Practical Report: Energy Supply for Industrial Trucks and AGVs in Industry and Logistics

What are the advantages of lithium-ion batteries for industrial applications and what charging concepts do they require?

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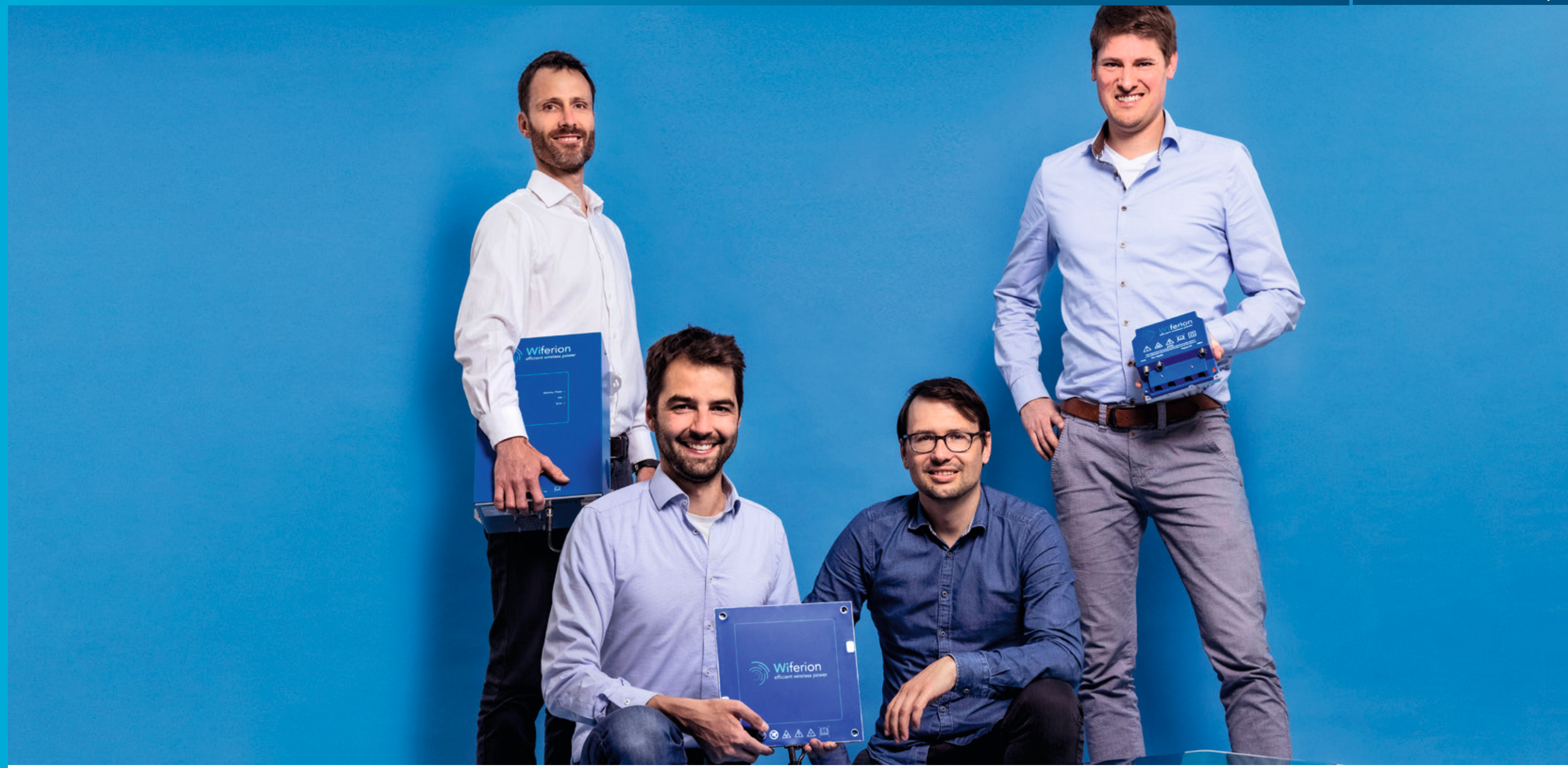
efficient wireless power

+49 (0) 7611542670
info@wiferion.com
www.wiferion.com
/wiferion

Content



Whether forklift trucks, automated guided vehicles (AGVs), autonomous mobile robots (AMRs) or the classic "ant" - modern industrial trucks in industry and logistics are now predominantly equipped with powerful lithium-ion batteries.

Lithium-ion technology offers significant advantages over lead-acid technology in terms of performance, durability, efficiency and handling. A real game changer is the batteries' ability to be charged intermediately. Vehicle batteries previously had to be fully discharged to avoid a memory effect whereas, lithium-ion batteries allow many partial charges at any given energy level.

The technology has many advantages - but only if charging is done with the right battery charging technology. This is because the selection of the optimum energy supply for the process is crucial to whether AGVs, AMRs and alike can develop their full potential.

This white paper gives you an overview of the battery technologies available, the advantages and disadvantages of the individual systems, and how you can use them to increase productivity.

Enjoy reading!

Johannes Mayer
Managing Director at Wiferion

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The Lithium-ion Battery

Lithium-ion (Li-ion) battery technology (Li-ion battery) continues to advance and is increasingly replacing lead-acid batteries. The reason: Compared to conventional lead-acid batteries that have been predominantly used up until now, these systems have clear advantages due to their chemical composition in terms of cycle stability, size, ca-pacity and, especially for mobile robots and AGVs, weight.

Advantages of Li-ion Batteries Compared to Lead-acid Batteries:

- Space-saving (three times more compact for the same power)
- Up to 50 times longer service life depending on cell technology
- Maintenance-free
- Constant charging voltage, independent of state of charge
- Up to 30 % higher energy efficiency during charging/discharging
- Opportunity charging possible and desirable
- No outgassing when reaching the end-of-charge voltage
- Overcharge and deep discharge safe due to intelligent BMS solutions
- Charging at least twice as fast
- Flexible charging stations, no more charging rooms necessary

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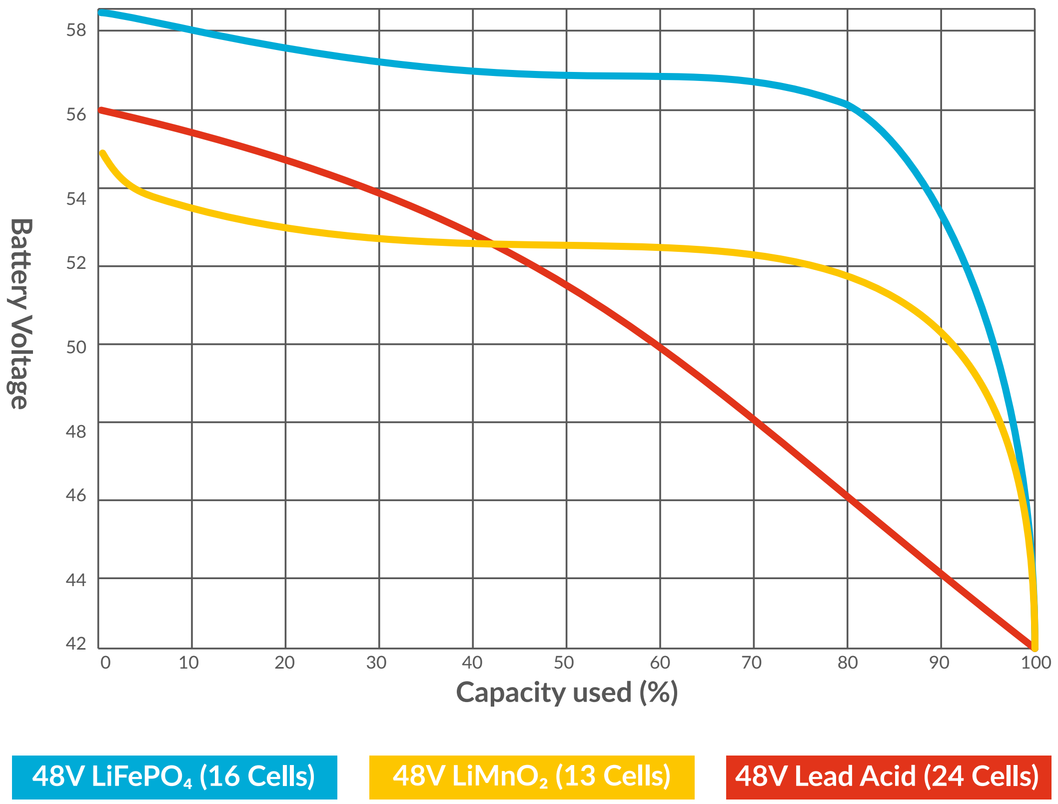
Acquisition and costs

Conventional lead-acid batteries still have an advantage in only one respect: acquisition costs. However, if you consider the above-mentioned advantages of Li-ion batteries (service life, maintenance, efficiency), it quickly becomes clear that the higher acquisition costs are amortized. Li-ion battery technology also scores points when it comes to safety. Compared with the conventional lead-acid battery, no extra charging space is required, as this technology does not involve any outgassing during charging and discharging. It enables acid-free operation and dispenses with environmentally harmful materials such as lead. In addition, lead-acid batteries can only be discharged about 30-50%. With Li-ion batteries, full use of the installed capacity is possible up to 90 %.

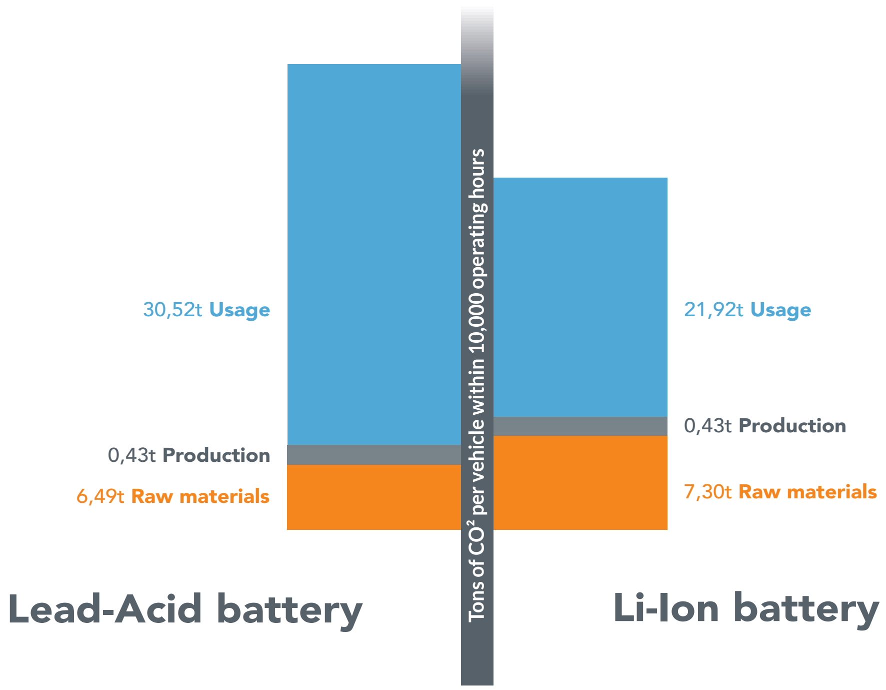
The graph below shows the discharge curves for lithium iron phosphate LiFePo4 batteries, lithium ion manganese oxide LiMnO2 battery, and lead acid (SLA) batteries. Note that LiFePO4 does not lose significant voltage until 90% of its capacity has been used.



Li-ion battery technology is also impressive in terms of sustainability and safety. Similar to the lead-acid battery, the energy storage systems can be recycled and the valuable materials such as cobalt, nickel and lithium can be repurposed. In addition, the li-ion battery produces up to 30% fewer CO2 emissions than a conventional lead-acid battery due to its higher energy efficiency and more constant voltage profile.

In addition, the lithium iron phosphate battery (LiFePO4 or LFP), for example, is one of the safest batteries, as it does not contain any cobalt, nickel, manganese or lead. It therefore contains no raw materials that are toxic to humans or the environment.

21% less CO_2 emissions



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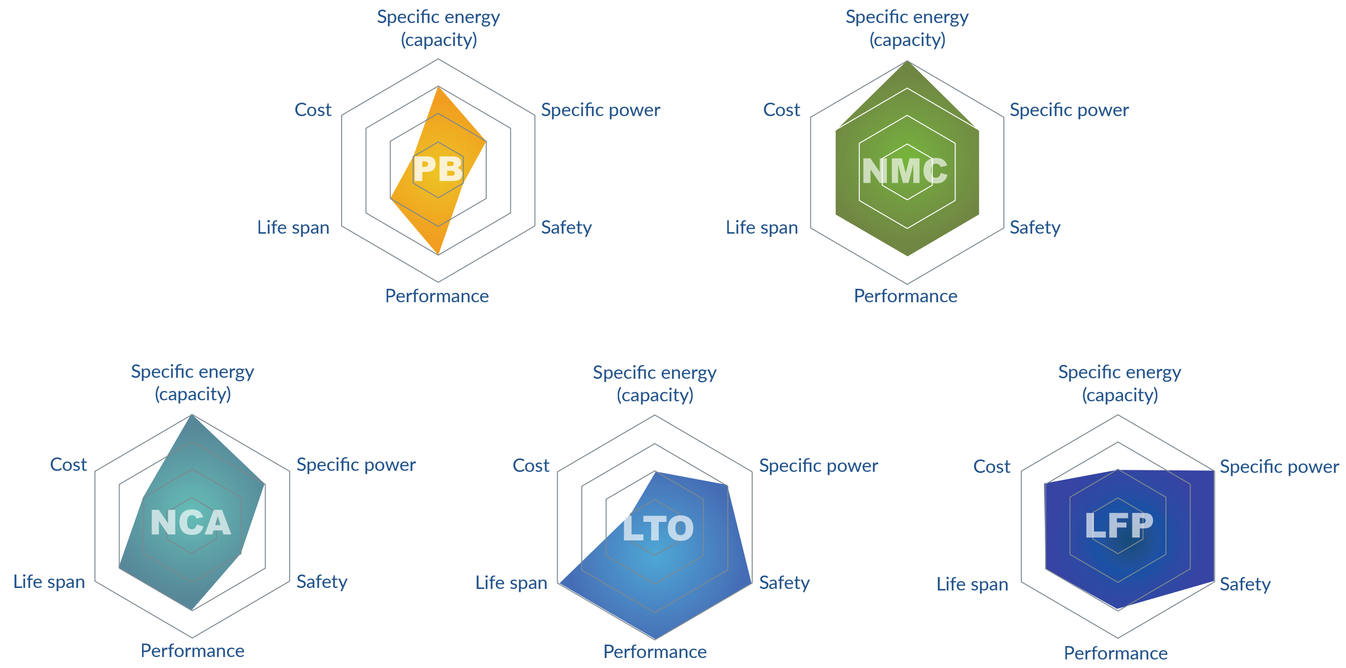
Basics: What lithium-ion batteries are there and what are their respective advantages?

Four Li-ion battery technologies have established themselves on the market: the lithium-nickel-manganese-cobalt (NMC), lithium-nickel-cobalt-aluminum-oxides (NCA), lithium-iron-phosphate (LFP) and lithium-titanate (LTO) batteries. They differ in properties due to their respective chemical composition. For example, one cell technology has a longer service life and is safer, while the other has a higher performance (see table).

	NMC/NCA	LTO	LFP	Lead-Acid
Volumetric energy density	2,2 Wh/L	0,64 Wh/L	1,2 Wh/L	0,22 Wh/L
Life span	3.000-5.000	>15.000	ca. 7.500	200-1.500
Security	– –	✓✓	✓	–
Acquisition costs	✓✓	–	–	✓✓



Source: Yu Miao, Patrick Hynan, Annette von Jouanne and Alexandre Yokochi: Current Li-Ion Battery Technologies in Electric Vehicles and Opportunities for Advancements & Wiferion

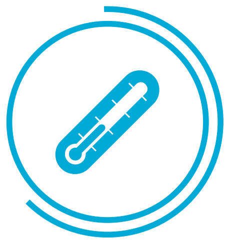
If very compact batteries are required for the application, there are good arguments in favor of the NMC and NCA cell technologies. In the industry for industrial trucks and in the electromobility of mobile robotics applications, the cell technologies LTO and LFP have become established due to their high safety. For industrial applications, this means, among other things, that the vehicles can be operated over their entire service life without battery replacement. Due to their high cycle stability and high safety, the trend in industry is clearly toward LFP technology.

With the Li-ion battery, there is no need for maintenance, battery replacement and extra change rooms with air circulation systems and high safety standards. This significantly improves the total cost of ownership (TCO) compared to lead-acid batteries. Li-ion batteries are therefore a particularly sustainable investment.

Good to know:
For Li-ion batteries, a distinction is made between full cycles and charge cycles. With lithium, the charging and discharging of the entire battery capacity counts as one cycle. In this case, the capacities of partial cycles are summed up in several charging steps. With lead-acid batteries, on the other hand, each individual charging process is a cycle - even if only part of the usable capacity is charged or discharged.

The Li-ion battery requires a battery management system

Like lead-acid batteries, Li-ion batteries are temperature-sensitive. For this reason, the energy storage systems are equipped with a battery management system (BMS). Among other things, the BMS protects the battery against overvoltage/undervoltage at the cells, overcurrent and deep discharge as well as overheating.



Battery cells are temperature-sensitive, electrochemical components that react differently to different temperatures.

The advantage: in the case of lead-acid batteries without BMS, for example, only the approximate SOC (State of Charge) is known, whereas in the case of Li-ion batteries this can be clearly read off from the measurement data thanks to the control unit. This offers the possibility of optimal control of the battery and optimal use through battery health monitoring. This is because the service life of the Li-ion battery always depends on how it is charged and cared for.

A BMS transmits data on the condition of the battery. Maintenance and condition can thus be directly seen and an optimal use of the battery cell is possible.

Battery cells are electrochemical components that react differently depending on temperature and other environmental influences. In addition, each measurement chain, such as in the BMS, also has measurement deviations. Therefore, a "maintenance charge" may be necessary from time to time. Intelligent battery technologies decide themselves when charging is necessary and run through the maintenance program automatically.

But the type of charge is also important for the service life of the lithium cells. Among other things, the Li-ion battery can be charged with a constant charge profile without intelligence. However, this does not take into account the current state of the battery, such as temperature, state of charge and possible disbalancing. Lithium-devices with intelligent control respond specifically to the state of the battery and charge with an adaptive charging curve. The effect: The battery is main-tained during charging, which guarantees a long service life. Since adaptive, intelligent charging interprets the battery status data live and adjusts the charging curve accordingly, it is possible to prevent the BMS from switching off the battery during operation, e.g. due to overheating, and the vehicle from coming to a standstill.

Another advantage of adaptive charging is the higher charging speed.

Here it depends on which battery charger you choose. On the one hand, they differ in terms of application, i.e., economy, maintenance effort, flexibility, and occupational safety, and on the other hand, they differ in terms of charging intelligence, i.e., battery care and monitoring.

Spotlight intermediate charging: more efficient processes with Li-ion batteries

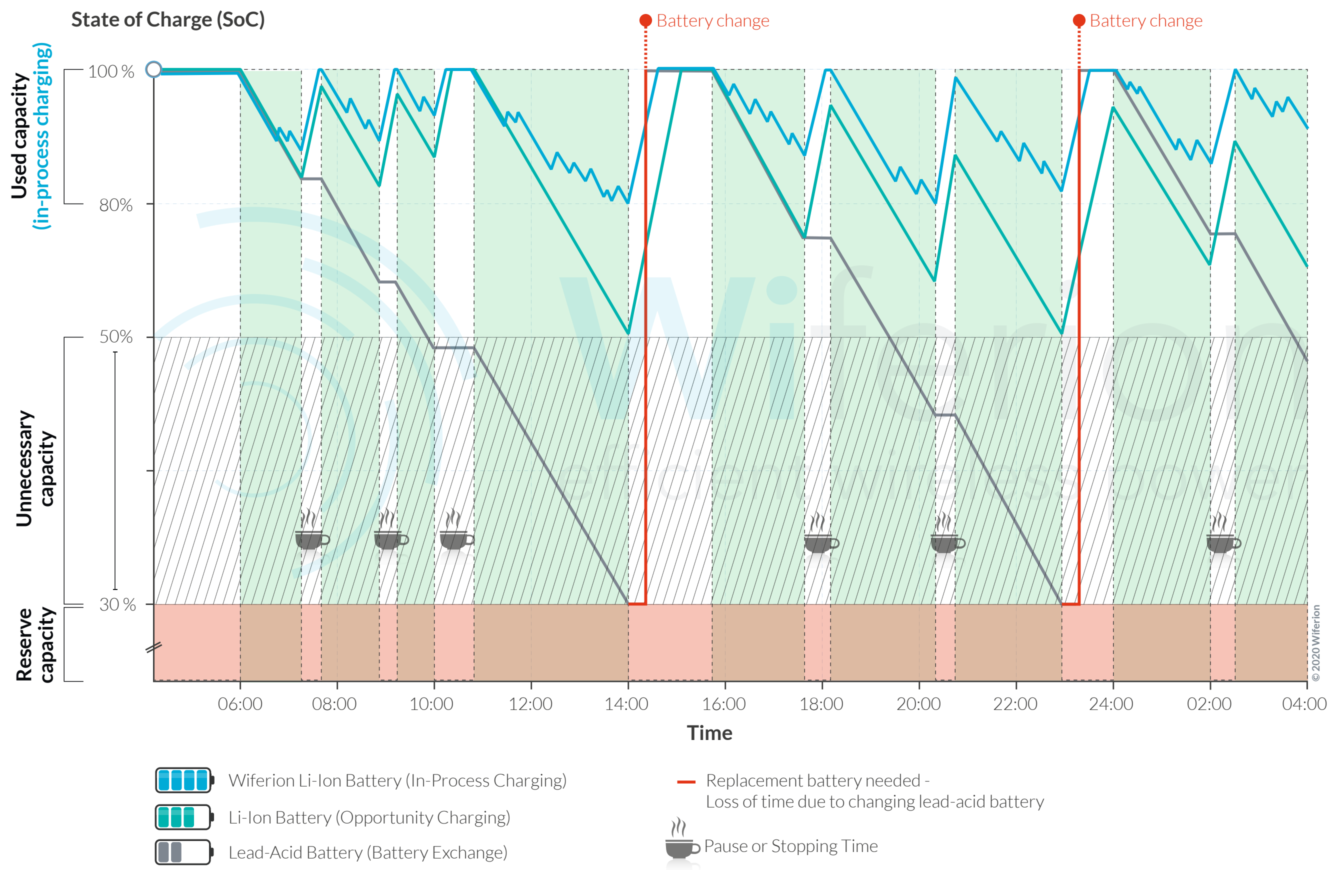
Li-ion battery systems offer the advantage that they can be charged temporarily.

Li-ion battery systems offer the advantage that they can be charged temporarily. This means that every stop in the operational process no matter how short allows an industrial truck or AGV to be supplied power. The result: Automated processes for industrial trucks paired with the Li-ion battery and corresponding charging solutions manage completely without "dead time". The vehicles can be used for the entire shift for there intended purposes - to do jobs, not to charge. This is where another advantage of Li-ion technology comes into play, the ability to "fast charge." During intermediate charging, energy can be supplied at higher currents than was previously possible with the lead-acid battery. This is expressed in terms of the "C-rate".

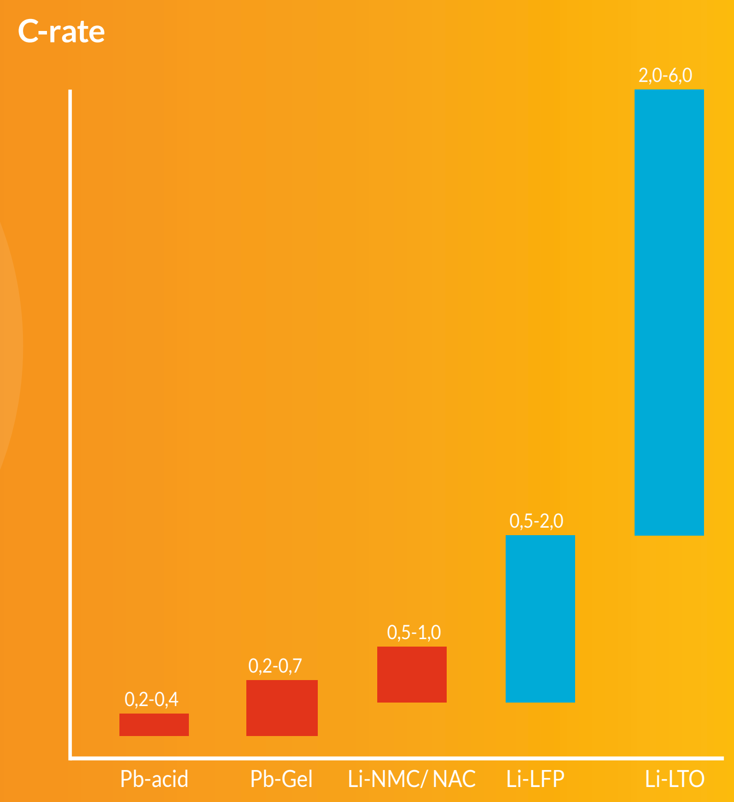
For example, an LFP battery with 1C-2C can be charged in under an hour, while an MNC with the same capacity and 0.5C requires two hours for this.
This makes LFP and LTO batteries particularly suitable for fast, short and intermediate charging in the process.

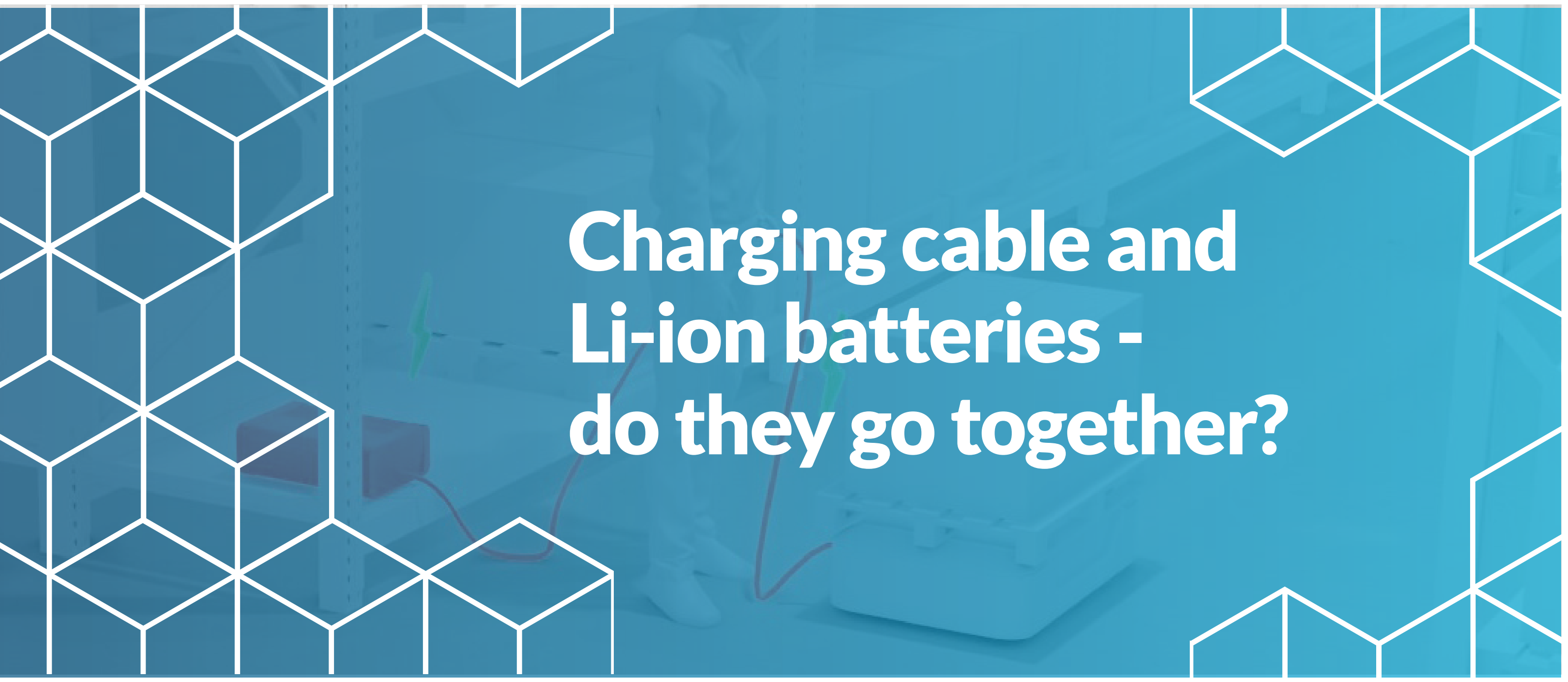
In practice, intermediate charging allows the utilization profile of a lithium-ion battery system to be described by a "sawtooth curve". Energy management is an important aspect in this context and has a significant influence on the availability of the industrial trucks used.

Intermediate charging can significantly reduce the battery capacity, i.e. the installed volume of batteries, of the vehicles compared to the lead-acid battery.



Good to know
The C-rate is the quotient of this current and the capacity C_N of a battery modulator, which can be used to draw conclusions about the charging and discharging currents depending on the nominal capacity. The C-rate can be different during charging and discharging and can be found in the respective manufacturer's data sheet.





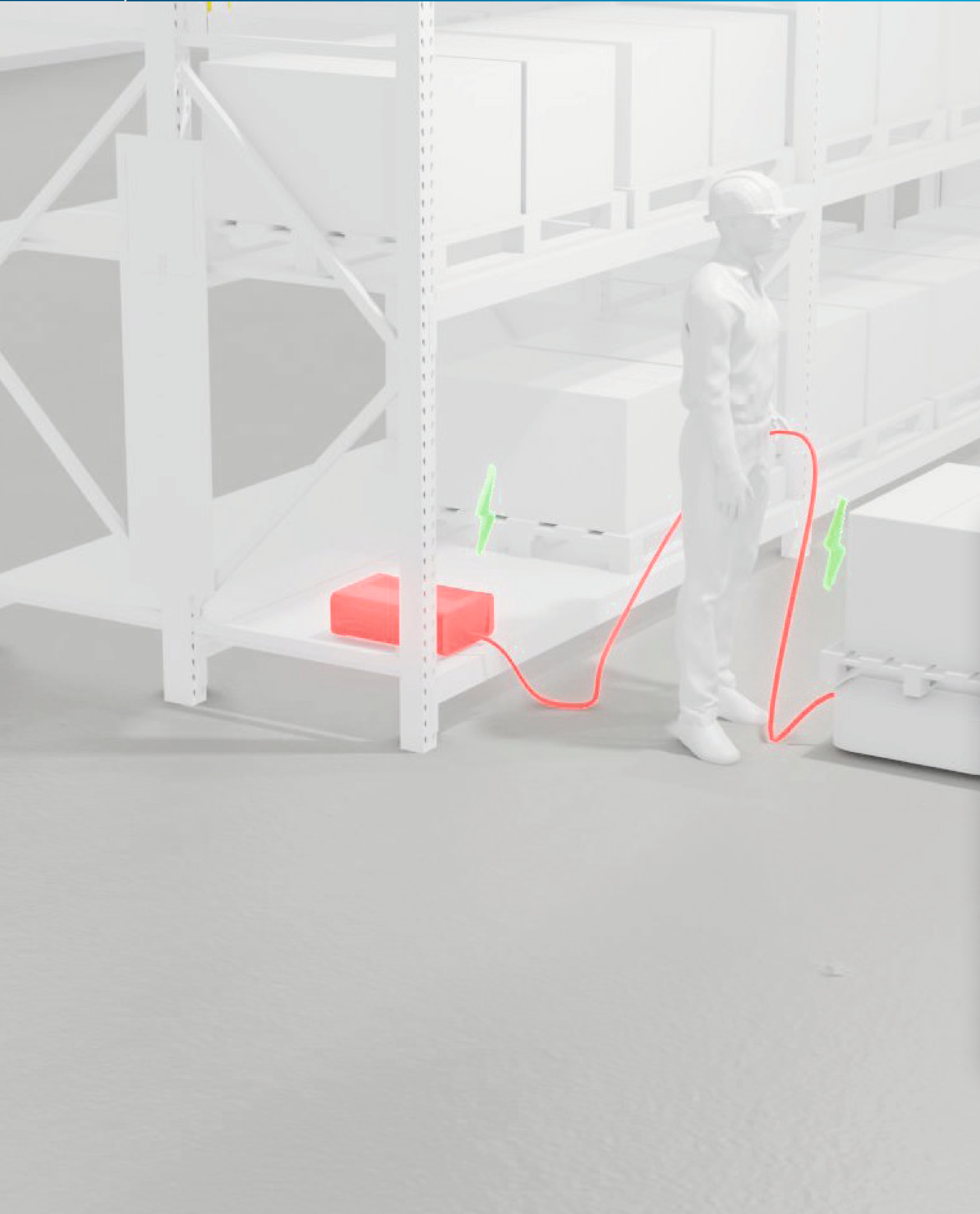
Charging cable and Li-ion batteries - do they go together?

In practice, the batteries of AGVs and AMRs are still charged via cables with plug-in contacts. This process requires the manual intervention of employees, which makes integration into the value creation process difficult.

The Li-ion battery scores with the ability to be intermediately charged with high currents in a short time. However, these advantages are very difficult to exploit in practice with wired chargers. This is because the process is manual, requiring the driver to actively insert the plug into the vehicle. This can lead to errors time and again. Whereas drivers were not involved in the battery replacement process with the lead-acid battery, and now they have to manage the energy supply to their industrial Trucks in addition to their transport tasks. In the process, the employees repeatedly forget to connect the plugs to the vehicles, even during short breaks. Since charging is not part of any value-creating process, it is repeatedly forgotten in everyday work. The result is that the energy level of the vehicles is too low, which can even lead to total failure for downstream tasks.

During operation, the vehicles are not supplied with power. During this time, the energy level of the batteries drops continuously. This is compensated for by longer charging phases, for example during breaks. As a result, the expensive li-ion batteries have to be much larger than necessary to ensure that the trucks always have sufficient energy. If, in addition, the entire fleet is plugged in for charging at the end of a shift, the increased power costs of peak loads will have an impact.

A remedy would be to automate the power supply. However, this is difficult to implement with this charging technology.

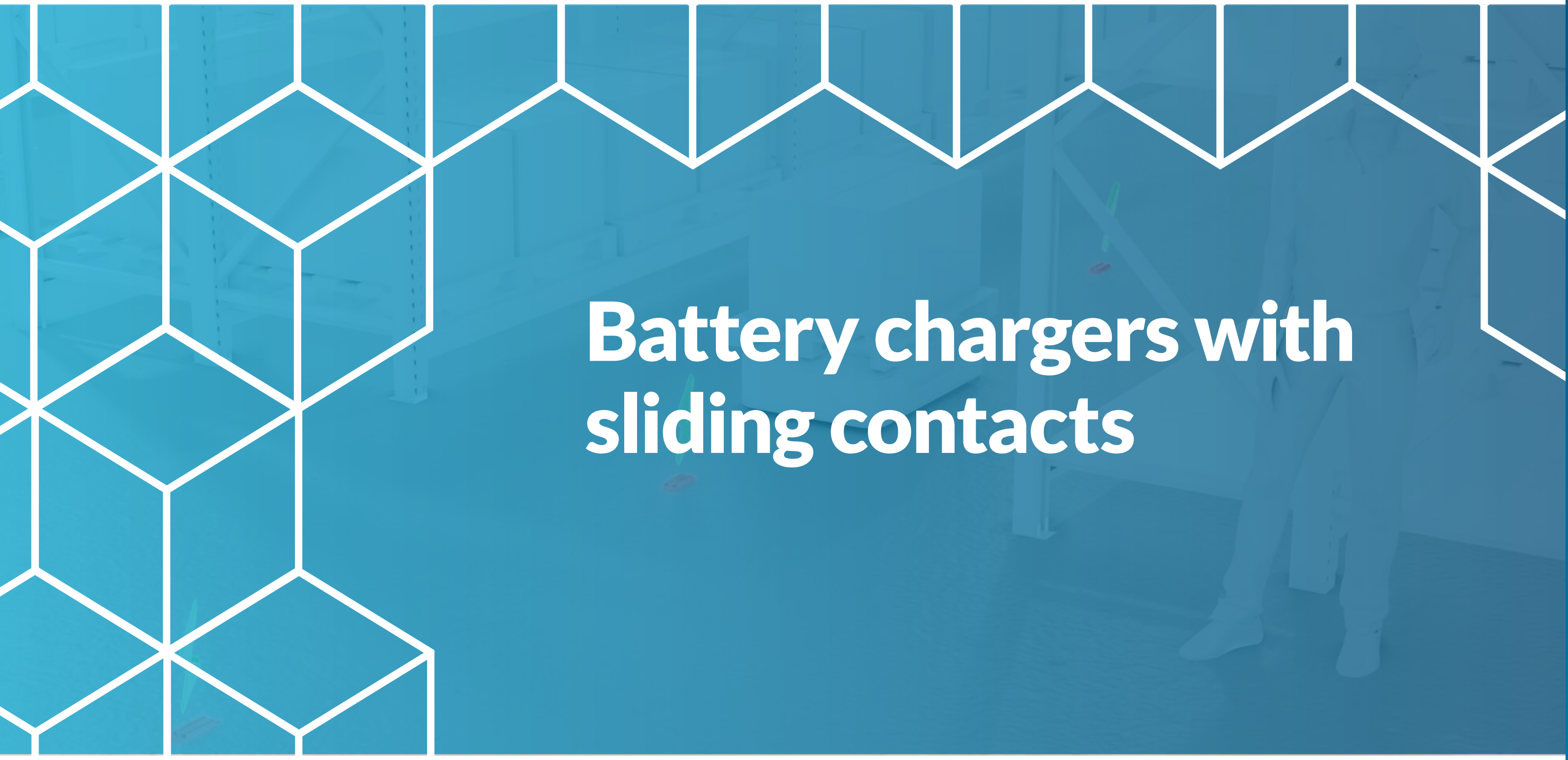


Advantages of charging with cable

- High efficiency
- Relatively inexpensive in the investment phase
- Established technology
- Very high currents possible
- Well-known application

Disadvantages of charging with cable

- High-maintenance
- Poor to automate
- No opportunity charging, Industrial trucks missing in workflow, downtime
- Requires large batteries
- Charging unit requires space and is therefore often not easy to distribute in the plant
- Plugs have no IP protection when not plugged in



Battery chargers with sliding contacts

Sliding contacts are often used to supply power to the battery of AGVs or automated vehicles. Stationary sliding contacts are permanently installed in the storage environment and a counter contact is mounted on the vehicles.

This charging technology can be automated: The AGV drives onto the stationary sliding contact with the counter contact and charging is started and stopped by a switch-on and switch-off unit. Intermediate charging of the lithium-ion battery is easy to implement. This concept is often tempting because of its initial simplicity. If one considers the overall concept from:

- Control for de-energizing the contacts
- Lateral mounting in order to generate sufficient contact pressure, or a mechanical lowering device in the case of floor-level mounting
- The solution to this problem, which requires additional communication for the charging process control, is often complex and unreliable via sliding contacts,

the complexity and thus the BOM (Bill of Material) increases rapidly.

The charging stations are quickly installed on the ground and on the vehicle. However, they have one disadvantage: The charging contacts protrude from the ground and are difficult to level without compromising reliability. As a result, charging stations always create tripping hazards for employees. To minimize the risk, the charging stations are not installed in the process, but outside in separate zones. With sliding contact technology, this allows for intermediate charging, but the vehicles are missing from the process during their journeys to the charging zones. To ensure constant availability, more vehicles must be purchased to replace the charging vehicles.

What you need to know about sliding contacts

Exact positioning necessary

For system availability, it is important that the positioning of the vehicles on the charging contacts is carried out precisely. This is because how the contact process is set up determines whether oxide layers are removed before charging and whether burn-in points can be avoided. If the "contacts" are not correctly controlled or stick together, the battery charging system with sliding contacts will not function correctly. There is then a risk of sparking after the charging process has been completed.

High costs with higher charging currents

The designs of the charging stations are complex and expensive at higher currents. This is because large energy transfers are only possible through strong contact forces and large contact areas. These in turn have to be absorbed by the charging stations. This means that greater design and maintenance effort is required to ensure smooth operation. In the case of lightweight vehicles, this also results in a limitation of the charging current.

Initiation time

Takes up to 10 seconds and then often additional ramp-up of the current. Standard chargers are not designed for dynamic applications and therefore have simple and slow control algorithms. When a vehicle pulls up to a charging station, it can take up to 10 seconds for the full charging current to flow. With increasing dynamic applications where even short process pauses are to be used, this "offset" is a disadvantage.

Switch-off device

The stationary charging contacts require a switch-on and switch-off device, otherwise the contacts are permanently energized.

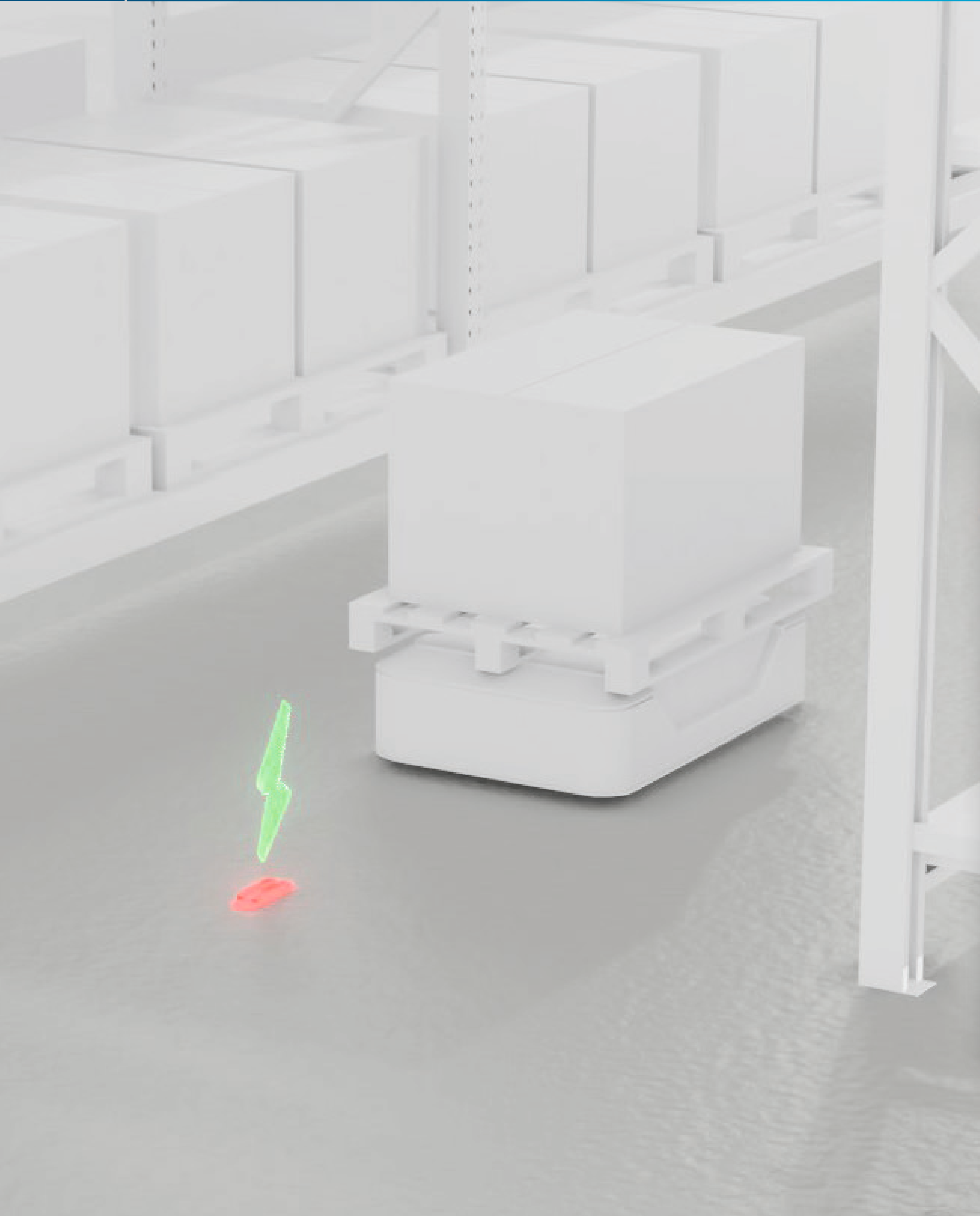
Constant charging current

Most contact chargers do not have intelligence on board and thus do not communicate with the battery. Therefore, they are usually charged with a constant current. Here, no attention is paid to the condition of the battery. This does not endanger the battery, but the life of the battery can suffer considerably.

Wear and tear brings several disadvantages

Sliding contacts are wearing parts, which can lead to more expenses for component changes in case of frequent loading processes. In addition, the contacts usually have to be checked and cleaned on a weekly basis. Therefore, from an organizational point of view, it is difficult to distribute the loading contacts for intermediate loading in the hall, since for this purpose the manpower has to run through the entire hall.

The continuous abrasion of the contacts produces copper-containing fine dust, which pollutes the charging station and the production environment. The fine copper particles created by the wear are suspended in the air. When inhaled, these pose a health hazard to employees who are permanently in the hall. In addition, the charging contacts mounted on the floor are a tripping hazard for employees. For this reason, the charging point of battery charging technology with sliding contacts is not installed in the immediate vicinity of the production areas for reasons of occupational safety. In addition, the open contacts cause unease among employees as to whether the power supply is actually switched off.



Advantages of charging with sliding contacts

- Automated charging
- Intermediate charging
- Easy integration
- Cost

Disadvantages of charging with sliding contacts

- High-maintenance
- Complex control system necessary
- Risk of tripping for employees or complex lowering unit
- Wear of loading contacts
- Vehicles missing in workflow, downtime
- Precise positioning necessary
- Up to 10 seconds to full power
- Not suitable for outdoor use
- Charging contacts must always be switched on and off by a process
- Health risk for employees
- Large bill of material at customer site

Battery charging technology with inductive conductor lines

Charging the battery via ladder line systems is less common than charging via charging contacts due to its cost-intensive complexity. In this charging system, automated vehicles such as AGVs move along predefined routes with integrated current conductors in the ground.

Charging is inductive. However, extensive intervention in the infrastructure is required to install the conductors in the ground. For these reasons, the system is very costly and maintenance-intensive.

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1st project phase: Integration

The lines are integrated into the system in a project phase and are aligned and fixed to the feed point with the help of additional components along the routes. For the implementation, extensive interventions in the infrastructure of the building fabric are necessary. The floor of the hall has to be milled out so that the conductor lines can be laid.

2nd: Change of the charging scenario

Due to the integration in the floor, ladder line systems cannot be changed without intervening in the hall infrastructure. The direction of travel of the AGVs is fixed. This can only be adapted to changing requirements with great effort. Any expansion of the fleet or change in the route becomes a problem.

3rd: Heating of the soil due to permanent magnetic field

Conductor lines generate a permanent magnetic field. When installing the chargers, a precise analysis of the infrastructure on site is necessary. This is the only way to rule out any interaction with ground reinforcement caused by the permanent magnetic fields around the line. Otherwise, considerable losses will occur in the reinforcement and the ground will heat up.

4th overall efficiency only up to 60%

Communication between the line and the components in the vehicle is not possible due to the system. Therefore, the line currents must be maintained at all times, which limits the efficiency of the chargers. In systems with discontinuous inductive lines, however, rarely all vehicles are on the line section. The feed-in power is usually heavily oversized and the line systems are permanently active. Depending on the design and number of vehicles used, good conductor line systems have an overall efficiency of around 60 %.

Renewed project phase possible

If the requirements for the work process change or the fleet is to be expanded, a new project phase becomes necessary.

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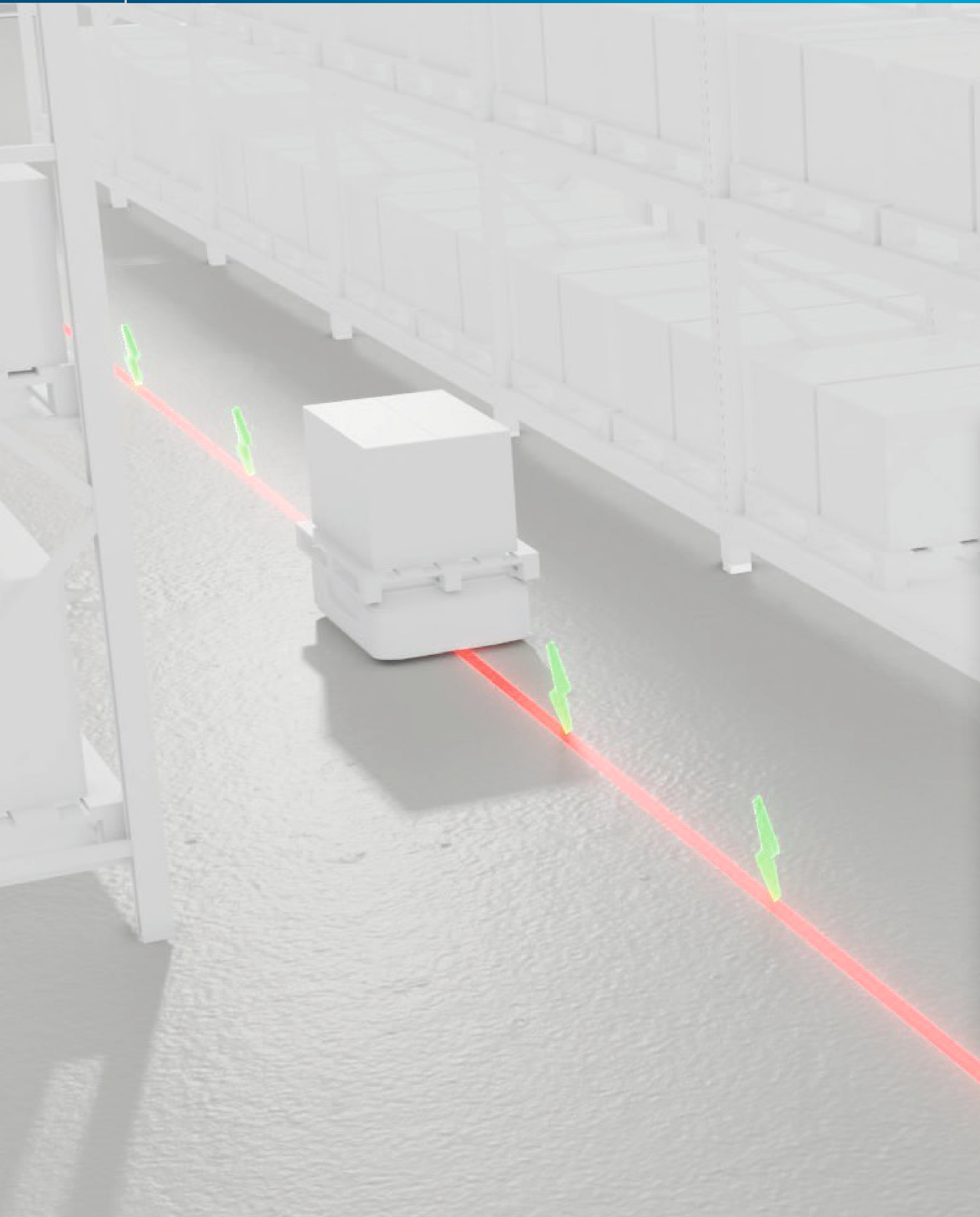

Advantages of charging with inductive conductor lines

- Automated charging
- Intermediate charging

Disadvantages of charging with inductive conductor lines

- Costly
- Complex planning and implementation
- Poor efficiency
- Inflexible, restructuring of the line, adding more vehicles to the line only possible with great effort
- Highly oversized, as vehicles can only be added at a later date with great effort
- Major intervention in infrastructure necessary

Inductive point chargers: automated energy supply with high process reliability

Inductive point charging systems are a new approach for supplying energy to the lithium-ion battery of industrial trucks. These are becoming increasingly popular for supplying power to AGVs and AMRs due to their numerous advantages. Based on the principle of magnetic induction, energy is transferred automatically and highly efficiently without contact.

Intermediate charging can be realized with inductive point charging systems and is the only one that can be installed in the process due to its technology. This is the first time that intermediate charging can be realized cleanly and the potential of the lithium-ion battery can be fully exploited. Thanks to the additional intelligence in the receiver unit in the vehicle, the batteries can be charged adaptively to their condition. Battery maintenance concepts and automatic balancing processes can be easily implemented automatically with this technology.

Instead of driving to an external battery charging station, the vehicles automatically start to charge temporarily throughout their workflowat commonly frequented points in the warehouse or in production without interrupting the logistical processes for charging breaks. The charging pads can be installed on the side or completely at ground level in the floor, like a tile. This means that the charging station does not interfere with the workflow and does not pose a tripping hazard.

As soon as a vehicle reaches the charging pad of an inductive point charger, the charging process starts automatically and hits full power within 1 second. It does not matter whether the vehicle is a forklift, a mobile robot or a driverless transport system. The manufacturer or the installed battery is also irrelevant, as long as the vehicles have receiving electronics.

"In-process charging" enabled with inductive point chargers:

- 24/7 continuous operation
- Elimination of unproductive downtime
- Increase in vehicle availability by up to 30%.
- Charging of different battery types with 24 or 48 volts
- Charging of vehicles from different manufacturers

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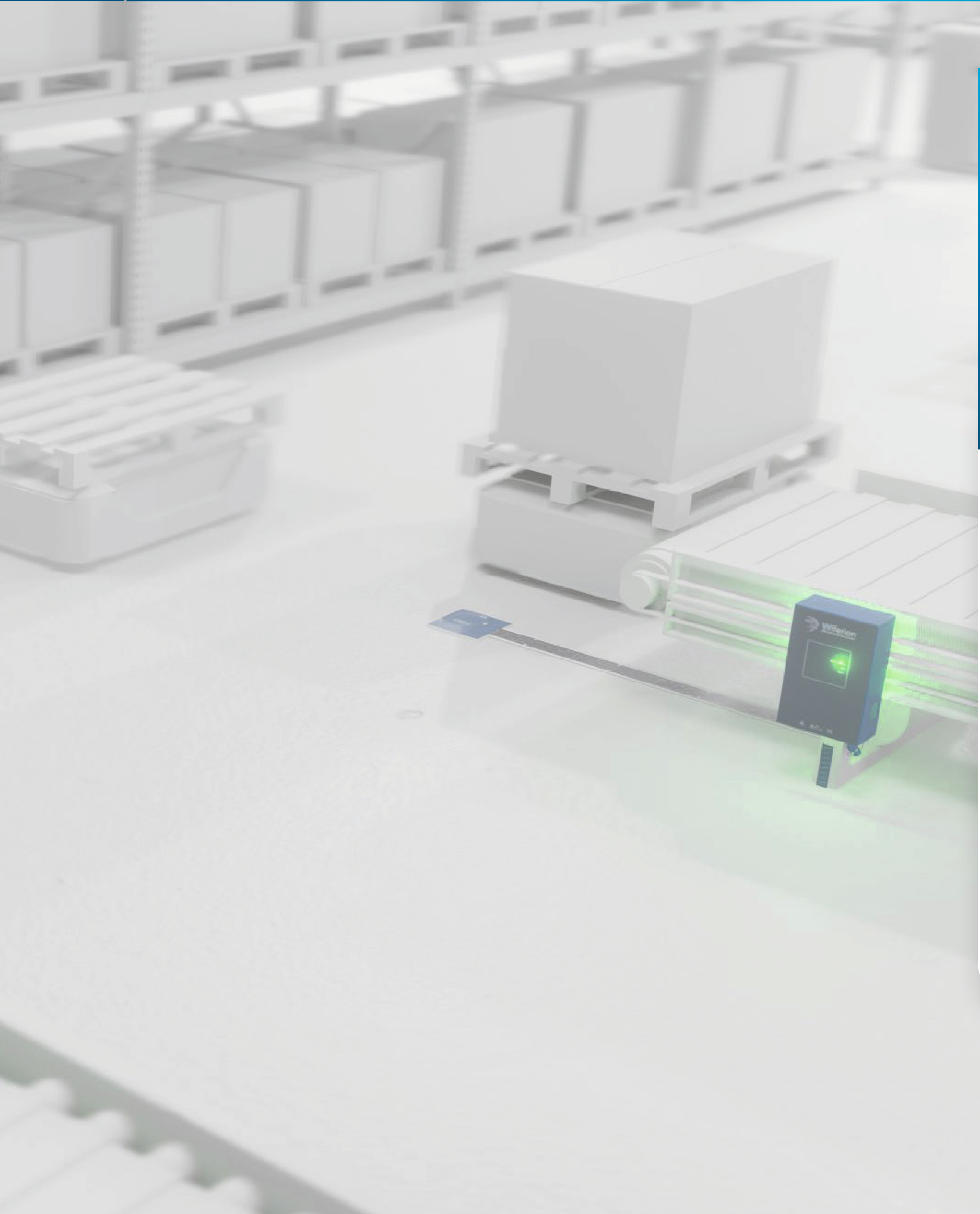

Advantages of charging with inductive point charging systems

- Automated charging
- Contactless charging
- Maintenance-free
- High availability
- Easy integration
- High efficiency
- Suitable for outdoor use
- All-4-one solution - same system serves 24 and 48 volts
- Data monitoring possible
- Fast ROI

Disadvantages of charging with inductive point charging systems

- Higher acquisition costs

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Differences between inductive point charging systems and conventional charging technologies

Inductive battery chargers only consume power when charging is taking place. The efficiency of inductive fast charging systems is up to 93% This makes them as efficient as the best chord chargers and significantly higher than the ladder line systems. Charging is fully autonomous without contact using "in-process charging". This keeps the vehicles continuously productive and busy with value-added tasks. Full power is available within 1 second (no initiation time and no slow ramp-up of power). Unlike battery chargers with plug-in or loop connections, no extra charging areas are needed. In addition, inductive point chargers do not require mechanical sliding contacts and are virtually maintenance-free. Problems of conventional charging processes with oxidized plugs or broken cables are a thing of the past.

Inductive point charging systems are easy to operate and can be installed almost anywhere - on walls, on the ground, on driveways, at parking areas or loading and unloading stations. The automation solution with the modular battery chargers can be quickly adapted to changes in the process or new requirements. The charging unit and receiver coil are installed on the vehicle within a very short time. Since the mobile electronics and receiver coil are separate components, numerous mounting variants can used.

With conventional systems, integration into warehouse processes can often take weeks or even months. In contrast, implementing automation with wireless charging technology such as Wiferion's does not require extensive infrastructure measures for most deployments.

For charging systems with plug-in and loop connections, elaborate peripheral circuitry and protective devices must always be installed to ensure safety for employees and equipment. Since there are no open contacts in an inductive charger, occupational safety increases enormously.

No maintenance

No cleaning

No wear and tear

In contrast to conventional battery charging technology, inductive point charging systems for the first time offer the possibility of evaluating all relevant live information on battery charging. With the aid of an integrated CAN interface, data such as energy levels, operating times and vehicle states can be looked up in real time. Process reliability can thus be increased many times over. Upcoming maintenance work can be intelligently scheduled and downtime avoided.

The charger is also weatherproof. Ambient conditions have no influence on its operation. Moisture, dirt or dust cannot harm the system. It is an encapsulated system in which the external elements have IP67 certification. This makes it possible for the first time to supply power to vehicles outdoors.

Inductive battery chargers with point charging are somewhat more expensive to purchase than cable-based charging solutions. However, you get a completely automatic system. Due to the many other advantages, the costs are quickly amortized. Compared to the solutions with sliding contacts and conductor lines, which involve interventions in the infrastructure, the point charging systems are significantly cheaper.

Wireless point charging systems from Wiferion GmbH

etaLINK 3000 with 60 amp charging power

Comparison of charging systems for lithium-ion batteries

Finally, the following table presents the previously discussed characteristics of the potential charging systems.

	Charging Contacts	Cable Charging	Next Generation Contactless Charging (Wiferion)
No wear no tear	X	X	✓
One-4-all use (ie. AGV, AMR, forklift)	X	X	✓
In-process charging	✓	X	✓
No seperate charging areas needed	✓	X	✓
Maximum safety for workers (tripping)	X	X	✓
Flexible positioning during charging	X	✓	✓
Hands-free	✓	X	✓
Spark-free	X	X	✓
Weatherproof / IP65 or higher	X	X	✓
Multiple currents & voltage capability with one charger	X	X	✓
Ground clearance between vehicle & charger	X	✓	✓
Switches on/off automatically	✓	X	✓
360° approachability	X	✓	✓
Full power in 1 second	X	X	✓
Data transfer always included	X	X	✓
No infrastructure work requested	X	X	✓
Smart charging (optimized dynamic charging)	X	X	✓
High efficiency and optimized power charging	X	✓	✓
High positioning tolerance	X	X	✓

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Notes

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About Wiferion

From inductive charging technology to energy management solutions, Wiferion offers a range of products that enable efficient energy supply to industrial trucks, automated guided vehicles (AGV) and autonomous mobile robots (AMR). The technology also includes retrofit projects for existing fleets.

The flexible and scalable integration of Wiferion products enables users to sustainably increase their utilization and fleet efficiency by up to 30%. Using lean manufacturing principles, Wiferion redefines value stream mapping (VSM) by eliminating unnecessary machine downtime and plug-in charging that requires high maintenance and costs. The etaLINK series of inductive battery charging systems have received prestigious awards such as the IFOY Award and "BEST PRODUCT" at LogiMAT.

Numerous companies from the logistics, industrial & automotive sectors rely on Wiferion's technology. These include leading automation solution providers such as robotics companies Safelog, KUKA and Magazino. Wiferion has sold more than 3500 etaLINK systems in over 20 countries.

Wiferion GmbH
Munzinger Straße 1
79111 Freiburg
+49 (0) 7611542670
info@wiferion.com
www.wiferion.com
/wiferion