



# *TPPL BATTERY TECHNOLOGY: Past & Future*

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Thin Plate Pure Lead (TPPL) is a well-established battery technology that is employed in a wide array of different application scenarios. As the name implies, it utilises electrodes that are of thinner construction than those employed in conventional designs (and of higher purity too). Among the many industry sectors that benefit from it are data centres, telecommunication infrastructure, public transportation, materials handling and logistics, as well as both military and commercial vehicles.

So what exactly is TPPL, and how does it fit in with the ongoing evolution of the lead-acid battery? In the following whitepaper we will look to answer these questions. Its development over the decades will be charted - going from its initial inception back at the start of the 1970s, right through to the latest innovations in this area. The advantages that can be derived from use of this technology will also be covered, and several case study examples given.

# ORIGINS OF TPPL

The early engineering work that led to TPPL took place at Gates® Inc. almost 50 years ago, where experimentation was done on thin plate technology by utilising patented gas recombination techniques. Thanks to their thinner plates, TPPL batteries could provide higher current peaks and were also quicker to recharge than competing batteries. These were both to prove very appealing attributes.

In 1973, the company launched Cyclon® - which was a spiral wound TPPL solution developed for high-energy, low maintenance applications. This is still used in some medical apparatus today, as well as featuring in the trackside equipment found on rail networks. Gates® launched its SBS product in 1983, which was a flat plate TPPL design. Through acquisition, EnerSys® would be responsible for driving forward TPPL-based batteries' technological progression.



Fig.1: Example of a Cyclon® battery

Along with Cyclon®, Gates® Inc. commenced to produce cell based Absorbent Glass Mat (AGM) technology. which is often referred to as Valve Regulated Lead Acid (VRLA). This technology, which EnerSys® also inherited, would allow products to be manufactured that were not flooded with electrolyte and that did not require water topping up. AGM relied on effective utilisation of the oxygen recombination.

Figure 2 explains the basic principles of AGM operation. In a conventional flooded battery (as shown on the left of this schematic) oxygen gas is generated at the positive electrode and, conversely hydrogen is generated at the negative electrode, leading to loss of water. The release of the gas and loss of water will mean that the battery must be topped up with additional water periodically. AGM (which is shown on the left of this schematic) works differently. The highly absorbent glass structure used here is slightly under-saturated so there are voids present. Thanks to these voids it is possible for generated oxygen to travel to the negative electrode. Over time AGM technology has been adopted by most lead-acid battery manufacturers, supplanting the flooded cell arrangement. EnerSys® has now enhanced this mature technology and leveraged it as the basis for its industry-leading TPPL products.

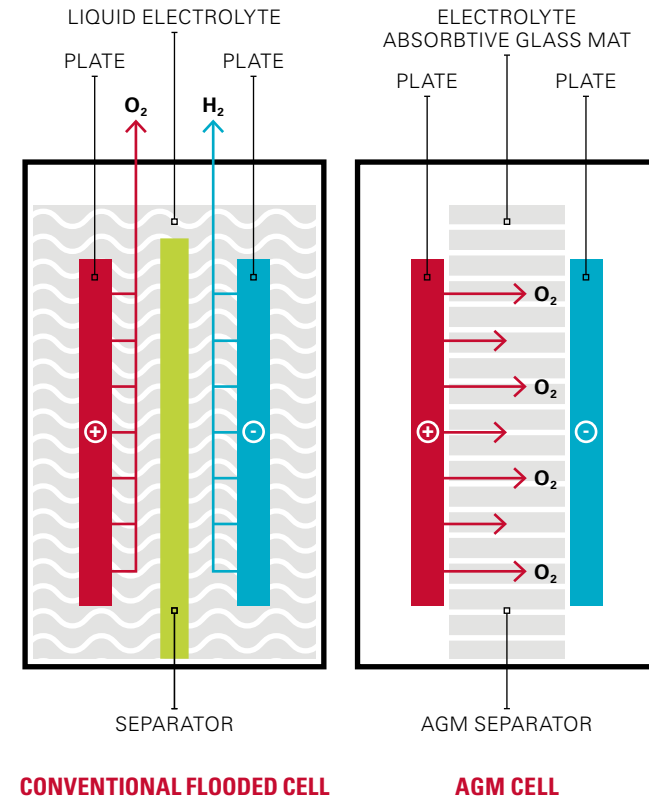
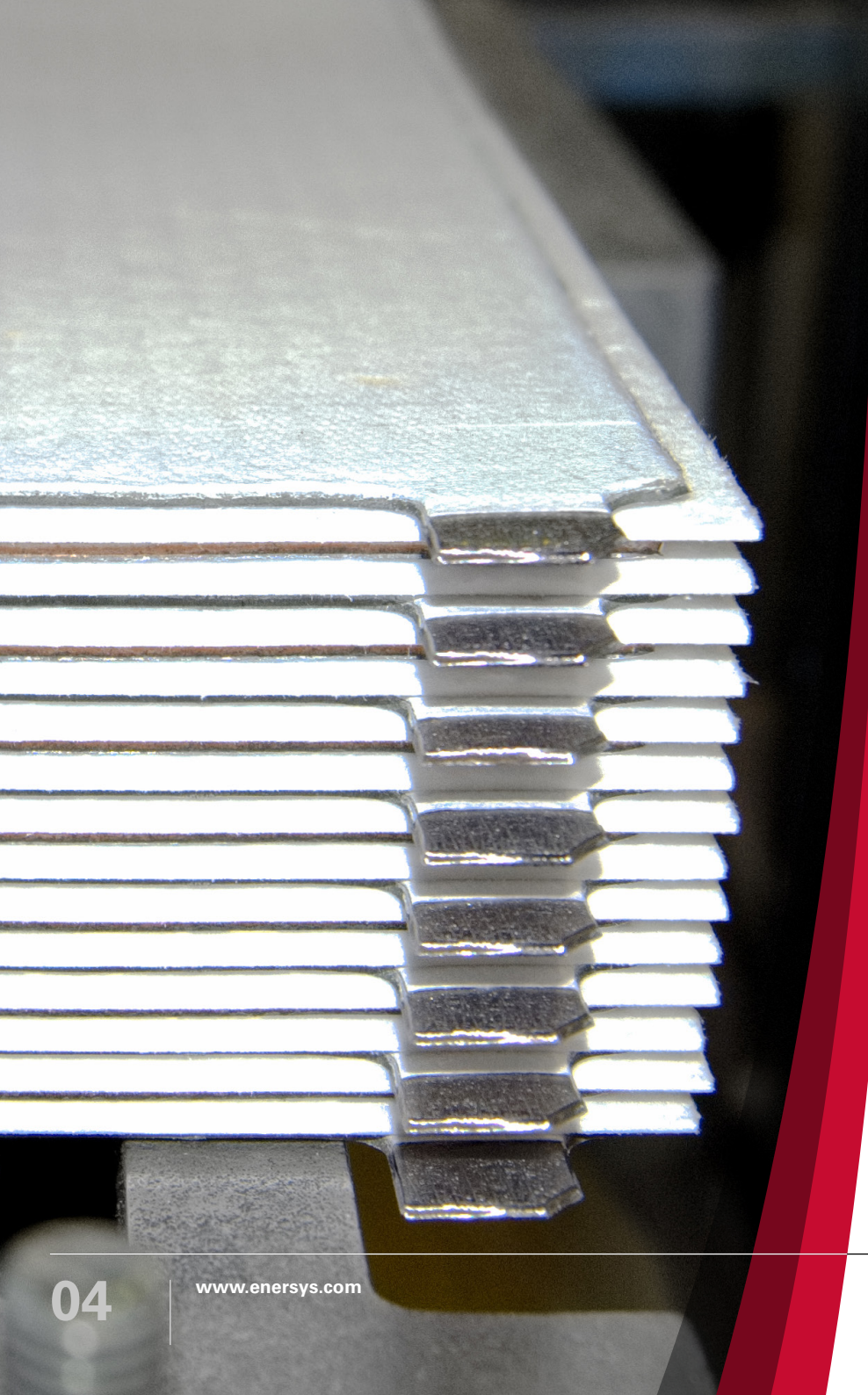


Fig.2: Schematic illustrating AGM operation



Early successes for TPPL would be seen within the avionics and defence sectors, but it was the telecom industry that would be the impetus behind the largest proportion of shipments for a long period of time - its high cyclic capabilities proving very attractive. In 2007, the SBS EON product range was launched. This was primarily targeted at off-grid telecom hybrid sites, where batteries would be cycled daily and sometimes multiple times within a day. Enabling faster charging, XFC products were subsequently released to attend to the motive power market (for materials handling and warehousing purposes).

In 2013, both the SBS EON and XFC product ranges were extended to provide units with greater capacity. Three years later a program was embarked upon to develop batteries to address a wider range of materials handling applications. These were branded as NexSys®. Pivotal to these products was a sophisticated new algorithm that allowed to move from a fast charge to a normal charging rate along with an optimised life cycle. Following on from this the range would be expanded to larger cells of up to 140Ah. By this time TPPL represented over 10% of the entire EnerSys® battery portfolio and this percentage was set to rise still further.

Development of carbon-enhanced TPPL would be another important milestone, enabling hybrid (multiple power source, without grid power) telecom power applications to be attended to. It meant that battery life could be increased by 50% compared with regular TPPL batteries. The first carbon-enhanced TPPL batteries were brought onto the market in 2018, for the telecom sector. Versions for motive power applications have been released in more recent times. Continued engineering advances here underlines the fact that, even with growing interest in lithium-ion (Li-Ion), there is still going to be an undoubted need for lead-acid batteries based on TPPL in the future.

## A BRIEF SUMMARY OF KEY TPPL FEATURES

Before going into greater detail, it will be worth highlighting the reasons why TPPL has seen such widespread market acceptance. TPPL plates have a thickness of a third to a quarter of standard batteries', so (as already discussed) more plates can be accommodated. This provides a large reactive surface area and low internal resistance, with power densities hence boosted. Consequently, TPPL batteries can be recharged within a short period of time and they can deliver high current peaks, without any voltage drop.

These batteries are maintenance-free, with no water topping-up required (due to AGM). In addition, their gas emissions are extremely low. They have a long cycle life, especially when subject to repeated micro cycles of discharging followed by partial opportunity charging. Low self-discharge rates allow battery storage for extended periods. TPPL also facilitates very high cell pack compression, which provides unsurpassed vibration resistance, as well as enhancing cyclic capability for transportation applications.

# FACTORS AFFECTING THE OPERATION & LONGEVITY OF LEAD-ACID BATTERIES

To appreciate the critical nature of lead purity in TPPL products, it is necessary to gain an understanding of some fundamental end of life mechanisms and performance characteristics generally associated with lead-acid batteries, and how lead purity and plate thickness affect them.

## 1. Extended high rate run times and long life

The positive grid of a lead-acid battery is the lead framework, which supports the battery's Positive Active Material (PAM). Together, the grid and PAM form an electrode, which is often referred to as a plate. Additionally, the grid is an electrical conductor which allows current flow - originating from reactions in the active material, through and out of the plates. However, over the battery's lifetime the lead within the grid will tend to corrode. This corrosion arises from metallic lead gradually converting to lead oxide.

Positive grid corrosion is always present in a lead-acid battery because the positive grid is operating in a sulfuric acid environment at a voltage in which it is thermodynamically favoured to oxidise. This corrosion is ultimately destructive to the battery in two ways. Firstly, as the grid corrodes it will lose its conductivity. This will make it less effective at allowing current flow. Secondly, since the corrosion product (which is an oxide of lead) is less dense than the original metallic lead, the grid volume will increase over time. As lead along the surface of the grid, and in the grain boundaries of the lead, are converted to lead oxides, stress is created on the remaining metallic lead, causing grid growth. This growth can cause the PAM to lose electrical contact with the grid. Both these dynamics can reduce the conductivity and performance of the battery, and will eventually result in battery failure.

This grid corrosion occurs in all lead-acid batteries, but at a rate controlled by several factors. Some, such as float voltage and temperature, relate to the specific application and operation. However, lead purity also impacts the rate of corrosion. High purity lead has a lower corrosion rate than lead with alloys (especially alloys such as calcium or antimony, which are often used in battery grids). Calcium is added to lead to increase the grid's strength and to make the grid structure easier to handle during processing. However, not only is the corrosion rate higher for lead-calcium alloys, but the corrosion tends to follow the calcium-rich grain boundaries. This means that corrosion can relatively quickly extend through the thickness of the grid, thereby reducing grid integrity.



TPPL technology, which has a high purity lead construction, significantly delays these issues. Figure 3 shows a comparison of pure lead and lead calcium positive grids after accelerated life testing. Note that there is some loss of metallic lead from the TPPL grid, but it is homogeneous along the surface and maintains current carrying capacity. In contrast, the calcium grid shows a complete loss of integrity, reflecting the increased rate of corrosion.

Other lead-acid battery designs based on alloys such as calcium tend to use thicker grids, effectively providing sacrificial material to extend the battery life as the corrosion eats the grid away. Alternatively, they may have thin grids and accept the reduction in battery life that comes with this. Using thicker grids to extend the life of alloyed grids can be of value when grain boundaries are correctly managed, but it results in thicker plates. These do not discharge as efficiently as thinner ones because the active material at the plates' centres will only have limited access to the electrolyte. With the non-alloyed TPPL design, the use of thinner electrodes means that a greater number of electrodes can be fitted within the cell. More electrodes translates into more electrode surface area (or, critically, more reactive electrode surface area).

The higher reactive surface area results in better active material utilisation. As the discharge rate increases, the effectiveness of a thick electrode to utilise the active material at the centre of the plate drops significantly. From a user perspective, this means that with thin plate batteries, smaller units can be used to achieve the same run times, and as discharge rates increase so does TPPL's worth. The bottom line is that TPPL products can use thinner grids without shortening battery life, because corrosion rates are reduced. This results in thinner electrodes and thus higher capacity levels.

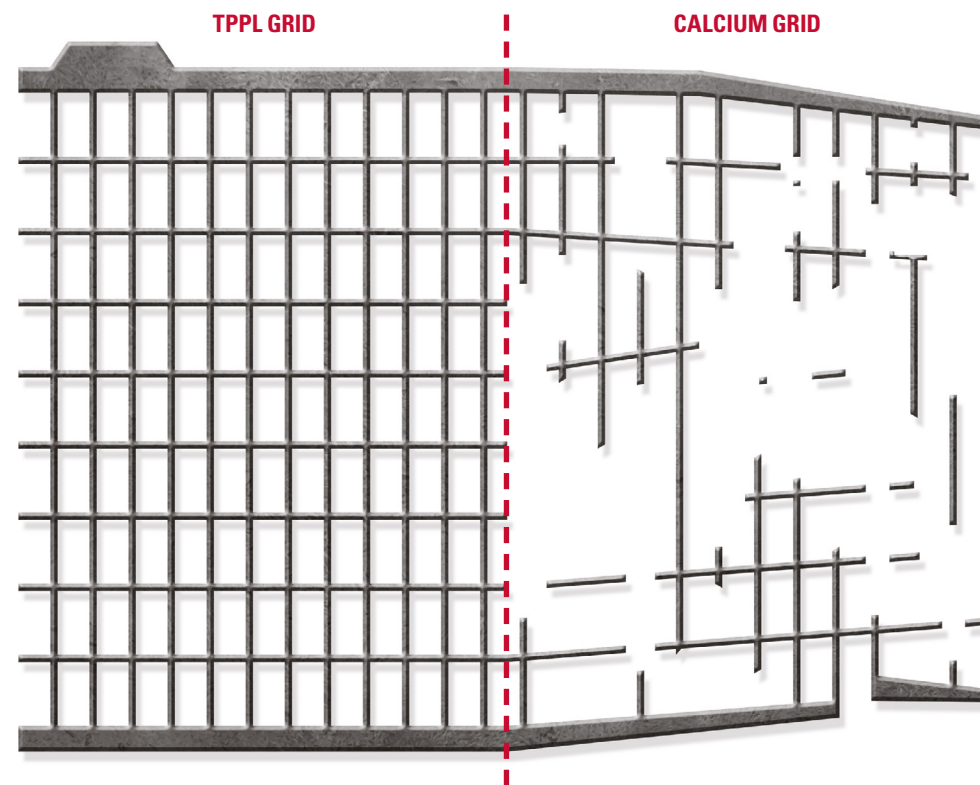


Fig.3: Example of positive grid corrosion

## 2. Rapid recharge capability

The factors that control active material utilisation efficiency during discharge also operate during recharge. With a larger reactive surface area available, TPPL offers the opportunity to reduce the recharge time of an Uninterruptible Power Supply (UPS) battery after a discharge event (provided that adequate recharge current is available). For example, TPPL products such as SBS and DataSafe® XE battery series do not require current limiting, provided that the charge voltage is appropriately regulated. The TPPL battery will readily accept 1C (100A for a 100Ahr battery) until it approaches 80 to 85% State of Charge (SoC) while maintaining a very high level of energy efficiency. That means the battery can achieve 80% SoC in around 50 minutes following a full depth discharge (and 100% SoC in less than 2.5 hours). Under the more typical condition of less than full discharge, the recharge times expected will be shorter.

## 3. Low gas generation and emission

A lead-acid battery electrolyte is a mixture of water and sulfuric acid. In the battery's internal environment, the water is thermodynamically favoured to decompose to oxygen and hydrogen. These gases will either exit the battery causing dry out (a failure mode) or react with other materials in the cell. If the reaction is with the grid, the result is grid corrosion and shortened life. Reaction with the active material causes self-discharge of the battery. However, the rate of decomposition is heavily influenced by other factors. Electrolysis tends to require a metallic surface for a catalyst and usually occurs very slowly on a pure lead surface. Conversely, metallic impurities tend to promote electrolysis. The suppression of electrolysis on TPPL's high lead purity surfaces significantly reduces gas generation rates, thus mitigating battery dry-out.

It should be noted though, that the rate of gas generation does not depend just on the plates' lead purity. This is also influenced by the purity of all the materials used in cell manufacturing (whereas grid corrosion is most directly impacted only by alloys within the grid metal). These other materials include the electrolyte and anything that comes into contact with it. With very high purity levels for all internal materials, TPPL exhibits extremely low gassing rates.

There is also a difference between gas generation and emission. Many AGM designs now offer high oxygen recombination efficiency, allowing low gas emission from the cell into the environment. Nevertheless, internal gas generation may still be high, leading to permanent positive grid corrosion. There may also be a recombination reaction which discharges the negative electrode - and this will manifest itself as increased float current. Additionally, the recombination reaction is exothermic, so it adds to the heat load that must be dissipated.

AGM-based batteries using TPPL technology offer a reduced rate of gas generation. This, in turn, lowers the operating temperatures and float currents, as well as curtailing positive grid corrosion. Furthermore, the lower self-discharge rate compared to conventional batteries mitigates issues associated with long supply lines to remote installations and eases inventory management.



# THE PERVASIVENESS OF TPPL ACROSS INDUSTRY SECTORS

TPPL technology has significant benefits in relation to many industries, but these benefits resonate differently with each of these. This next section will look at four key sectors - motive power for warehouse vehicles, truck and bus batteries, reserve power and finally armoured land vehicles.

## 1. Warehouse and factory vehicle motive power

Applications from food retailers through to car manufacturers depend on vehicles like forklifts, order pickers, pallet trucks, cleaning machines, automated or laser-guided vehicles and personnel carriers. Via these vehicles, quick, safe and efficient movement of stock and people can be assured.

It is increasingly commonplace for these vehicles to be electric - with batteries providing the motive power. To maximise productivity, it is desirable for forklifts to be continuously available. However, as recharging is often necessary after a shift, then either the vehicle must be taken out of service or the battery must be changed. If batteries could instead be partially fast charged during shifts, without needing to be transported to a dedicated charging room, productivity levels could be significantly improved.

Batteries that can be charged without gassing, and do not require water top-ups, save time, reduce acid spill and safeguard against explosion risks. They will reduce costs and also have less impact on the environment. Additionally, warehousing operations are keen to minimise energy usage relating to battery charging and the maintenance work needed due to overcharging<sup>1</sup>. Other factors that contribute to the overall Total Cost of Ownership (TCO) include the battery operating cycle lifetime, recharging requirements during storage, and reliability and degradation due to corrosion.

TPPL is able to meet all of these criteria. The batteries are sealed, with minimal gassing and no need for water top-ups. It can deliver a very high rate of discharge, and supports fast, efficient charging too. Because of this, operating in Partial State of Charge (PSoC) mode becomes possible. This is known as 'opportunity charging', because operators can use occasions such as shift changes or lunch breaks to charge at high currents for short time periods. Opportunity charging can be used to bring discharged batteries to a high SoC quickly. Weekend full recharge with cell equalisation will return the battery pack to full SoC, so it is ready for operation in subsequent weeks without any decline in the battery's cyclic capabilities.

TPPL also offers greatly improved power density figures. Energy consumption is reduced, as the batteries require lower overcharging. Up to 30% energy savings can be achieved by using batteries based on this technology, when accompanied by suitable chargers. Spare battery stockholding becomes easier, with less capital investment required. Unlike conventional batteries that must be recharged every six to twelve weeks during storage, TPPL-based units can be stored for up to two years at 20°C when starting from a fully charged condition.



## 2. Truck and bus batteries

The transportation industry encompasses a wide variety of large commercial vehicles used in many different ways, yet all experience a common problem. Although engine starting currents have not changed, evidence shows that ever-increasing electrical demands placed on vehicles (including running GPS devices, heaters, Wi-Fi on buses, etc.) is leading to markedly elevated battery failure rates.

With its high energy density, TPPL technology can provide considerably more usable capacity on demand, and a superior cycling life compared with competing products. This enables these batteries to cope with multiple engine starts, and meet the heavy demands associated with auxiliary power, on-board systems, hotel loading and other modern fleet vehicle requirements where conventional batteries have failed.

Additionally, TPPL batteries can be discharged to a lower SoC compared to conventional types, while still being able to provide a successful engine start. This means they can be run for far longer without requiring an engine start, resulting in fuel savings, reduced carbon footprint and NOx emissions. For starting, they can provide a cold crank amps (CCA) rating of up to 1500A.





### 3. Reserve power in data centres

Traditionally, data centre operators have specified UPS battery autonomies of typically 15 minutes, to allow power to be restored or generators to start up and phase-sync with the system. However, today generators can be switched on and brought up to speed much faster and loads can be transferred a lot quicker.

In this environment, the required autonomy time is shortened to just a few minutes. Such reductions create a desire to minimise battery size and weight, as well as curbing the capital costs in respect to mechanical and electrical infrastructure. At the same time, there is a trend toward reduced temperature management in battery charging rooms, because the electronics are more robust and there is potential for cost savings to be made. However, higher temperatures will reduce battery life - therefore, a trade-off between operating expenses and early battery replacement will be called for.

Battery requirements for the modern critical UPS market can be summarised accordingly:

- Optimisation around discharges shorter than five minutes so that battery size and weight may be lowered
- Reduced requirements for temperature control in the battery room
- Long life, even at increased operating temperature levels
- Ability to recharge quickly
- Minimal gas generation and emission (due to confined space, possibly with little airflow)
- Low self-discharge rates, for increased storage in event of delay in project deployment
- As low a TCO as possible

In response to these criteria, TPPL technology has been used to develop UPS-oriented batteries. These are smaller, lighter and more able to handle multiple hits. They consume less energy, while also providing longer life and higher reliability. Through these characteristics they can help keep long term expenses down - with lower initial purchasing cost, longer periods between replacements, reduced energy consumption, plus less frequent maintenance of the battery string. There is also more choice for where batteries can be located, along with only minimal temperature control requirements.

#### 4. Armoured land vehicles

Here there is the prospect that a lack of battery charge could impinge on these vehicles' ability to complete an assigned mission, or potentially put the lives of personnel in danger. Unfortunately, the likelihood of this happening is increasing, as the array of electrically powered systems fitted to such vehicles rapidly expands. This risk of power loss is exacerbated when vehicle commanders have to work without accurate information on how much power remains available for completing their mission.

In addition to strong performance levels, TPPL batteries have been enhanced for use in combat and tactical vehicles. Features that are incorporated into these units include integrated flame arresters, high shock resistance, superior cold-cranking capabilities and an operational temperature range spanning from -40°C to +80°C.



# CASE STUDIES

Here are a couple examples that describe where TPPL is proving of value to the EnerSys® global customer base.

## 1. Metro Cash & Carry France

Part of German trade and retail giant Metro AG, Metro Cash & Carry France has 93 wholesale centres in total. It wanted energy-saving technology to provide more truck autonomy, longer operational life, lower charging time and more flexibility at its sites. Gel batteries proved impractical because they are not able to charge in short break times - and as the warehouse has both day and night shifts, adequate time for a full recharge was not always available. However, TPPL-based NexSys® batteries offered the increased energy density and faster charging required. These maintenance-free batteries can be recharged at any time an opportunity arises, so energy reserves can be replenished. A specific charging profile allows a rapid recharge in less than four hours from 60% Depth of Discharge (DoD) back to 100% SoC. Furthermore, access to the Lifetech® and Life IQ™ modular chargers that accompany these units has yielded longer battery lives, with augmented performance and significant energy cost savings.

## 2. Daimler Mercedes-Benz Bremen

With its 37.74 acres of plant area, the Daimler Mercedes-Benz manufacturing operation in Bremen is the company's second-largest in Europe. When the building of a new production hall was recently completed, the company wanted to reduce the number of battery changes for its forklift fleet and close the charging rooms in favour of decentralised charging near the production line. This posed a challenge, however, as charging gases and acid aerosols could not be allowed to contaminate the vehicle production environment. Therefore, traditional flooded batteries would not be applicable. The company selected NexSys® TPPL batteries. The reasoning behind this was they offer fast charges times and have opportunity charging capabilities, as well as negating the need for battery changes - thereby delivering significant operational benefits, plus safety and lifetime cost savings compared with traditional flooded and gel-based battery alternatives. As these batteries are fully sealed, gas generation is minimised, and the formation of acid aerosols is wholly eliminated.

# LATEST DEVELOPMENTS

In recent times, EnerSys® has been working on energy storage solutions for hybrid applications. These involve powering off-grid telecom networks either only by diesel generators and batteries or via intricate arrangements of renewable energy sources (such as wind turbines or photovoltaic arrays).

The EnerSys® development program has involved adding advanced carbon compounds to the existing TPPL negative plate expander formulation. The result is a significant improvement in cyclic performance coupled with an ability to run at a controlled PSoC, where the battery is deliberately operated in a PSoC so as to minimise operating expenditure. The battery is periodically returned to a full SoC when predefined trigger points are reached. Another upshot of the carbon, is that the battery can be subjected to higher ambient temperatures.

Time spent on recharging and generator operation is reduced. The recharge strategy has been optimised for prolonged battery life - up to 1.5x that of a normal TPPL battery - and minimal TCO. Development of lead technologies will continue into the future, both for the established transportation and UPS segments and for emerging markets too. These include Energy Storage Systems (ESS), etc. There will also be a greater emphasis on system engineering and modular kit development in the years ahead. Figure 4 summarises the development roadmap for next generation lead-acid batteries.

## FUTURE DEVELOPMENT IN LEAD ACID BATTERIES

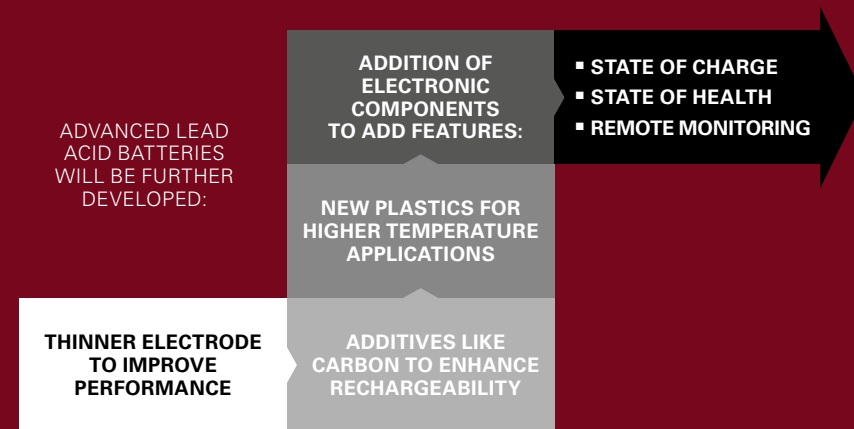


Fig.4: Roadmap for advanced lead-acid battery development



## CONCLUSION

This whitepaper has shown how TPPL can bring a plethora of benefits, and these are being seen across a whole host of different industries. Along with a reduction in ownership costs, this technology offers unmatched resilience and reliability. It also means that opportunity charging can be made use of. And this innovation won't stop - it is an ongoing story, with new developments planned for many years to come.

### Editor's Notes

<sup>1</sup> To ensure maximum performance, both in terms of battery capacity and expected life, correct charging is essential. Excessive charging will tend to corrode the positive spines into lead dioxide, weakening them physically and increasing their electrical resistance. If overcharging is at comparatively high rates, gassing will also be excessive. Overcharging will result in damage to the plates and high cell temperatures. All these factors reduce the capacity and shorten the life of the battery.



## About EnerSys®

EnerSys, the global leader in stored energy solutions for industrial applications, manufactures and distributes reserve power and motive power batteries, battery chargers, power equipment, battery accessories and outdoor equipment enclosure solutions to customers worldwide. Motive power batteries and chargers are utilized in electric forklift trucks and other commercial electric powered vehicles. Reserve power batteries are used in the telecommunication and utility industries, uninterruptible power supplies, and numerous applications requiring stored energy solutions including medical, aerospace and defense systems. With the recent Alpha acquisition, EnerSys provides highly integrated power solutions and services to broadband, telecom, renewable and industrial customers. Outdoor equipment enclosure products are utilized in the telecommunication, cable, utility, transportation industries and by government and defense customers. The company also provides aftermarket and customer support services to its customers in over 100 countries through its sales and manufacturing locations around the world.



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