost and commercial maturity.



	Performance	Attribute (unit)		Ref.	Battery Technology				Superior Technology?
					EFB	AGM	LFP	LTO	
A. Technology Capability	What are the maximum capabilities for each battery chemistry? (important factors in **bold**)	Battery voltage	(V)	1,2,3	12	12	13.2	13	n.a.
		Nominal capacity	(Ah)	1,2,3	70	70	60	-	n.a.
		Cold Cranking Amps (CCA) at -29°C	(% of 700A)	5	75	75	75	-	Equal
		CCA at -18°C	(A)	5	760	760	900	-	Equal
		Max Battery Temperature possible (NOTE Typical max = 60°C; some standards specify 75°C)	(°C use)	1,2,3	70	70	60	-	Lead
			(°C storage)	1,2,3	70	70	60	-	
		DCA(dynamic charge acceptance) Recuperation (max)	(A)	5	140	140	200	-	Li-Ion
		DCA Recuperation (min)	(A)	5	90	90	200	-	
		Energy throughput / Micro-hybrid shallow cycling	(capacity turns)	5,6	800	1200	1200	1200	Equal
		Weight (without crash protection)	(kg min)	1,2,3	18	19	10	-	Li-Ion
			(kg max)	1,2,3	20	21	11	-	
		Weight of additional structures (e.g. crash protection)	(kg)	5	0	0	3	3	Lead
		Unit cost	(€)	5	100	150	500	-	Lead
		Lifetime	(years min)	5,6	5	5	8	-	Li-Ion
			(years max)	5,6	7	7	10	-	

(EFB: Enhanced Flooded Lead Battery, AGM: Absorbent Glass Mat Lead Battery, LFP: Lithium Iron Phosphate Battery, LTO: Lithium Titanate Oxide Battery)
Figure 2 Comparison of key 12V SLI battery capabilities

Current commercial 12V battery technology relies heavily on lead-based chemistries. Globally, over **400 million 12V lead-based batteries** are produced every year to supply OEMs and aftermarket light-duty vehicle applications. **In Europe, around 60 million batteries** are required each year.

Enhanced Flooded Batteries (EFB) and Absorbent Glass Mat (AGM) batteries provide significant improvements compared to conventional lead-based flooded batteries, in charge acceptance and cyclic durability, and have been deployed for micro-hybrid applications.

Lead-based batteries, especially EFB and AGM batteries, are **extremely stable and durable** in comparison to competing technologies; failure modes, and safety of lead batteries, are well understood by the battery supply chain.

Lead-based batteries for SLI applications are covered by established **European and international standards** including battery testing procedures and service requirements.

Li-ion batteries being commercialised for 12V applications have high energy density, high cycle life, and high calendar life but currently have higher self-discharge rates compared to lead-based batteries. Standardisation is still in progress.

The low-temperature performance and durability of Li-ion batteries has improved significantly in the past few years; Li-ion battery manufacturers now report parity with lead batteries in terms of cold cranking (albeit only within standard industry limits). However, use of new electrode materials to ensure lithium batteries can meet cold cranking requirements, has resulted in a trade-offs in high-temperature performance and safety. Moreover, the charging performance of the batteries at low temperatures also requires further investigation.

Three main failure modes exist for Li-ion batteries, initiated by mechanical damage, temperature extremes, or incorrect charging. The battery management system must prevent failures. The performance of Li-ion batteries can be reduced significantly by exposure to elevated temperatures; degradation mechanisms are still under investigation.

Recycling processes for low voltage Li-ion batteries are relatively complex and immature; development is expected through 2030 but will never be as efficient as the closed loop recycling processes seen for lead. Moreover, 12v Li-ion batteries are typically based upon lithium iron phosphate chemistry that contains no economically valuable metals and thus have very low incentive for recycling.

We are likely to see most development in alternative battery technologies for high voltage (>75V) traction applications. As a consequence of this focus, future battery technologies are **unlikely to be deployed for <75V applications before the late 2020s**

Technical Requirements:

RSC grouped vehicles likely to be deployed through 2030 into three major categories: Low electrification (ICE-only traction propulsion), medium electrification (ICE and electric machine traction) and high electrification (electric machine traction). Figure 3 highlights the main existing and possible powertrain solutions.

Powertrain Type	Indicative Role of ICE	Electrification Category	Battery			Board net			Current non-traction solution	Current traction solution
			SLI	Aux	Traction	12V	48V	HV		
Conventional ICE		Low Electrification	Default			Default			12V Lead	n/a
S/S and Micro Hybrid			Default	Possible		Default			12V Lead	
Mild Hybrid		Intermediate or Medium Electrification	Possible	Possible	Default	Default	Default	Possible	12V Lead	12V or 48V Li-ion (small size)
Full Hybrid			Possible	Possible	Default	Default	Possible	Default	12V Lead	HV Li-Ion (medium size)
Plug-in Hybrid			Possible	Possible	Default	Default	Possible	Default	12V Lead	HV Li-Ion (medium or large size)
Full electric	n/a	High or Full Electrification		Default	Default	Default	Possible	Default	12V Lead	HV Li-Ion (large size)
FCEV				Default	Default	Default	Possible	Default	12V Lead	HV Li-Ion (medium size)

Default
Possible

Figure 3 Categories of light-duty vehicle powertrain solutions featured in this report
(Source: project workshops & interviews)

Our detailed analysis found that:

> **For SLI applications, 12V batteries will need to continue to enable stop/start operations, support critical safety applications, and support ADAS and autonomy deployment.**

> Autonomy and connectivity will require 'always-on' functionality; batteries must not only meet rising power consumption demands, but also be 100% dependable. **Battery health will become a critical attribute**.

> **For auxiliary applications, redundancy, 100% reliability, and durability are primary requirements** (cranking is not required); a 12V board net will power warning lights, airbags, and door locking/unlocking.

> Auxiliary batteries must enable **'always on' functionality** for vehicles; increasingly, 12V batteries must support operations while a vehicle is unoccupied, and in some cases when either the vehicle's ICE or HV system is disconnected.

> Battery manufacturers and OEMs must ensure that batteries are located where **ambient temperatures will not exceed operating requirements**, and in a location that is unlikely to be severely impacted during a crash.

- For all vehicle types, 12V batteries must be suitably compatible with vehicle platforms and their electrical architectures.

- Beyond 12V batteries, we see a strong demand within low-voltage (<75V) batteries for 48V batteries; our assumption is that the needs of this application will be wholly fulfilled by Li-ion technology. Although 48V lead batteries have been developed, we do not foresee any significant commercial demand for these batteries. One potential consequence of 48V deployment is a reduction in size of any complementary 12V battery (because the workload is shared).

Although lead and lithium battery technologies each have areas of technical superiority, a consideration of battery requirements from a vehicle perspective is also necessary. Battery application maps were created to summarise technical performance of different battery chemistries of both lead-based and Li-ion 12V batteries whilst accounting for the vehicle requirements and wider industry-level requirements.

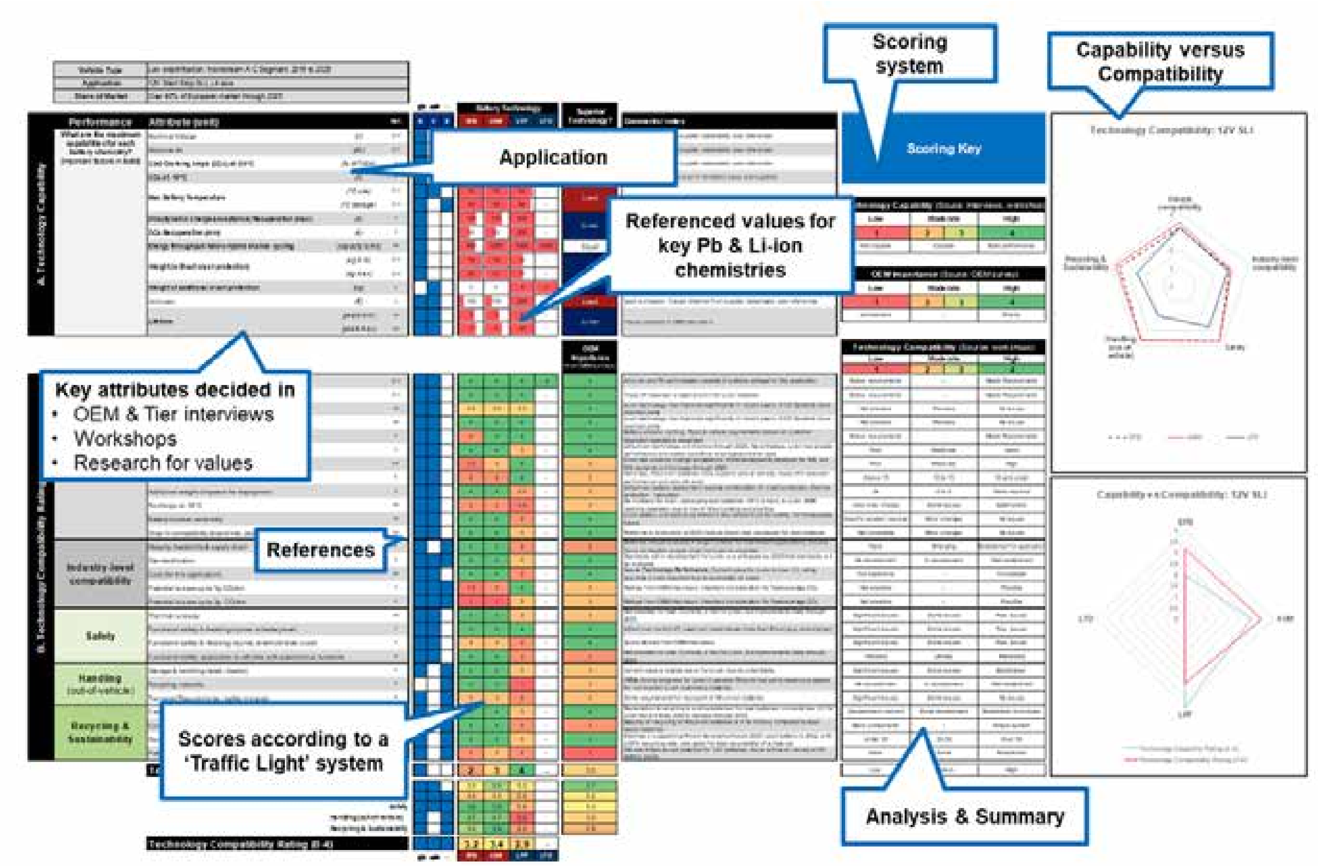


Figure 6 Snapshot of Battery Application Map

The battery application maps suggest that from a **technology capability, or performance, perspective**:

- Li-ion batteries (LFP) have several technical advantages in comparison to lead-based batteries, in particular shallow-cycling capabilities, charge acceptance, and low weight.
- However, lead-based batteries are better in terms of high-temperature usage, and lower cost.

from a **technology compatibility perspective**:

- **Lead-based batteries** are established, and fulfil all critical industry requirements; **Li-ion batteries** do yet not fulfil all these requirements.
- **Lead-based batteries** offer OEMs superior safety, handling, technology maturity, standardisation, lower cost, and better recycling rates.
- **Lead-based batteries** are easier for OEMs to position in a vehicle; they can be located anywhere in a vehicle and are compatible with existing platforms and board nets.
- **Li-ion batteries** offer OEMs superior charge acceptance, and theoretically have the potential to increase vehicle and fleet CO_2 savings by 3%. Although lead-based batteries do not offer such an opportunity, current vehicle architectures do not allow this saving to be realised in practice and hence in-vehicle the batteries have equivalent performance..

From an overall perspective:

- **12v Li-ion batteries** still need to improve in several key areas — in particular, high temperature sensitivity, safety, functional safety, cost, and recycling — before all industry requirements are met satisfactorily.
- For 12V SLI applications, **Li-ion batteries** offer OEMs some performance advantages, but RSC believes that **lead-based** AGM batteries not only offer sufficient performance, but also offer superior vehicle- and industry-level compatibility.
- For 12V auxiliary applications, **Li-ion batteries** offer OEMs a lower weight solution. However, given the critical nature of these batteries' functions, we believe that lead-based batteries offer OEMs some important functional-safety advantages.

Comparison of performance attributes across battery types, SLI & Aux applications (2019 to 2025)		
Lead advantages	**Lithium advantages**	**No clear advantage for either technology**
Low unit cost	*Long service life*	*Cold cranking (general)*
Higher max use temperature	*High dynamic charge acceptance*	*Energy throughput*
Recovery from deep discharge	*Low weight*	*Nominal capacity*

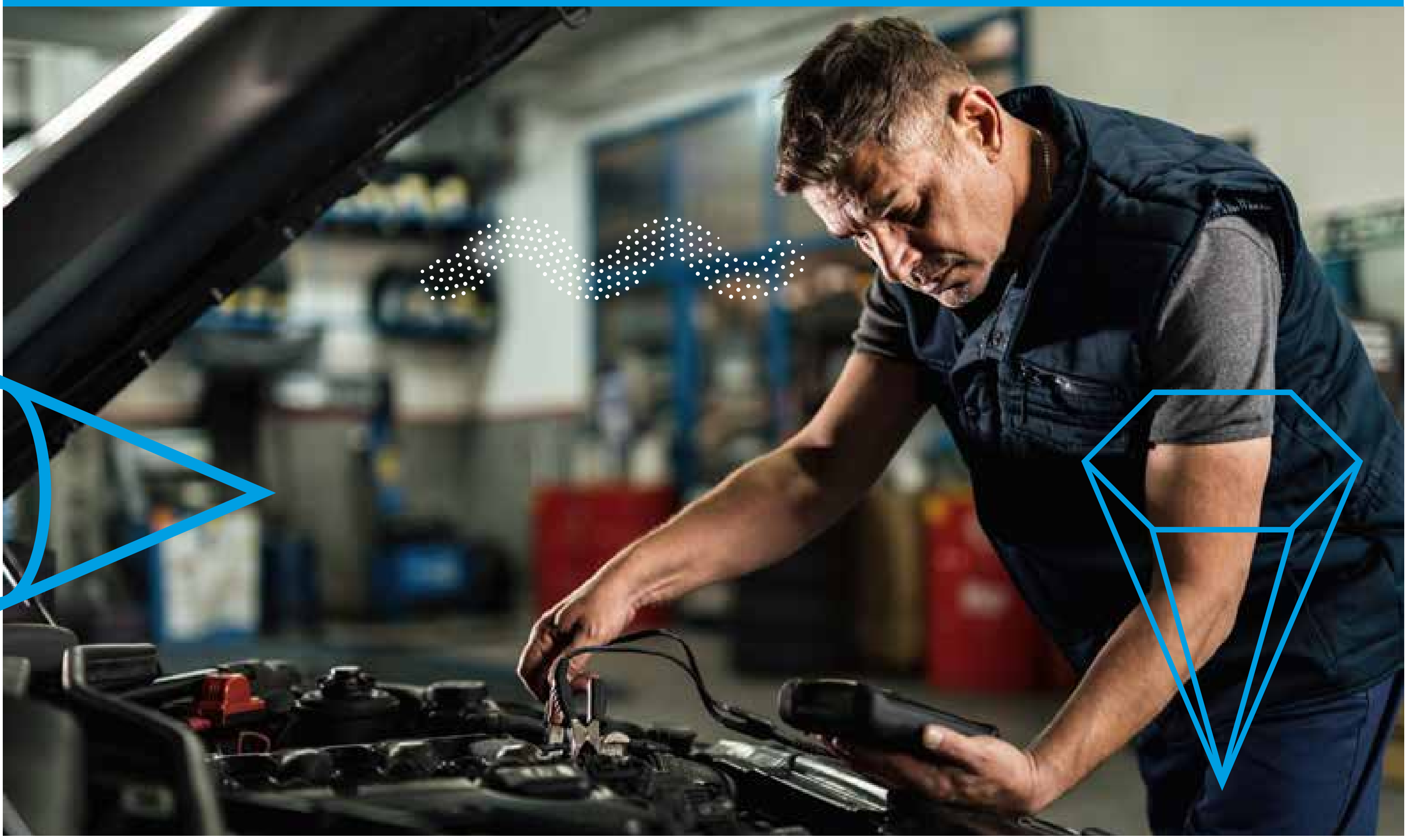
Comparison of technology compatibility across battery types, SLI & Aux applications (2019 to 2025)		
Lead advantages	**Lithium advantages**	**No clear advantage for either technology**
Industry-level compatibility	*Some orientation flexibility*	*Vehicle compatibility*
Location flexibility		
Safety		
Handling (out of vehicle)		
Recycling & sustainability		

Breakdown of attributes considered in Technology Compatibility rating		Advantage?
Vehicle compatibility	Voltage	-
	Cold cranking	-
	Ah	-
	High temperature compatibility	Lead
	Charge acceptance	Lithium
	Weight at standard size & rating	Lithium
	Additional weight of system needed for deployment	-
	Recharge at -18°C	-
	Battery location sensitivity (e.g. under the hood, in trunk, etc)	Lead
	Drop-in compatibility (board net), popular platforms to 2025	Lead
Industry-level compatibility	Maturity: Availability & supply chain	Lead
	Standardisation	Lead
	Potential to reduce CO2 emissions (SLI only)	Lithium
	Cost	Lead
Safety	Thermal runaway	Lead
	Functional safety A: Avoiding injuries at battery level	-
	Functional safety B: Avoiding injuries at vehicle level; crash	Lead
	Functional safety; application to vehicles with autonomous functions	-
Handling (out-of-vehicle)	Storage & handling (retail / dealer)	Lead
	Recycling networks	Lead
	Transport Requirements / safety in transit	Lead
Recycling & Sustainability	Ease of recycling	Lead
	Complexity of battery / composition	Lead
	Recycling rate (%)	Lead
	Potential for second life / use	Lithium

Sources: Ricardo analysis, projetc workshops, OEM interviews, OEM surveys.
Figure 7 Summary of battery application map findings

CONCLUSIONS

1. The future European parc will comprise a **complex suite of partially and fully electrified products**, including micro-hybrids, mild hybrids, full-hybrids and plug-in hybrids, and battery electric vehicles.
2. Use of **12V batteries in vehicles will remain critical through 2030**.
3. **12V auxiliary battery applications** will grow in importance in this time period.
4. Beyond 12V batteries, there will be a strong demand within low-voltage 48V batteries; this application will be wholly fulfilled by **Li-ion** technology.
5. The adoption of **autonomous driving** features will necessitate the use of at least **two battery chemistrie**s per vehicle.
6. **Lead batteries are the only** technology that currently meet all OEM requirements for **12V applications**.
7. **Li-ion** technologies have made significant improvements in terms of cold-cranking and are now comparable to lead batteries. However, further research is required into Li-ion batteries in terms of **high-temperature durability and safety**.
8. Although **Li-ion** technologies have several performance advantages applicable to 12V SLI applications they remain costly, are not commercially mature enough and **do not currently meet ALL** critical OEM requirements in terms of vehicle compatibility, safety, high temperature sensitivity and recyclability.
9. Due to high temperature sensitivity and board net compatibility, **Li-ion** batteries should **not** be used as 'drop- in replacements' for lead SLI batteries.
10. From a global perspective, **use of lead-based batteries in vehicles will continue for at least a decade**.



The European Automobile Manufacturers' Association (ACEA) represents the 16 major Europe-based car, van, truck and bus makers. BMW Group, CNH Industrial, DAF Trucks, Daimler, Ferrari, Fiat Chrysler Automobiles, Ford of Europe, Honda Motor Europe, Hyundai Motor Europe, Jaguar Land Rover, PSA Group, Renault Group, Toyota Motor Europe, Volkswagen Group, Volvo Cars, and Volvo Group.

- ACEA works with a variety of institutional, non-governmental, research and civil society partners - as well as with a number of industry associations with related interests.
- ACEA has permanent cooperation with the European Council for Automotive R&D (EUCAR), which is the industry body for collaborative research and development.
- ACEA has close relations with the 29 national automobile manufacturers' associations in Europe, and maintains a dialogue on international issues with automobile associations around the world. **www.acea.be**

EUROBAT is the association for the European manufacturers automotive, industrial and energy storage batteries. EUROBAT has more than 50 members from across the continent comprising more than 90% of the automotive and industrial battery industry in Europe. The members and staff work with all stakeholders, such as battery users, governmental organisations and media, to develop new battery solutions in areas of hybrid and electro-mobility as well as grid flexibility and renewable energy storage. **www.eurobat.org**

ILA is the only global trade association dedicated to representing lead producers and companies with a direct interest in lead and its use. The Association's team of technical, regulatory, environment and health experts work with stakeholders to promote the benefits of lead and the safe and responsible use of the metal in manufacturing and other applications. **https://www.ila-lead.org/**

Japan Automobile Manufacturers Association, Inc. (JAMA) is a non-profit industry association which comprises Japan's fourteen manufacturers of passenger cars, trucks, buses and motorcycles. JAMA works to support the sound development of Japan's automobile industry and to contribute to social and economic welfare. **http://www.jama-english.jp/**

The Korea Automobile Manufacturers Association (KAMA) is a non-profit organization representing the interests of automakers in Korea. We are promoting the sound growth of the automobile industry and also the development of the national economy. **http://www.kama.or.kr/**