Technical manual

Nilar Energy Battery

High power industrial energy storage and battery solutions that are safe and environmentally friendly

Contents

Nilar batteries and energy storages

Nilar provides customers with low and high voltage industrial energy storage and battery solutions that are safe and environmentally friendly. Solutions are built on modular and flexible battery packs based on the Nilar battery energy module and integrated, easy-to-use, battery management systems for high and low voltage systems.

The 12 V Energy Module

The 12 V Energy Module is the building block in Nilar's energy storage and battery solutions. The module is a maintenance-free, energy-optimized battery with high power capability designed for demanding professional applications. The high energy throughput, long cycle life, wide operational window and excellent safety and environmental characteristics of the nickel-metal hydride technology makes it possible to supply power to a large number of applications.

- The patented Nilar bipolar design enables Nilar to offer safe, reliable and cost efficient energy storage solutions.
- High energy density with excellent discharge power capability over a wide temperature range.
- The Nilar battery requires very low maintenance, in many cases no maintenance, and is a sealed design with no emissions of gases or electrolyte during its service life.
- The Nilar battery is easy to transport and is not affected by any costly or complicated transport regulations.
- The Nilar battery contains none of the regulated heavy metals mercury, cadmium and lead. The design design has been developed to enable a cost efficient recycling process and a high degree of reused materials.

Solutions and applications

Nilar bipolar batteries deliver unrivalled industrial power solutions for a number of applications across a wide range of market segments. By combining the modular and flexible Nilar battery module and integrated battery management systems, Nilar can serve customers with:

- Simple to use **low voltage** battery solutions
- Advanced **high voltage** energy storage needs

Nilar provides dedicated battery management systems for modular charging of serial and parallel configurations in low voltage systems (12-24-36-48 V) and local monitoring units for high voltage systems (72-720 V). For specific applications, when the customer wants to integrate their own battery management systems, Nilar will provide algorithms and settings in cooperation with the customer.

Simple to use low voltage battery solutions:

- Wheelchairs
- Automatic guided vehicles (AGV)
- Cleaning equipment
- Go-carts

Advanced high voltage energy storage:

- Solar- and wind-power
- Uninterruptible power supply & telecom
- Storage
- Marine – electric ferries

Nilar battery pack features

Nominal voltage
The cell voltage of a battery cell is governed by the electrochemical potentials of the active materials used in the negative and positive electrodes and the electrolyte. For the nickel-metal hydride system used in Nilar battery packs, the nominal cell voltage is 1.2 V. The smallest units in a Nilar battery pack are the 12 V modules with 10 cells assembled in series. Modules in a pack and packs are connected in series to achieve a nominal battery voltage in multiples of 12 V.

Rated capacity
The battery capacity is rated in ampere-hours (Ah) and denotes the quantity of electricity a fully charged battery can deliver at a 5 h discharge to 1 V per cell at +20 °C. Modules have a capacity rating of 10 Ah. Modules in a pack and packs are connected in parallel to achieve rated battery capacity in multiples of 10 Ah.

Operating voltage
Typical cell operational voltage is 1.6 V during charge to 1 V per cell at discharge corresponding to 16 to 10 V for a 12 V module.

Operating temperatures
The batteries can be operated in temperatures from -20 °C to +50 °C.

Intermediate state of charge
Batteries can be stored or operated at an intermediate state of charge without loss of performance.

Installation
The design is a sealed design. At normal operating conditions Nilar battery packs do not produce any emissions and require no forced ventilation to remove flammable gases generated during operation of the battery.

Reliability
The Nilar battery is a stable electrochemical system regarding structural integrity of its components. There is no corrosion of components resulting in premature and unpredictable critical damage to the battery or any type of sudden death. The design is shock and vibration resistant. The end-of-life characteristics of Nilar battery packs display a graceful decline in performance over the life of packs.

Storage
Nilar battery packs can be stored several years without loss of performance.

Maintenance
Nilar battery packs use a sealed design that requires a minimum of maintenance, for many applications no maintenance at all is required.

Operating features

Discharging

Discharge performance
After a moderate initial voltage drop the discharge voltage is stable over more than 80 % of the discharge and ends with a distinct knee at end of the useful capacity. Discharge voltage is dependent on discharge rate, temperature and the state of charge. The discharge voltage decreases with increased discharge rates and decreasing temperature. The discharge performance is affected moderately at elevated temperatures but at low temperatures the effect of temperature on discharge performance is more pronounced, mainly due to the increase in resistance at low temperatures. The discharge capacity, or the run-time to end of discharge, is mainly affected by discharge rate and temperature. Delivered capacity depends on the selected discharge cutoff voltage and decreases with increasing discharge cutoff voltage.

Test currents in this manual are expressed as multiples of the rated capacity value denoted by C. E.g. a discharge current of 2C for a Nilar battery pack with a rated capacity of 10 Ah equals 20 A.

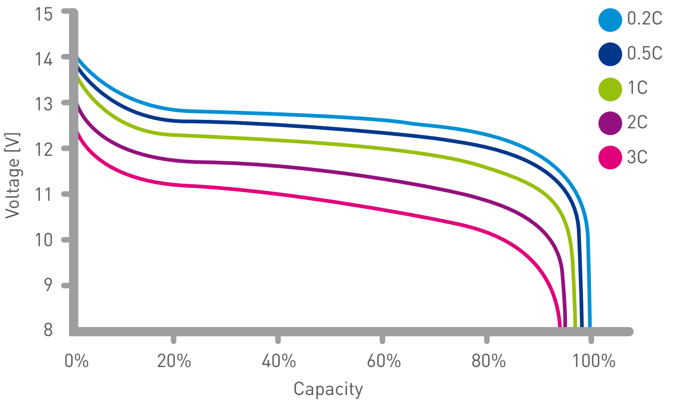


Figure 1.
Typical voltage profiles for constant current discharges with various discharge rates. Charging and discharging made at +20 °C.

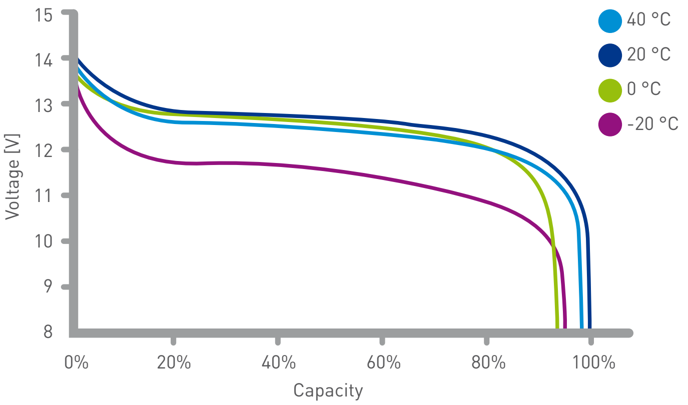


Figure 2.
Constant current discharge with 0.2C at various temperatures. The battery was fully charged at +20 °C, acclimatized for 12 h at test temperature and then discharged.

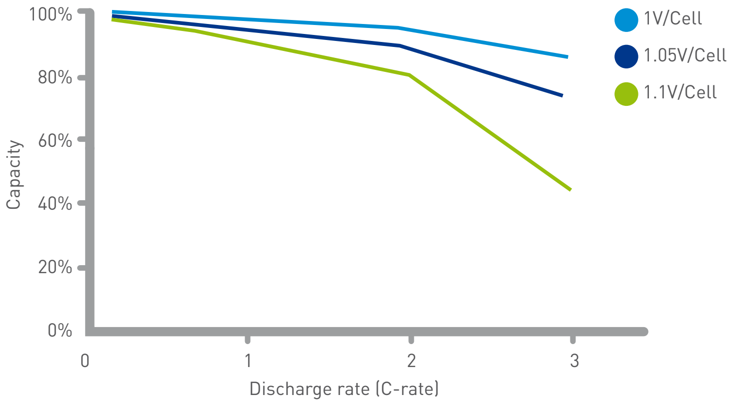


Figure 3.
Available constant current discharge capacity for various discharge cutoff voltages. Constant current discharge with 0.2C at +20 °C.

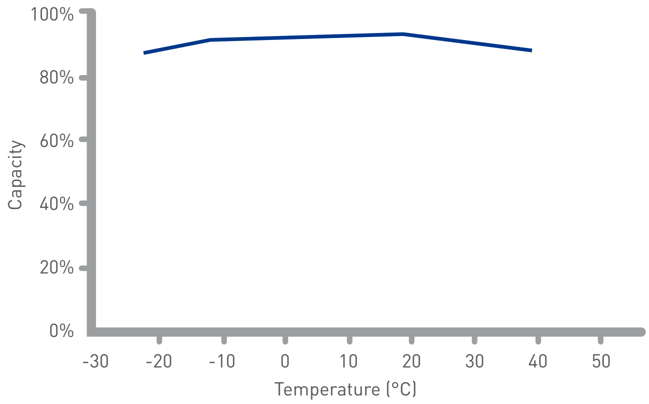


Figure 4.
Constant current discharge capacity at various temperatures. The battery was fully charged at +20 °C, acclimatized at test temperature for 12 h and then discharged with 0.2C to 1 V per cell at test temperature.

Discharge cutoff voltage

Recommended minimum discharge cutoff voltage is 1.1 to 1 V per cell depending on discharge rate, battery size and environmental conditions. Lower cutoff voltage can be used at low temperatures and high discharge rates for better utilization of the capacity. Discharge to low voltage may result in deep discharge, or in extreme cases reversed polarity, of one or several cells in the battery before the entire battery reaches the pre-set discharge cutoff voltage. Deep discharging, and especially reversed polarity, will have a detrimental effect on the performance. Pack voltage and module voltages are available for monitoring by the 15-pin signal connector.

Discharge resistance

The resistance varies with temperature and state of charge. At +20 °C the optimum resistance is achieved at 80 to 30 % state of charge. Below 20 % state of charge the resistance increases significantly. The resistance increases with decreasing temperature.

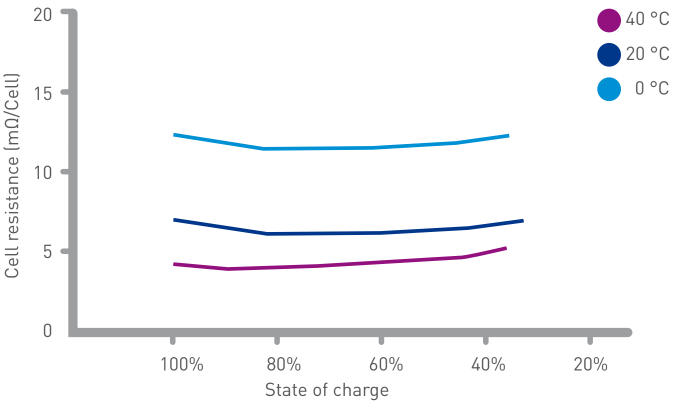


Figure 5.
Cell resistance at various temperatures and charge levels. 30 s pulse duration and a discharge pulse current of 3C.

Charging

Nilar charging systems

Nilar battery packs require optimized charge procedures and charge settings to ensure performance and service life. Constant current chargers modified to enable control from the Nilar charging system are required. Packs with modules connected in series, with a rated pack capacity of 10 Ah, can be charged with constant current chargers with specific charge termination settings that are based on pack temperature, pressure and terminal voltage. In parallel configurations packs have to be charged with electronic charge control systems controlling individual modules in the pack. The electronic charge systems offered by Nilar can be used with both serial and parallel pack configurations.

Charging with chargers and charge settings not approved by Nilar will void warranties and may damage the battery.

For specific applications, where the customer wants to integrate their own battery management systems, Nilar will provide algorithms and settings in cooperation with the customer. The following specified charge procedures and settings are presented as general charge recommendations. If the electronic charging systems developed by Nilar are not to be used please contact Nilar for detailed information on charge procedures and settings.

Low voltage BMS

- Packs with modules in series and parallel configurations
- Low voltage systems 12 – 48 V
- Controls charging on module level
- Communicates with Nilar approved chargers to regulate charge power

High voltage BMS

- High voltage system 72 – 720 V
- Communication interface with charge settings, alarm signals and pack status indicators for large format energy storage systems
- Communicates with main control system through Programmable Logic Controller (PLC)

Recommended charge procedure

The recommended charge procedure is constant current charge with charge termination based on rate of temperature increase (dT/dt) together with a maximum allowed pressure and pack temperature. The recommended charge rate is 0.3C to dT/dt corresponding to 0.3 °C in 2 minutes. The charge procedure can be used for charging battery packs with battery pack temperature in the range of -20 °C to +40 °C. Maximum allowed pressure is 586 kPa corresponding to 85 PSI. Charging shall be terminated when the battery pack temperature reach +60 °C. A deep discharged battery pack is recharged in less than 3.5 h.

An inherent feature of the NiMH electrochemical system at constant current charging is the build-up of pressure and temperature at the end of the charge. It is therefore important to use a correct charge method to ensure sufficient performance. At low temperatures the charge rate can be limited by an increased voltage needed to charge the battery. At elevated temperatures the maximum charge rate is limited by the rise in temperature and pressure at end of charge.

For a battery in service the cells in the battery will with time reach various charge levels due to temperature gradients in the battery causing small variations in self discharge rate and impedance. The result is reduced run-time and, in extreme cases, accelerated ageing of the battery due to deep discharge of the low capacity cells in the battery. Balancing of cells in Nilar battery packs can be achieved simply by a limited overcharge allowing the low capacity cells to become fully charged. Heat generated at overcharge is detrimental to the performance and have to be considered in the charge design. Cell balancing is included in the electronic charge solutions provided by Nilar.

Typical terminal voltage, pressure and temperature when charging a 12 V / 10 Ah Nilar battery pack at +20 °C with a constant current charge rate of 0.2C is shown in Figure 6.

Self discharge

The state of charge of a Nilar battery pack during storage slowly decreases with time due to self discharge. The self discharge is caused by internal electrochemical reactions that slowly discharge the battery. The self discharge rate is high the first days of storage but then levels out to a few percent per month depending on temperature. The rate of self discharge is increased at elevated temperatures and decreases at low temperatures. A fully charged Nilar battery pack, on storage at +20 °C, will lose about 6 % capacity after one day and 13 % capacity after 28 days. Parasitic loads on the battery from charger, load and electronic systems will increase the rate of capacity loss during storage.

Cycle life

Cycle life is the number of charges and discharges a battery can achieve before the discharge capacity drops to a predetermined capacity. Cycle life is affected by temperature, charge method, charge and discharge rates and the depth of discharge. The depth of discharge has a large impact on the cycle life. The less deeply a battery is cycled the greater the number of cycles is achieved until the battery is unable to sustain the required minimum design limit. Nilar battery packs can achieve cycle life in the range of several thousand cycles at intermediate depth of discharge and more than one thousand cycles at deep discharge.

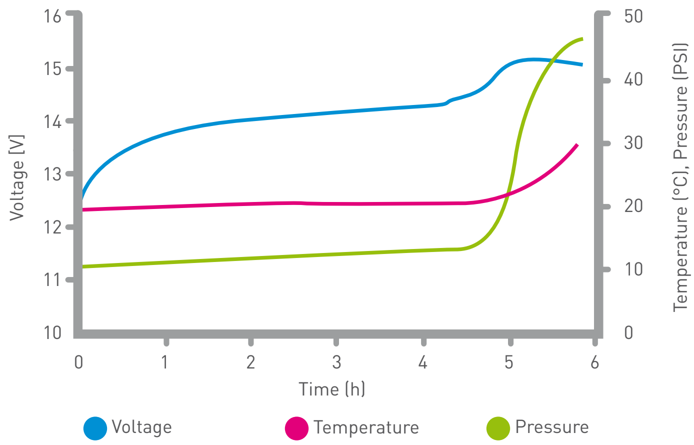


Figure 6.
Typical charge characteristics at +20 °C. Constant current charging with 0.2C.

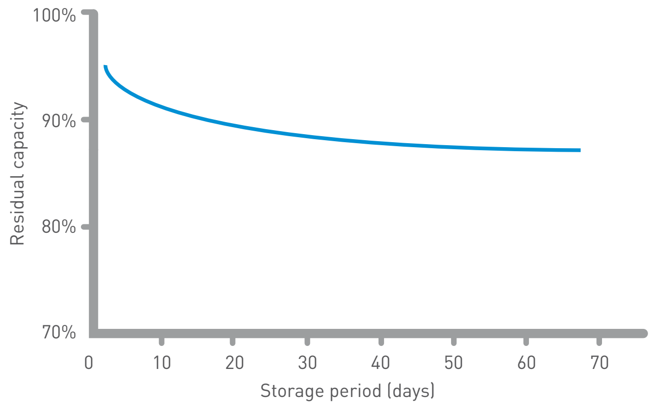


Figure 7.
Typical charge retention at +20 °C at various storage periods. The batteries were fully charged before storage.

Installation and operation

Receiving the battery

On receiving the shipment check the packages for transport damage. Carrying straps should be threaded through the openings at the corners of one of the end-pieces. Please make sure the strap locks are securely locked before lifting.

Commissioning

Nilar battery packs are shipped charged to 75 % state of charge and are ready for immediate use. It is recommended to fully charge the battery before the first discharge to eliminate the risk of unbalanced cells caused by heat exposure during transport or storage.

Storage

Nilar battery packs can be stored for several years without loss of performance. Store packs indoors in a dry, clean, cool and ventilated location. Take the packs out of the boxes and store the packs on open shelves. Do not expose to direct sun light, UV-radiation or excessive heat. For long term storage the recommended storage temperature is -20 to +25 °C at a maximum relative humidity of 65 %. For short term storage, i.e. transport, packs can sustain temperatures from -25 to +50 °C.

Installation

Packs can be fitted on to stands, floor-mounted or fitted into cabinets. Packs can be installed in any orientation but possible orientations may be limited by electronics attached to the packs and the design of the battery installation. The preferred orientations are standing on one of the end-pieces or laying on one of the long sides as shown in Figure 8. A minimum of 1.6 cm of free space around the packs is recommended to facilitate heat dissipation. The safety valve is placed on the End piece with the positive terminal marking and it is recommended that the pack is installed with the safety valve oriented in a safe direction regarding personal safety.

Figure 8.
Preferred orientations.

Ventilation

Air ventilation should be provided for in the battery installation to ensure that heat generated by the battery can be dissipated and to allow release of gases from packs in the event of over pressure at abusive conditions. The Nilar battery pack is a sealed design with no emissions of gases or electrolyte during normal operation but at abusive conditions, like excessive overcharge, short circuit or exposure to extreme temperatures, the safety valve may ventilate ejecting electrolyte and flammable gases.

Mounting brackets

Mounting brackets should be mounted on the pack in accordance with Figure 9.

Power cables

The power cables should be connected to the positive and negative pack terminal pillars shown in Figure 10. Ensure that the pack is installed with correct polarity before connecting the pack. It is recommended to protect the connectors by applying a thin layer of anti-corrosion oil. Re-mount the terminal covers after connecting the battery cables.

Make sure all cables are of the same length, type and dimension to minimize the variation in impedance over the battery installation. This is especially important for packs connected in parallel. Ensure that the electrical connections to the packs have appropriate strain relief.

The cable connector lugs should be placed directly on the terminal connector with the washer between the cable lug and the screw head. The terminal connector fastener is of type Hex Cap Screw M6 x 12 mm. Maximum height for cable connector lugs are 1.5 – 2 mm with 2 washers and 2 – 4 mm with 1 washer. Recommended torque for the pack terminal screws is 9.8 Nm.

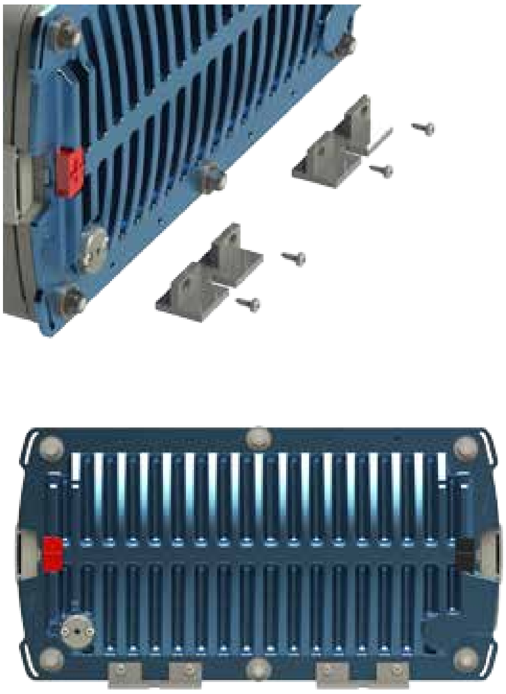


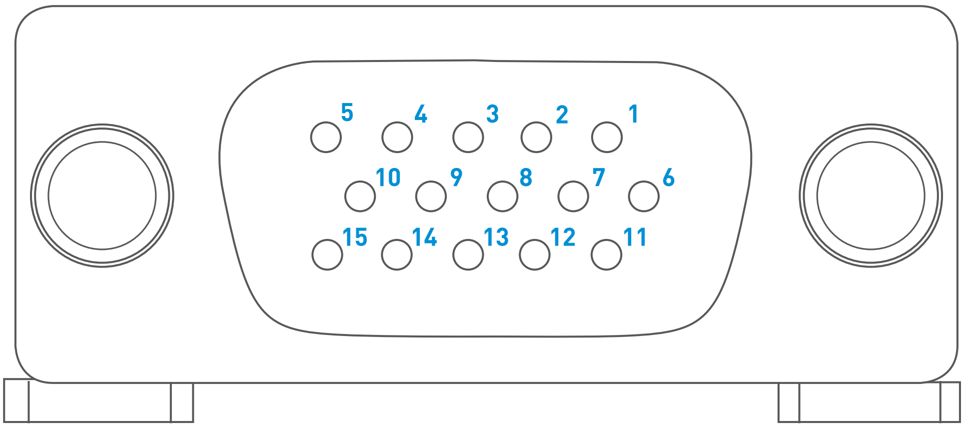
Figure 9.
Fastening of mounting brackets.

Figure 10.
Pack terminal pillar (positive) and fastening of power cable.

15-pin signal connector

The connector for monitoring of module voltages, pack pressure and pack temperature is of type D-SUB with 15 poles and with the female socket mounted in the end-piece. To translate the pressure signal in Volt to pressure in bar equation 1 is used. U is measured DC-voltage between pin 10 and pin 15 when an external voltage of +5 V (DC) is applied between pin 5 and pin 15.

Figure 11.
Connection of the D-SUB connector to the battery.



Equation [1] p = 2.5 * U - 1.25 [bar] 1 bar ≈ 14.5 psi. 1 bar = 100 kPa

D-SUB pin configuration

1. Module 8 Voltage Tap
2. Module 5 Voltage Tap
3. Module 2 Voltage Tap
4. Temperature signal
5. +5 V Signal power
6. Module 10 Voltage Tap
7. Module 7 Voltage Tap
8. Module 4 Voltage Tap
9. Module 1 Voltage Tap
10. Pressure signal
11. Module 9 Voltage Tap
12. Module 6 Voltage Tap
13. Module 3 Voltage Tap
14. Negative Terminal Voltage Tap
15. Signal GND

Maintenance

It is recommended to carry out a visual inspection once a year of the charger, battery packs and electronics to ensure that the battery is operated at optimum conditions. The battery is a sealed battery that requires no topping up with water. The following actions are recommended at inspection.

Check battery cleanliness
A clean battery is important to ensure proper insulation of the battery pack from earth and external conductive parts. A clean and dry battery will also prevent corrosion and make it easier to observe any physical damage to the battery. Dust and moisture can cause leakage currents and affect the performance of the battery system. The safety vent shall be clean and free from foreign objects. The exterior of the battery can be cleaned with water using a damp cloth. Do not use a wire brush or solvents of any kind.

Check tightness of pack terminal screws
Check that all pack terminal connectors are tightly fastened. Recommended torque for pack terminal screws is 9.8 Nm.

Check charger settings
Specified charger settings depend on the application and the type of charger used for the specific battery. It is important that the charger settings are not altered during the life of the battery to ensure optimum performance and service life.

Reapply anti-corrosion oil
Check that the anti-corrosion coating is intact. If necessary, reapply a thin layer of anti-corrosion oil.

Check for signs of venting
If subjected to abusive conditions, such as excessive overcharge, extreme temperatures or short circuit, one or several packs may have vented ejecting electrolyte from the safety valve. A vented Nilar battery pack can in some situations continue to operate without any loss of performance. In other situations the pack may have insufficient amount of electrolyte to achieve designed performance and service life and the battery has to be replaced.

Check for corrosion and physical damage
Corrosion and physical damage to the battery may have a detrimental effect on the battery system and should be assessed regarding possible effects on performance and service life.

Transport

One of the advantages with Nilar battery packs, as compared with many other battery types and especially Li ion batteries, is that UN approved packaging and marking is not required for transport by sea, road, rail and air.

No dangerous goods documentation is required when transporting Nilar battery packs by road or rail.

A dangerous goods declaration is required if batteries are transported by sea in quantities of over 100 kg in one transport unit. Nilar battery packs are then defined as dangerous goods, class 9. UN number and Proper Shipping Name are UN 3496 and Batteries, Nickel-Metal Hydride respectively.

An Air Waybill or similar is required if batteries are transported by air. Nilar battery packs are not classified as dangerous goods and belong to the entry "Batteries, dry" in the list of dangerous goods in IATA (no UN number). If an Air Waybill is used, the words "Not Restricted" and the Special Provision number (A123) must be included in the description of the substance on the Air Waybill, according to IATA-DGR.

The safety precaution that all battery types, including Nilar battery packs, must fulfill in transportation is that the batteries must be separated from each other to prevent short-circuits and be securely packed to prevent movement that could lead to short-circuits. Terminals should be effectively insulated.

In the case of transport in equipment, the battery must be disconnected and exposed terminals must be protected from short-circuits.

Please observe that special regulations apply for defective or damaged batteries that have the potential of leading to a hazardous event during transportation. Please contact local expertise or Nilar for advice regarding transport of damaged or defective batteries.

Disposal

Environmental protection is highly prioritized by Nilar, starting at the design and development of new products, during production and process development, to end-of-life collection, disposal, and recycling. Nilar continuously works to improve all stages of the battery's life cycle with the aim to minimize environmental impact. Nilar stays in the front line of recycling technology by participating in different research programs for recycling. The pack design is optimized for a high level of recycling of the materials and to enable cost efficient recycling processes.

In Europe handling of battery waste is regulated according to Battery directive 2006/66/EC and EU Member state national legislation. Nilar takes full responsibility for taking back our batteries and for the recycling process of our batteries. Returned batteries are systematically recycled and the materials are re-used either in new batteries or in other industries.

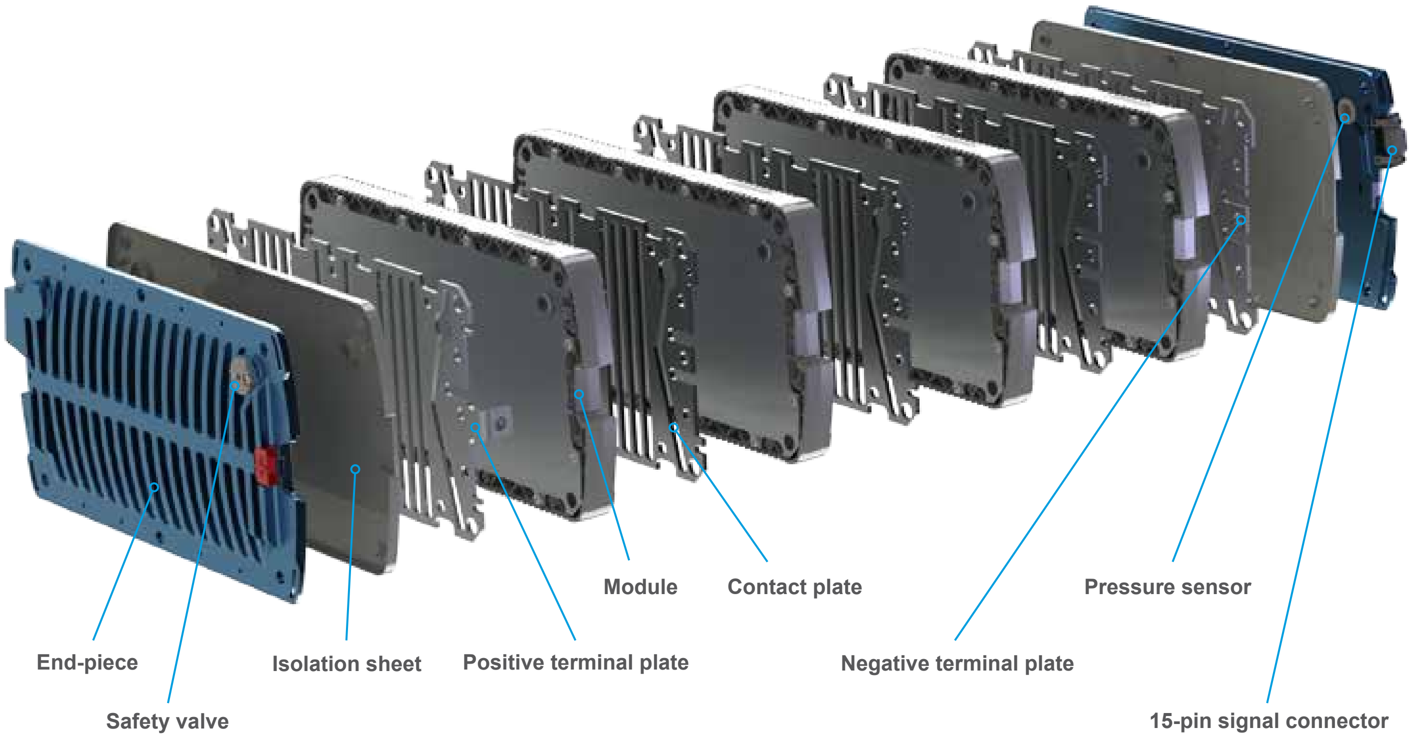
When your Nilar battery is ready for disposal it is recommended to send the battery to the local Nilar battery dealer or to Nilar Svenska AB.

The battery must be protected from short-circuiting during transport. Please see section regarding transport.

Never incinerate or dispose of Nilar battery packs as landfill.

Design

The bipolar design enables Nilar to produce modular batteries with improved volumetric power density and simplified battery construction. The modular concept makes it easy to match packs to different design requirements and to refit existing batteries to new demands in run-time or power. The main advantage of the bipolar design utilized by Nilar is the common and shared large area current collector. This important feature reduces the volumetric overhead of the current collectors and inherently results in uniform current flow across the cell. Uniform current and resistance paths promote uniform heat gradients over the electrodes. A uniform battery temperature promotes a uniform electrochemical aging of the electrodes in the modules, which translates into a long service life.



Pack design

The pack design achieves a compact assembly of cells and other components required in a battery pack to meet required system voltage and run-time. A typical pack consists of 12 different types of components, assembled to a pack by a pick and place manufacturing process, followed by electrolyte filling and formation by a few cycles of charging and discharging to activate the electrochemical system in the cells.

End-piece
There is one end-piece on each side of the pack connected with tie-rods to assure the required cell compression. Besides providing uniform cell compression over the electrode surfaces they also provide impact protection to the modules.

Safety valve
Nilar battery packs are fitted with one self-resealing pressure valve per pack with an opening pressure of 689 kPa corresponding to 100 psi. The pressure valve is located on the end-piece with the positive terminal pillar marking. The pressure valve is only activated at abusive conditions.

Isolation sheet
The isolation sheet insulates the end-pieces from the pack voltage potential.

Terminal plate
The terminal plate is a contact plate with an integrated terminal pillar for connecting power cables to the pack. There is one positive and one negative terminal plate per pack. The terminal connector design of Nilar battery packs does not require any means of sealing between terminal and container to maintain the integrity of the electrochemical system within the cells. The design eliminates the risk of electrolyte or gas leakage through any terminal sealing.

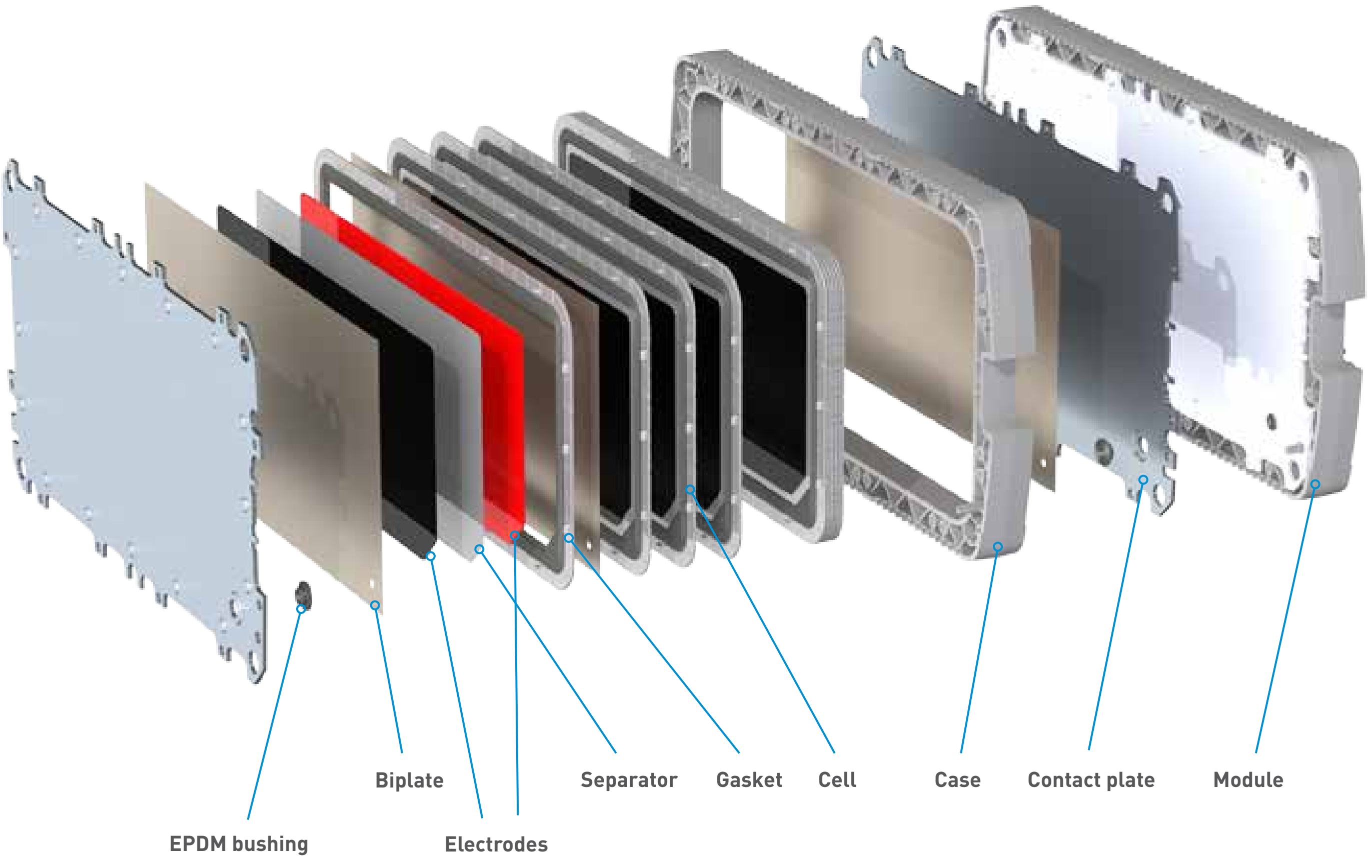
Contact plate
The contact plate electrically connects the adjacent modules in the pack and thus eliminates the need for external connectors between modules. The design of the contact plate allows for efficient active air cooling in demanding high power applications.

Module
Modules with a rated capacity of 10 Ah are the building blocks for all Nilar battery packs.

15-pin signal connector
Connector for monitoring analog signals for pack and module voltages, pack pressure (common for all cells in the pack) and pack temperature.

Modular design

The modules are the building blocks of all packs offered by Nilar. The modules are manufactured in a fully automated pick and place manufacturing process with binders and volatile organic solvents eliminated in the process. The high quality of the modules is an inherent feature of the patented Nilar bipolar design and the state-of-the-art manufacturing process.



Electrodes
The positive and negative electrodes are manufactured by a patented method for compression of dry powders without any expensive plate support material, binders or volatile organic solvents. Active materials and additives, as dry powders, are mixed with each other before being compressed in a calendar system to form continuous sheets of compressed electrode material. The sheets of active materials are cut into electrode plates. The electrode manufacturing process yields very low deviations in electrode plate dimensions, weight and capacity and are one of the main contributions to the high quality of Nilar battery packs.

Separator
The separator prevents electrical contact between the positive and negative electrodes in the cell while holding the electrolyte necessary for ionic transport. The separator consists of a non-woven, melt-blown, acrylic acid-grated polyolefin.

Electrolyte
The electrolyte is a solution of potassium hydroxide and lithium hydroxide. The design is a so called starved electrolyte design with no free volume of electrolyte in the cells. All of the electrolyte volume is absorbed by the positive and negative electrodes and in the separator. The electrolyte will maintain its function over the service life of the battery and does not need to be replaced or adjusted.

Biplate
The biplates, together with the gaskets, are the means for sealing each cell. The biplates also provide electrical contact between cells. The biplates are made of thin nickel foil. Each biplate is provided with an opening to enable electrolyte filling.

Gasket
Each cell is surrounded by a gasket. The gasket together with the biplates provide a seal between the interior of the cell and the exterior. The hydrophobic properties of the gasket prevent the creation of electrolyte bridges between adjacent cells. Each gasket is provided with an opening to enable electrolyte filling.

Case
The case provides impact protection to the cells in the module and prevents the gaskets from being deformed by the cell pressure. The case is made of injection molded polyamide. Openings are provided in the case for the tie rods connecting the end-pieces.

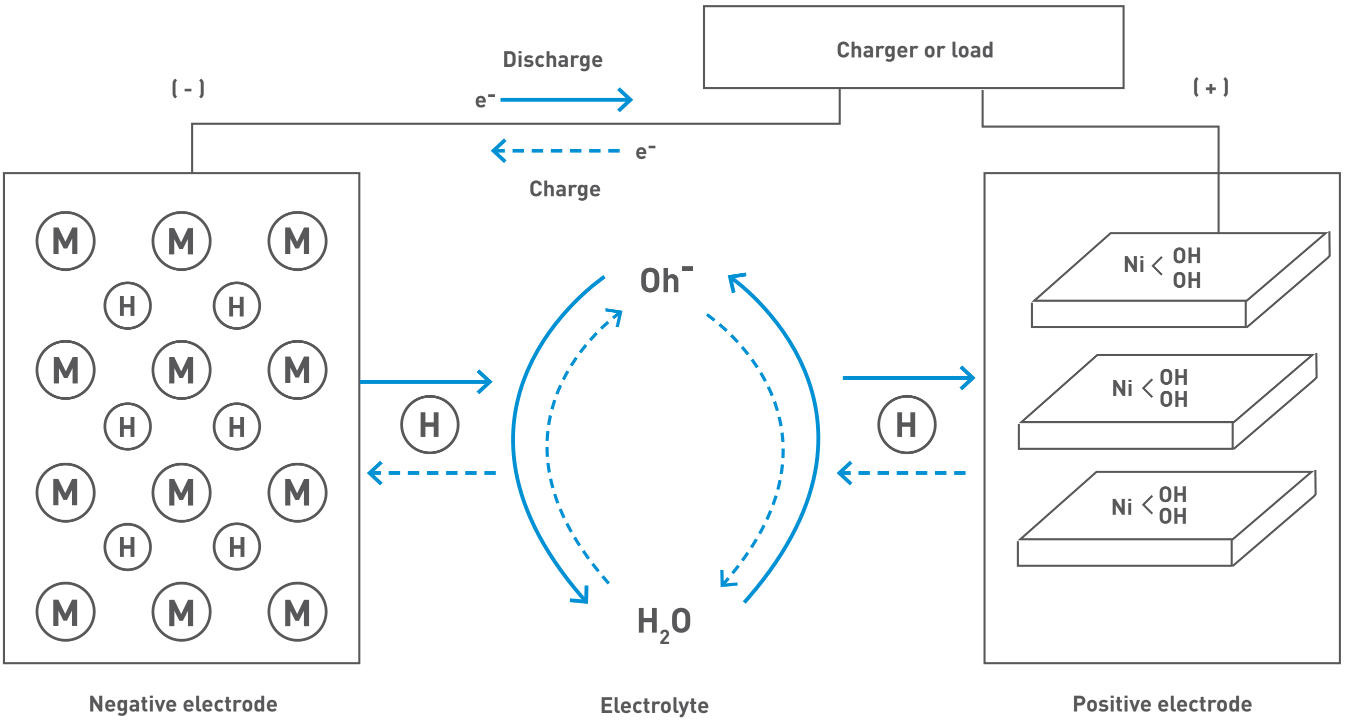


Figure 12.
Electrochemical principle.

Electrochemistry

The Nilar battery would commonly be referred to as a rechargeable nickel metal hydride (NiMH) battery. We also refer to it as a hydrogen or H-battery, due to its close overall similarity to Li-batteries. In H- and Li-batteries, hydrogen or lithium atoms, respectively, move between the electrodes when the cells are charged and discharged. In a charged H-battery, hydrogen atoms are stored in a metal alloy constituting the anode. When the cells are discharged these hydrogen atoms are transferred to the cathode via the electrolyte in the form of water molecules. The chemical energy is essentially contained in an oxygen hydrogen bond.

One major difference between the chemistries is the possibility to include a chemically based overcharge and overdischarge protection in the H-battery. This is a consequence of a water based electrolyte and that hydrogen can form gaseous hydrogen molecules and be transported in the gas space between the electrodes. When the H-battery is overcharged oxygen gas will form at the positive electrode by splitting water molecules at the cathode. In Nilar's design, this oxygen gas can pass through the separator and be recombined again to water at the anode electrode. Thus, no net reaction takes place, but the energy input will result in increased temperature and pressure. These can be monitored and used to terminate charging. Similarly, during overdischarge hydrogen gas will evolve at the cathode but again it can be recombined to water at the anode – again resulting in heat generation and a pressure increase but no net reaction. In extreme cases of overcharge and overdischarge the recombination reaction will not be able to reduce the pressure and the safety valve will open to reduce pressure and avoid cell rupture. The cell voltage allows for a water-based electrolyte to be used. The Grotthus hydrogen hopping mechanism between water molecules in water, gives water-based electrolytes superior conductivity. This adds to safety as the electrodes can be kept well separated by robust separators.

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