# Guide to Effective Warehouse Design, Maintenance, and Modernization

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The **Global Cold Chain Foundation's (GCCF)** mission is to strengthen the global cold chain through education, research, and international development. Cold Chain Institute trains industry practitioners in the best practices of temperature-controlled product storage, handling, and transportation. Research manuals developed by the foundation serve as the definitive guide for the proper handling, storage, and freezing of perishable products as well as energy and facility management.

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## Acknowledgement

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## Executive Summary

This Design Manual establishes a unified set of standards and technical guidelines to support the planning, construction, operation, and maintenance of facilities, aligning with best practices in safety, efficiency, and performance. The manual is intended for engineers, facility managers, designers, and technical consultants who require clear, actionable direction across the full range of facility systems.

To improve accessibility and operational efficiency, this latest edition is being published in a modular format—organized into 15 focused chapters. Each chapter addresses a core system or component of facility design and management, enabling users to quickly reference specific content and apply standards directly to their area of responsibility.

1. Design – Foundational planning principles and performance objectives
2. Maintenance – Preventive strategies and operational reliability standards
3. Structural – Load-bearing frameworks and compliance specifications
4. Walls – Materials, insulation, and environmental controls
5. Floors – Surface treatments, drainage, and durability
6. Roofs – Construction systems, weatherproofing, and safety features
7. Refrigeration – Temperature control systems and efficiency metrics
8. Doors – Selection criteria, access control, and insulation
9. Lighting – Illumination standards, energy use, and fixture design
10. Material Handling – Flow optimization and equipment interfaces
11. Batteries – Storage, charging protocols, and hazard mitigation
12. Fire Protection – Risk reduction measures and system integration
13. Racking – Load standards, anchoring, and spatial planning
14. Dock Equipment – Levelers, seals, and operational safety
15. Automated Systems – Integration of robotics, controls, and data systems

This format enables continuous updates and targeted usage while reinforcing technical consistency across disciplines. The manual is designed to serve as both a foundational reference and an evolving toolset for ongoing facility innovation and compliance.

**What follows is Chapter 11**
**Batteries – Storage, charging protocols, and hazard mitigation**

# Chapter 11: Batteries

## 11.1 Introduction

A battery has three key components that allow electrical energy to be stored as chemical energy. The three components are a positive plate, negative plate, and electrolyte. All batteries undergo reduction / oxidation reactions in order to store electrons that will later be used to power the piece of equipment. There are several types of commercial batteries available which include, but are not limited to: alkaline, lithium, lead acid, and nickel-metal hydride. The lift truck industry is currently dominated by lead acid batteries for two reasons: the power they can generate and the cost they can be manufactured. Another good reason to use lead acid battery technology is the fact that the lead acid battery is 100 % recyclable.

## 11.2 Battery Room Design

### 11.2.1 Battery Room Overview

The battery room is an integral part of the day-day operations, and it is imperative to include its layout in the original floor plan of any warehouse. The location of the battery room should minimize the time spent traveling to and from the battery room and work areas. If the industrial lift truck fleet is dispersed throughout the warehouse or distribution center (DC), a centrally located battery room would be most efficient. For companies where industrial lift truck usage is primarily isolated to a specific area, it is recommended to locate the battery room near the area of highest usage. In larger environments, multiple battery rooms should be considered.

Figure 11. 1

The battery room should be located in an area that allows adequate space for traffic flow in and out of the room. Traffic aisles should be wide enough to allow industrial lift trucks to pass one another as required and should stay clear of obstructions. The size of the battery room is

important. The planned area must be sufficient for the size of fleet it is servicing and should allow room for expected future growth.

Figure 11. 2

The battery room must have adequate electrical service and should be located near a main power feed, as distance from the power feed will increase costs. Chargers, ventilation, heating, cooling, and battery handling equipment all require electricity and should be considered when calculating the power requirements for the battery room. Plumbing, including drainage, will also be needed inside the battery room for battery filling and washing, as well as safety eye washes and showers.

### 11.2.2 Battery Handling Equipment

Weight is a significant safety concern with industrial lift truck batteries. Incorporating handling equipment to move, store, and maintain the batteries must be a priority in the planning of any battery room. Even the smallest battery fleet should have battery handling equipment available for maintenance purposes.

The ideal battery changer will efficiently handle battery changes as often as required. Eliminating a line of industrial lift trucks waiting for changes increases productivity. Considerations for selecting the appropriate battery handling equipment include:

- Overhead Extraction vs. Side Extraction
- Daily number of battery change-outs
- Space available for the system

***Overhead Extraction***

A fork attachment and lifting beam along with sufficient charging racks and/or service stands are suitable for the following applications:

1. Fleets requiring overhead extraction

2. Limited battery changes
3. Removal for maintenance

As an alternative, a small portable gantry crane would increase efficiency by eliminating the need for a second available industrial lift truck. Larger systems requiring multiple changes per day would benefit from a track mounted, powered gantry crane.

***Side Extraction***

For fleets with side extraction, choices are similar, but more options are available. Small park and charge operations may only require a manual transfer carriage and battery service stand for battery maintenance purposes. Multi-shift operations with a small fleet and minimal battery changes per day may find that a powered transfer carriage will make the battery changing process more efficient and then the manual transfer carriage.

For maximum efficiency in larger fleet operations, a fully powered Operator Aboard Battery Extractor will be required. Operator Aboard Battery Extractors are available in multi-level systems. Deciding which system is right depends on space availability and the number of batteries to be stored. Ceiling height of the battery room may eliminate some options. Depending on the charger quantities, specifications, and stackability, the system layout may require additional charger storage stands. Increasing the system height can save between 10% and 50% of floor space *(see figure 11.3 below)*.

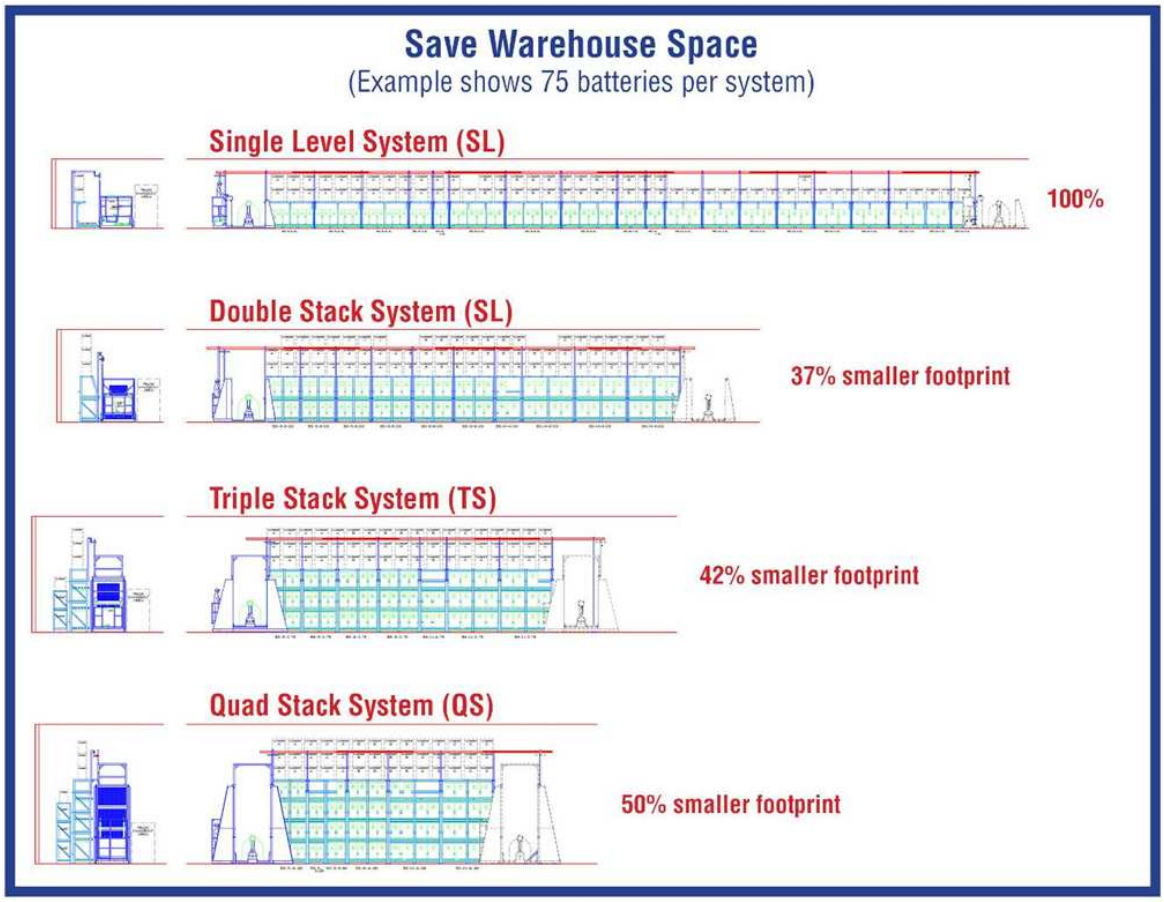



Figure 11. 3

It is common for an industrial lift truck and battery fleet to consist of multiple types and sizes. It is important that the battery handling equipment is designed to safely transport all of the batteries in your fleet.

**BHS Equipment Application Guide.** The following chart may assist in determining the proper battery handling safety (BHS) equipment according to the number of stored batteries in the warehouse.

| Number of Stored Batteries | BHS Equipment Recommendation | Change-out Time | Type of Extraction |
|---|---|---|---|
| 1 – 49 | BE-SL (Single Level) | 2 – 3 minutes | Operator Aboard Side Extraction |
| 40 – 139 | BE-DS (Double Stack) | 2 – 3 minutes | Operator Aboard Side Extraction |
| 140 – 299 | BE-TS (Triple Stack) | 2 – 3 minutes | Operator Aboard Side Extraction |

| | | | |
|---|---|---|---|
| 300 – 619 | BE-QS (Quad Stack) | 2 – 3 minutes | Operator Aboard Side Extraction |
| Up to 50 Batteries | MBE (Mobile Battery Extractor) | 3 – 5 minutes | Side Extraction |
| 15 – 18 | ATC (Automatic Transfer Carriage) | 3 – 5 minutes | Side Extraction |
| 2 - 3 | BTC (Battery Transfer Carriage) | 5 – 8 minutes | Side Extraction |

Table 11. 1

### 11.2.3 Maintenance

Daily inspections by trained operators along with planned maintenance are vital to the battery handling equipment's functionality and operator's safety.

Frequent inspections support the prevention of system malfunctions while planned maintenance, such as lubrication and cleaning, ensure proper system operation. It is imperative that all battery handling equipment sustain a scheduled maintenance program. The battery handling equipment's owner and operator manual should be referenced for maintenance checklists and intervals. In addition, the BHS Service School is offered as an excellent tool to advance the knowledge of the battery handling equipment's operators and technicians.

### 11.2.4 Battery Room Floors

The floor of the battery room should be code approved flooring which resists acid damage. Consult applicable building codes and regulations issued by the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), the National Fire Protection Association (NFPA), and others. The BHS Operator Aboard Battery Extractor operates on a fixed travel path that requires a defined specification.

An uneven floor in a fixed travel path causes vibration, flexing, and stress on equipment resulting in decreased productivity of the Operator Aboard Battery Extractor. Lift heights of battery extractor systems magnify the effect of an uneven floor. As elevation increases, so does the amount of flex and strain on the machine. A floor with an appropriate F-min rating provides for safe and proper operation of your equipment. Consequently, you will save money with fewer

repairs, fewer parts purchased, less downtime, and less potential for personal injury or equipment damage.

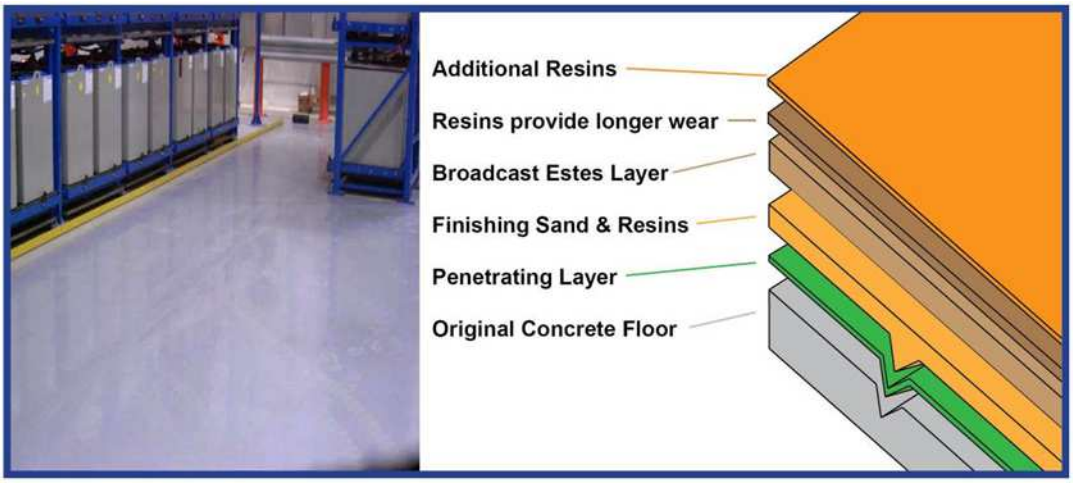



Figure 11. 4 Recommended floor layers in a battery room

A single number, F-min, is used to measure the floor flatness and levelness for defined traffic paths. F-min rating results from four different F-numbers representing the floor's longitudinal levelness, longitudinal flatness, transverse levelness, and transverse flatness. The floor is measured along the exact travel path that each wheel of the Operator Aboard Battery Extractor follows. Changes in elevation along each wheel path are used to determine whether the floor meets the specified F-min requirements. Any area of the path that falls outside of the specification is identified for correction as part of the measurement process. As systems increase in height, any defects in the floor further amplify both static and dynamic shifts of the load while traveling.

**Defined Traffic Floor Requirements for Operator Aboard Battery Extractor Travel Path**

| **American Concrete Institute 117 (ACI 360)** | |
|---|---|
| **Machine Type** | **F-min** |
| SL, DS | 40 |
| TS | 60 |
| QS | 85 |

Table 11. 2 Minimum F-min requirements to ensure satisfactory operation. Note: Contact factory if seismic certification is needed.

### 11.2.5 Battery Management

Improper battery rotation is a leading cause of reduced battery run time and reduced battery life. Tests have shown that when battery selection is left to an operator, thirty percent of batteries will be underutilized while another 20% will be overused. Underutilized batteries will lose capacity due to corrosion on the plates. Over utilized batteries do not have time to cool and become over-heated, causing corrosion which leads to a shortened life. Proper rotation of all batteries is

required in order to ensure maximum battery life and run time. Selecting the battery that has the longest cool down time since charging ensures proper rotation.

First-in-first-out systems, such as BHS' FleetTracker, select the next available battery based on the battery's time on the rack. The battery which has been on the rack the longest will be logically selected, as it is the battery which has had the longest cool time after charging. This type of system requires no input from the chargers or the batteries, so there is no additional wiring, or modules to connect. The system can track multiple battery types. The addition or removal of batteries, racks, or trucks can be done simply at any time. The FleetTracker system also alerts operators when batteries require equalization, washing, or watering based on parameters set by the user during setup. Unauthorized use of the extractor can be prevented by requiring a user to login to the FleetTracker in order to activate machine travel. All transactions are recorded and all information is available for review in a variety of reports. These reports track battery and truck usage, maintenance intervals, and operator performance. Review of the battery and truck usage may identify shortages or overages in fleet availability. This allows the battery room to be "right-sized", avoiding costly wastes of time, space, and energy.

Figure 11. 5 FIFO BHS FleetTracker Battery Tracking System

Multiple charger monitoring systems, like the BHS NAB-2000, utilize the same first-in-first-out theory, but do so by monitoring the charge state of all of the batteries on charge. Remote modules on each charger monitor charger output and queue the batteries in the order charging was completed. Again, the battery with the longest cool down time is shown as the next available. If no batteries have completed charge, batteries are displayed in order of most fully charged. By monitoring the charger output, the NAB-2000 can also alert operators when a charger does not come on, when chargers shut off prior to the battery reaching an 80% charge, or when chargers do not shut off after 15 hours of runtime.

Figure 11. 6 Multiple Batter Charger Monitoring System

Regardless of the system chosen, ensuring that batteries are properly rotated, even by simply recording information manually, will not only increase the lifespan of the batteries but also the overall efficiency of the battery room.

### 11.2.6 Charger Storage

To save floor space and comply with OSHA regulations, chargers should be mounted to shelves or stands designed for that purpose. Many charger layout variations are available depending on the size of the fleet and space requirements. The chargers must be mounted securely in all four corners, regardless of the quantity. Chargers can often be stacked, but it is important to follow all manufacturer's instructions and recommendations. Manufacturer's instructions must also be followed when spacing the chargers to allow adequate ventilation during use.

When positioning battery charger cabinets, consideration should be given to the charger DC cable lead length. It is important to design the battery charger layout in a manner that enables the charger DC cable leads to connect to the battery, yet ensures that the charger manufacturer DC cable lead length specification is not exceeded.

Accommodations should be made for charger maintenance during the design of the battery room layout. The incorporation of a catwalk and/or multi-level charger shelves into the overall system design allows for easy accessibility to the chargers.

### 11.2.7 Safety

Safety equipment is essential in the design and planning of the battery room. Proper planning is necessary in order to provide a safe and productive environment for those operating and maintaining the equipment. Hydrogen gas can reach dangerous levels in the warehouse. It may be required to install hydrogen gas detectors which will activate ventilation and alarms when this occurs. Installation of emergency wash equipment is imperative. Personal protective equipment must be available to machine operators and maintenance personnel. This equipment includes acid-resistant face shield, goggles, gloves and apron. Nonconductive tools for maintenance must also be supplied. It is necessary to keep spill kits on site to control spills of dangerous materials such as battery acid.

As part of all safety programs, it is important that warehouse management properly train personnel. Operators must be trained on the proper operation of the battery handling equipment. This training includes daily inspections which help to determine that the equipment is in proper operating condition and safe for use. Personnel must also be trained on the use of the personal protective equipment. Appropriate signage denoting locations of safety equipment must be

present. Other signage marking travel paths, pedestrian warnings and other safety related information are also recommended.

### 11.2.8 Personnel

The proper training and management of the battery handling equipment is crucial in determining its lifespan and efficiency. It is recommended to assign a dedicated battery handling equipment operator to manage all industrial lift truck battery change-outs as well as the battery handling equipment's maintenance. A dedicated operator is responsible for performing the daily inspections, planned maintenance, and all repairs thus heightening his or her familiarity with the battery handling equipment and its functions. Implementation of a dedicated operator increases productivity and ensures the battery handling equipment's preservation.

## 11.3 Battery Design

This section provides basic information to understand how batteries and chargers react and perform during their daily use in a warehouse. This section will also discuss effective ways to charge batteries to get the longest life.

### 11.3.1 Design Overview

What is a lead acid battery? Lead acid batteries were invented in 1859 by Gaston Plante. It is the oldest form of a rechargeable battery. It is a unique battery in the fact that both the positive and negative plates become lead sulfate when the battery is discharged, most batteries have two different types of material for their positive and negative plates. The electrolyte used in all lead acid batteries is sulfuric acid. Because two of the major components of the battery are made of lead, a lead acid battery has two major disadvantages to other battery technologies: low energy to weight and energy to volume ratios. The first is not as much of a disadvantage when used in forklift trucks because most batteries are a significant part of the counterbalance requirement of the forklift truck. However, these disadvantages mean that the batteries need to be fairly large and very heavy to supply the energy needed to run a forklift truck.

Battery charging is typically done one of two ways. It is either done in a two-stage process, or a three-stage process. The two-stage process is much easier for charger manufactures to write controls and algorithms, so early on this type of charge dominated the market. They soon realized that this type of charge had some detrimental effects to batteries if the charger was under or oversized. Usually the charger was under sized to save money and hence the battery would not get enough ampere-hours returned to bring the battery to a full state of charge. This undercharge would cause a significant reduction in battery life. The over sizing of a charger also causes a significant reduction in battery life do to over charging the battery which creates heat and excess sediment to deposit on the bottom of the cell or cover the sides of the plate (mossing.) In either case this sediment would then cause a short between the positive and negative plate and cause the battery to not perform. As control boards and circuitry technology improved, the charger manufactures realized they could help prevent these two problems by going to a three-stage charge. The three-stage charger has a constant current portion to top off the battery once it

reaches about 80 to 90 percent state of charge. This allows the battery to get the right amount of over charge so that the life of the battery is not significantly affected.

### 11.3.2 Terms and Definitions

- **Battery Rating -** The amount of power a battery can give over a specific time period. In order to get more power, either cells need to be added, or plates per cell need to be increased.
- **Battery Voltage -** The number of cells is determined by the required nominal operating voltage of the equipment. Since each cell has a nominal of two volts, a thirty-six-volt industrial lift truck will require an eighteen-cell battery (2 volts/cells * 18 cells = 36 volts.)
- **Ampere-hour (AH) -** The electrical capability of a storage battery is usually expressed in ampere-hours. The ampere-hour capacity is the number of ampere-hours which can be delivered under specified conditions of temperature, rate of discharge, and final voltage. Basically, ampere-hours are determined by multiplying the number of amperes which the battery will deliver by the number of hours during which the current is flowing.
- **Positive Plate Capacity -** Positive plate capacity is the ampere delivery for a fixed period of time (usually six hours) for a particular size positive plate. Example: A Deka D100 type positive plate has the capability of delivering 16.66 amperes for six hours or hundred ampere-hours (16.66 amperes * 6 hours = 100 ampere-hours) to a final voltage of 1.70. Increasing or decreasing the number of positive plates in the cell can vary this ampere-hour rating or capacity. To determine the battery capacity, take the total number of plates and subtract one. The answer is then divided by two and multiplied by the rating of the plate.

Example: The previous example is an 18-D100-13 battery. So, 13 plates – 1 plate / 2 = 6 plates * 100 ampere-hours / plate = 600 Ampere-hours.

- **Specific Gravity -** The term specific gravity describes the ratio of the density of electrolyte to the density of water. Electrolyte weighing 1.2 times as much as the same value of water has a specific gravity of 1.200. The full charge specific gravity of a cell is a matter of design and depends on several factors. The specific gravity must be high enough to contain the amount of sulfuric acid necessary to meet the chemical demand of the cell. If the sulfuric acid content is too high, damage may result to the cell. Since the acid content of the electrolyte decreases linearly as the cell is discharged, a decrease in the specific gravity is directly proportional to the amount of ampere-hours removed.

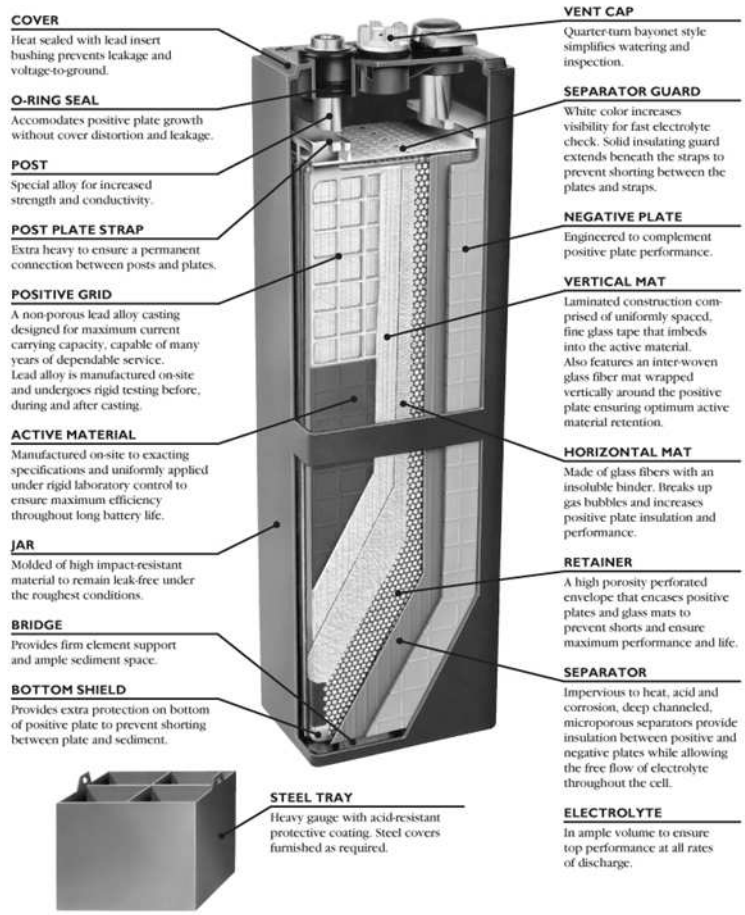



Figure 11. 7 Basic components of a battery cell and their functions

## 11.4 Battery Maintenance

There are several keys steps that should be followed when receiving a new battery to put into service. First, if there are any signs of rough handling, damage to the battery, or electrolyte leakage file a claim with the carrier immediately and advice your battery consultant. Once the battery is received check each cell and insure that the electrolyte level is above the separator protector. In taller cells, enough gas may have been displaced during shipment to drop the level just below the separator protector, but should be visible with a flash light through the holes in the protector. If the electrolyte is not visible contact your battery consultant. If the electrolyte level is ok the battery may be given its initial charge.

Check the nameplate of your charger against the nameplate of the battery to ensure that they both show the same voltage and that the six-hour ampere-hour capacity falls within the eight-hour recharge range of the charger. If both of these items do not match, contact your battery consultant. The next step is to ensure the battery is the proper type for the industrial lift truck in which it will be installed. The voltage of the battery and the truck should agree as well as the "Battery Type Identification" (E, EO, EE, or EX). The service weight of the battery which is

stamped on the side of the tray below the lifting hole must fall within the battery weight range on the truck nameplate. This is necessary so the truck has enough counterbalance so as not to tip over when lifting. Finally, give the battery an equalize charge and ensure the electrolyte levels are visible above the separator protector and the specific gravity is between 1.280 – 1.295 when temperature corrected to 77° F (25° C).

Upon installation in the truck, all the battery restraints should be adjusted so that the battery moves no more than ½ inch in the horizontal direction. An insulated spreader bar should be used any time the battery is lifted or hoisted. Batteries should not be discharged more than 80 % of their rated capacity to achieve longest battery life.

All batteries must be properly maintained, or there will be a significant reduction in battery life and efficiency. A good battery maintenance program needs to keep accurate records of battery cycles and repair / maintenance work done to all batteries. Another part of the maintenance program is regular battery inspections. A visual inspection of the battery every time the battery is put into or out of service will help maintain a proper battery. Keys things to look for during the battery inspection are: Corrosion on the tray, terminals, or intercell connectors; leaks or damage to the cell; damaged cable leads, terminals, or connectors; and damaged, clogged, or missing vent caps. All of these items should be repaired as soon as they are found to ensure long battery life and efficiency. A major hurtle for battery maintenance is to water the battery cells on a weekly basis (1 time per 7 days) unless the application requires more frequent watering. A battery should be watered either during or just after an equalize charge. Only approved water should be used to water cells because certain impurities reduce battery life and efficiencies. The last general rule is to equalize your battery on a weekly basis to ensure that all sulfates are removed from the plates and thoroughly mixed into the electrolyte. An equalize charge also is responsible for evening out the cells. There is always a weak cell in a battery that requires a little more charge than the others to get the voltage back, or the specific gravity into nameplate rating. This additional charge every week at or close to the finish rate is able to do that and keep the battery healthier for a longer period of time.

| | Daily | Weekly | Monthly | Quarterly |
|---|---|---|---|---|
| Visual Inspection | X | | | |
| Electrolyte Level | | X | | |
| Addition of Water | | X | | |
| Equalize | | X | | |
| Specific Gravity | | | X | |
| Clean Top of Battery | | | X | |
| Battery Cables | | | X | |
| Charger output | | | | X |
| Water System Injectors | | | | X |
| Battery Cell Voltage | | | | X |

Table 11. 3 Suggested battery inspection schedule

To determine the health of a battery or whether or not the battery should be replaced, a discharge test (capacity test) should be performed. The test is conducted by discharging a fully charged

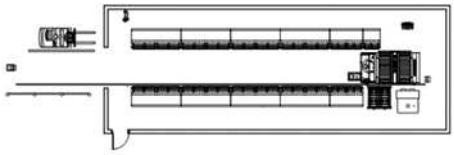
battery at the six-hour rate until the battery voltage drops to a final voltage of 1.70 volts per cell, times the number of cells in the battery. The six-hour rate in amps is a number equal to the rated capacity at the six-hour rate divided by six hours. By noting the elapsed time when the battery reaches the final voltage, you can determine if the battery is delivering its rated capacity. Take the elapsed time in minutes and divide by 360 and then multiply by 100. This calculation is the battery's capacity. A battery should deliver at least 80 percent of its rated capacity or should be replaced.

In order to receive the longest life of a battery, a pilot cell should be chosen upon receipt of the battery. This cell should be near the middle of the battery and can be marked in some way to distinguish it. Before and after every charge cell this pilot cell should have its voltage, temperature, and specific gravity recorded. This data should be recorded and trended over time to help determine the battery health. If any of these readings start to deviate from the original reading your battery consultant should be contacted immediately. The remaining cells of the battery should be compared to this cell on a monthly basis in order to determine their health. If any of these cells deviate from the pilot cell, your battery consultant should be contacted immediately. It is much easier to correct an issue the earlier it is detected, and there is less loss of life on the battery with the issue being corrected as quickly as possible. For instructions on the best practices to obtain these readings contact your battery consultant.

## 11.5 Power Lift Technologies

This section will act as a guide to various power technologies and their impact on the building design. The most common forms of power technology are lead acid batteries, fuel cells, and lithium ion. Various charging methods for lead acid batteries will also be explored. The selection of a power technology will have a direct impact on operations, work flow, and power cost. Traditional lead acid batteries and battery charging methods for material handling equipment have changed in recent years. The traditional means of centralized charging of lead acid batteries is also being challenged. Charging methods of lead acid batteries now ranges from traditional battery rooms to opportunity and fast charge systems. Fast charging utilizes newer power electronics to provide energy to industrial batteries very quickly. Challenging lead acid batteries are other technologies influencing conventional material handling equipment including newer battery technology with lithium ion batteries and the use of hydrogen fuel cells. Selection of a power technology has long term effects on the building design, operation, and energy costs of a facility.

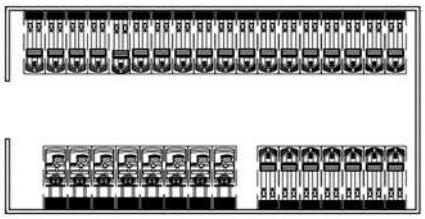
### 11.5.1 Lead Acid Batteries



CENTRAL BATTERY
HANDLING/ CHARGING

Figure 11. 8

**Lead Acid Battery Fast Charge**



CENTRALIZED
PARK & CHARGE

Figure 11. 9

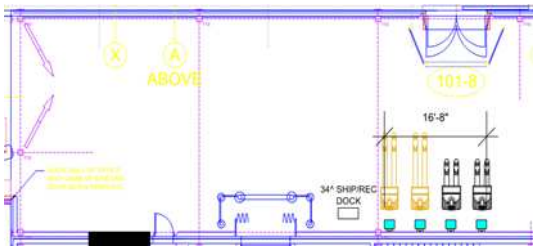



Figure 11. 10 Fast Charge on a Dock

Lead acid batteries are the most common power technology used in the cold storage warehouses. Large industrial batteries are charged with electric current. These batteries serve as the primary power source for most material handling equipment.

The motive power battery/industrial lead acid battery is an assembly of cells used for the primary purpose of propelling a vehicle.

**Discharge Process:** As the cell discharges, the acid separates from the electrolyte in the pores of the plate and attaches itself to the plate material changing it into lead sulfate. The process continues throughout the discharge and as it proceeds, the remaining solution becomes more water than acid. The acid is the conductor and the water is an insulator causing the energy transfer process to become less and less efficient between the plates.

**Charge Process:** When the cell is placed on charge the process is reversed. The $SO_4$ (Acid) is driven out of the active plate material back into solution thus increasing the specific gravity in the solution. As the charge is completed all components of the battery are back to their original make up (positive is lead peroxide ($PbO_2$); Negatives, sponge lead (Pb)) and the acid is back into the electrolyte solution.

**Battery Life Expectancy:** Except for lightly-worked or infrequently-cycled batteries whose life is likely to exceed normal expectancy, most battery applications are sized to run one shift for 5-6 years in typical change out applications and 3-5 in opportunity or fast charge applications. Other

factors influencing battery life are: operating temperature, quality and design of battery, quality of charging, watering practice, cleanliness, acid loss, and grounding.

**Normal Life Expectancies:** Assuming 300 cycles per year and discharges limited to 80% of rating, good charging and proper care, the normal life expectancies are five years for flat-plate and six years for tubular. Whenever a shortened battery life is detected, examine the life-influencing factors as noted above, as well as the cycle rate and depth of discharge. In claims of short life, it is often found that the battery was short-life in time only, but delivered a normal number of cycles or amp hours

When operating in cold environments, the average lift truck battery life cycle and rate of charge can decline by 20% - 50%, meaning a battery rated for an 8-hour cycle in ambient warehouses might only last 4 to 6 hours in the cold. The capacity of a lead acid battery is reduced at low temperatures due to the increased viscosity and resistance of the electrolyte.

An approximation of this reduction in capacity for batteries of these types is shown below:

Internal Temperature of Cell (°F) Percent Capacity

77° = 100%

60° = 095%

40° = 087%

20° = 073%

In the coldest freezer applications, it may be necessary to exchange the battery up to 5 times in one day. Batteries operating at sub-normal temperatures, due either to climate or to working in cold-storage plants, will have their electrical capacity reduced. This in turn will impair vehicle performance.

**Charging:** Batteries that are cold are harder to charge and the charger must be set to put out more current to get the job done. Some chargers will have a setting for temperature correction in cold storage environments. It is imperative that all batteries being used in Freezer Applications are charged on a charger with a specific charge profile developed to deal with heavier acid densities and higher battery resistances (i.e. - Cold Storage Charger). It is advised that when looking at charging equipment being used in these applications that the charger have the capability to have the ambient average temperature as an adjustable setting in the program to arrange the proper charge profile for the operations batteries.

A lead-acid motive power battery can be an extremely useful, safe, source of electrical power. On the other hand, if improperly used, it can be an extremely dangerous piece of equipment. The difference between the two conditions is determined by the care and safety procedures exercised in handling batteries. Before considering the safety procedures, first consider the hazards inherent to a lead-acid battery.

**Safety Hazards:** A lead-acid battery, by its very construction, exposes working personnel to four potentially dangerous elements: sulfuric acid, explosive gases, electricity and heavy weight.

A sulfuric acid solution is used as the electrolyte in lead-acid storage batteries and has a concentration of approximately 40% by weight of sulfuric acid in water. Even in this diluted

state, sulfuric acid is a strong oxidizing agent and can burn the skin and eyes and "eat" holes in clothes made of many common materials.

An explosive mixture of oxygen and hydrogen is produced in a lead-acid storage battery during the charging process. The two gases can combine explosively if a spark or flame ignite them. Because hydrogen is so light, it normally floats away and disperses into the air before it can collect into an explosive mixture. However, if it accumulates into gas pockets, it will explode when ignited.

A lead-acid battery is capable of discharging at extremely high rates and under conditions of direct shorting, which can cause much damage and serious injury. The weight of these heavy batteries can crush hands and feet if care is not taken when charging and handling them. Adequate and proper handling equipment should be provided. The average lift truck battery weighs over 2000 pounds.

Ventilation and Fan cost can be as high as $8 per square foot and depending on location may need to meet specific codes. Reference Mechanical Ventilation and Institute of Electrical and Electronic Engineers (IEEE) Standard 484-2002. Additionally, Fire Suppression guidelines may need to be followed Such as NFPA-13.

**Battery Costs:** Operators using electric vehicles will need to add the battery and charger to the cost of the lift truck. Continuing to compare the 2,000-hour per year operation or 167 hour per month, data suggests electric lift trucks use 3 to 4 kWh per hour. In that operation, the expected monthly usage on the electric vehicle would be 500 – 700 kWh per month. Assigning the proper battery for that operation depends on the client's operation and available time to recharge the battery. These constraints will affect the price of the power because of the amount of the power needing to be returned. If the operator has more time to charge the batteries, a smaller charger may be used resulting in decreased costs.

**Monthly Cost of a Forklift's Battery and Charger:** Using 167 hours per month over a five-day workweek, the daily usage of approximately eight hours yields a 24 to 32 kWh usage by the electric lift truck. In this example, a 40-kWh battery would provide the necessary power to complete the daily usage. In smaller footprint vehicles, two 20 kWh batteries could fulfill the energy requirement. The estimated price for a 40-kWh battery and high efficiency charger at the end of 2016 is approximately $ 10,000.

*Note: (Specify specific scenario to be used for comparison on all power methods)*

**Cost to Charge an Electric Forklift Battery:** Assumptions of the higher energy usage of the Electric vehicle will be calculated at 40 kWh per day or 700 kWh per month. According to the Department of Energy estimates the national cost of energy at $ 0.09 cents per kWh. Accounting for the recharge efficiencies of forklift chargers in lead acid batteries, a conservative estimate of 25 % can be added for estimations. Monthly estimates of 700 kWh + 25% = 875 kWh used each month. At $ 0.09 cents per kWh, the operator would see a monthly cost of $ 79.00 in electricity costs per battery.

**Peak Demand:** In some locations Monthly Peak Demand Charges could be increased due to concurrent multiple batteries charging. Care should be taken to schedule charging during off

peak times when refrigeration load is at its lowest point to avoid setting a new peak demand while charging multiple batteries at the same time.

**Maintenance Costs:** PM Costs are approximately $80 per year per battery and charger, excluding parts costs.

**Battery Watering:** Lead acid batteries need weekly maintenance. As the cell approaches full charge it cannot absorb all the charging current. The excess charge breaks up the water which passes off the battery as the gases of hydrogen and oxygen. This lowers the water content of the cell which typically requires the function of replacing the water on a weekly basis.

**Operator Costs:** When a battery suffers a loss of charge it must be swapped out with a fully charged battery. A single battery change takes somewhere between 10-15 minutes. In a large warehouses a battery handling system operator may be required, resulting in an additional full time position at the approximate cost of $35,000-$50,000 per year per shift.

**Battery Room:** A battery room with an extractor is typically 1,500-2,000 sq. ft. Construction of the dedicated charging room is an expected cost of $65,000 – $140,000

- Construction of the dedicated charging area- $30-$40 per square foot
- Ventilation fan and duct work- $5-$8 per square foot
- Special floor coating to protect against acid spills- $9-$12 per square foot
- Additional cost: roll up door $20,000

**Cost of Ownership:** Based on a facility having 100 Batteries and 50 Chargers the following costs could be expected to purchase and operate lead acid batteries. It would be expected that you would need to replace the Batteries sometime between year 5 and year 10.

| Lead Acid Battery Central Battery Charging/ extractor | |
|---|---|
| Construciton Cost | $ 140,000 |
| Equipment Cost | $ 797,500 |
| Operation and Energy Cost | $ 427,750 |
| Year 1 Cost | $ 1,365,250 |
| | |
| 1 year cost per battery | $ 13,653 |
| 5 year cost per battery | $ 30,763 |
| 10 yer cost per battery | $ 60,125 |

Table 11. 4

| Lead Acid Battery Centrelized Park and Charge | |
|---|---|
| Construciton Cost | $ 350,000 |
| Equipment Cost | $ 747,500 |
| Operation and Energy Cost | $ 427,750 |
| Year 1 Cost | $ 1,525,250 |
| | |
| 1 year cost per battery | $ 15,253 |
| 5 year cost per battery | $ 32,363 |
| 10 yer cost per battery | $ 61,225 |

Table 11. 5

## 11.5.2 Fuel Cells

**Fuel Cell Technology.** Fuel cells, or more specific hydrogen driven fuel cells, combine chemically hydrogen and oxygen, generating electricity and heat.

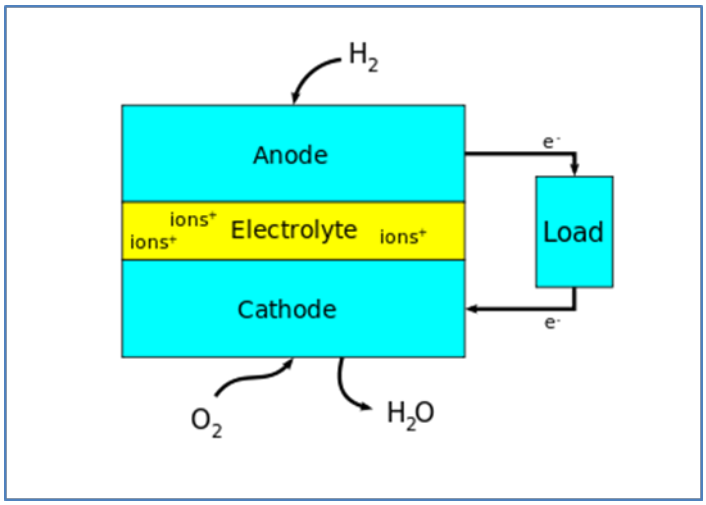



Figure 11. 11 Fuel Cell, Block Diagram

There are different types of fuel cell technologies. The best selection for fork lift application is based on operating temperature, the lower the better, see Figure 11.12. We also can exclude methanol powered fuel cells because carbo dioxide is the product of the process and will be release into the environment. Conclusion: PEM Polymer Electrolyte Membrane Fuel Cells are the preferred fuel cells for forklifts.

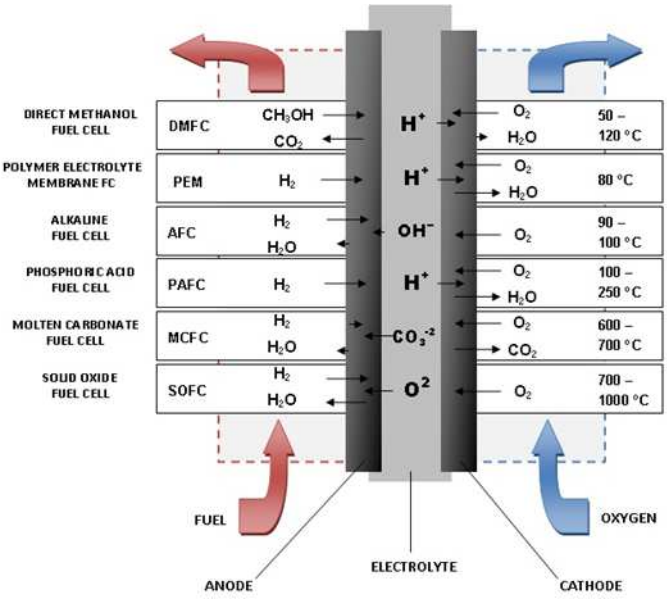



Figure 11. 12

Figure 11.13 shows more details of a PEM fuel cell. Typical efficiency of PEM FC is between 50% and 70%.

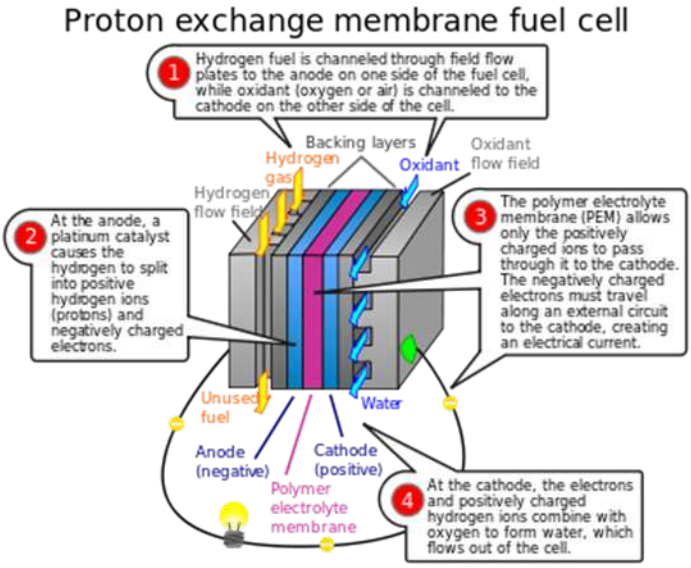



Figure 11. 13 Proton Exchange Membrane Fuel Cell

**Operation.** Fuel cells can work in low temperature refrigerated warehouses. The typical operating temperatures are from -40°C (-40°F) to +50°C (122°F). Thus, fuel cell powered material handling equipment (MHE) is an alternative to battery powered MHE. While batteries have to be recharged with long recharging times fuel cells will be reloaded in a few minutes. Fuel cells also have a longer operating time between refueling compared to batteries.

Figure 11. 14

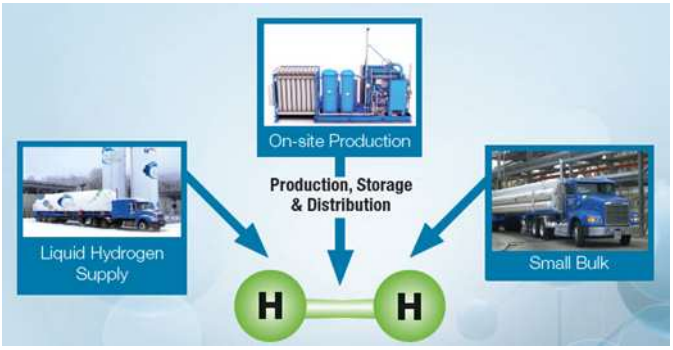



Figure 11. 15

The necessary infrastructure consists of dispensers and either hydrogen storage or hydrogen generator at the facility (figure 11.15). Existing MHE's can be retrofit with fuel cells. The small foot-print dispensers or refueling stations can be conveniently located into existing space (figures 11.16 & 11.17). For smaller facilities and where there is no space for onsite hydrogen generation storage cabinets can be distributed to meet facility requirements (figures 11.18 & 11.19). Where applicable onsite hydrogen generators may be a good alternative to being dependent on hydrogen suppliers, in particular when installed before the end of 2016, because the cost can be reduced by a 30% federal investment credit. It is estimated that an onsite hydrogen generator is financial feasible for fleets of 40 forklifts and more (figure 11.19).

Figure 11. 16

Figure 11. 17

Figure 11. 18 Hydrogen Storage Cabinet

Figure 11. 19 Outside Hydrogen Generator and Storage Unit

**Cost of Operation.** Typical cost for fuel cell is estimated to be between $14,000 and $30,000. The average fuel cell system lifetime is 10 years, with the fuel cell stacks refurbished every 3 years. The cost of hydrogen (including delivery and storage) is priced at $8.00 per kilogram.

NREL published a report called "An Evaluation of the Total Cost of Ownership of Fuel Cell-Powered Material Handling Equipment" in April 2013. The evaluation was done for a fleet of about 60 lifts for 2 -3 shifts per day, 6 – 7 days a week. NREL found that for Class I and II forklifts (three- and four-wheel, sit-down, counter-balanced forklifts) used in multi-shift operations, fuel cell could reduce the overall cost of ownership by 10%, from $19,700 per year per lift truck to $17,800 per year per lift truck. The cost of ownership of Class III forklifts (also known as pallet jacks) can be reduced by 5% from $12,400 per year to $11,800 per year for each lift truck. Details are shown in figure 11.20.

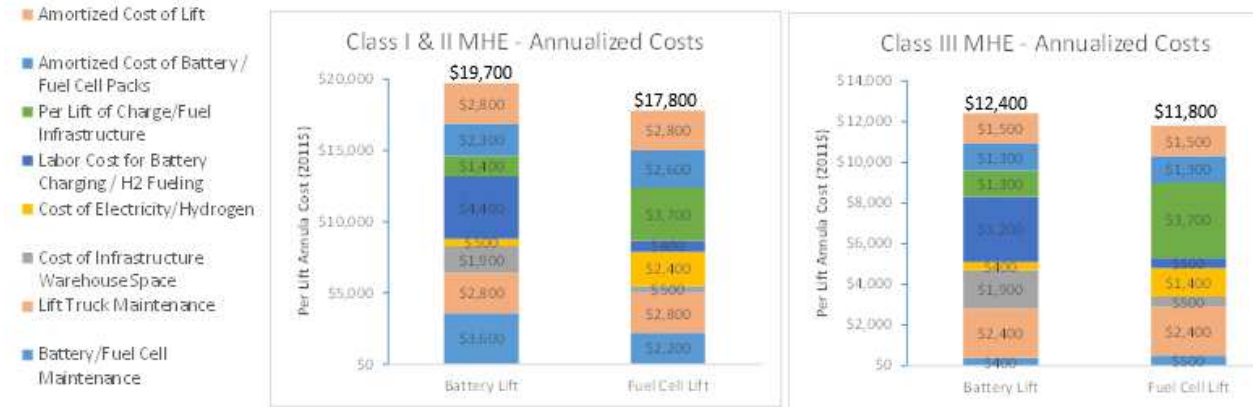



Figure 11. 20 Total annual cost of ownership of battery & fuel cell Material Handling Equipment. Source: NREL/TP-5600-56408

NRELs evaluation doesn't include potential benefits of fuel cell MHE – Material Handling Equipment such as improved productivity. It is expected that fuel cell powered forklifts deliver a 2 – 5% productivity gain versus battery-powered vehicles, since there is no need for battery recharging and servicing. Hydrogen-powered vehicles can be refueled from conveniently located

fueling stations in less than four minutes, reducing down time and elimination the need for dedicated battery-charging area and support. A major advantage over batteries is the 100% power availability, while the power of batteries starts to drop typically after 6 hours.

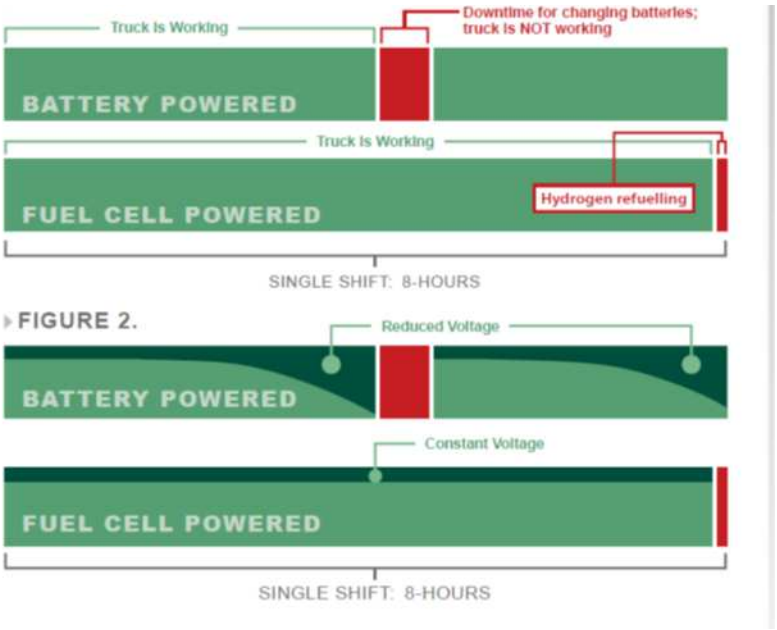



Figure 11. 21 Driving Productivity. Source: Ballard "Economics of Fuel Cell Solutions for Material Handling"

**Maintenance.** Fuel cells are low maintenance. Fuel cells operate maintenance free. Typically, they require maintenance every three years or 10,000 hours refurbishing the fuel cell stacks. The expected lifetime is ten years or more.

**Safety.** Most fuels have high energy content and must be handled properly to be safe. Hydrogen is no different. In general, hydrogen is neither more nor less inherently hazardous than gasoline, propane, or methane. As with any fuel, safe handling depends on knowledge of its particular physical, chemical, and thermal properties and consideration of safe ways to accommodate those properties. Hydrogen, handled with this knowledge, is a safe fuel. Hydrogen has been safely produced, stored, transported, and used in large amounts in industry by following standard practices that have been established in the past 50 years. These practices can also be emulated in non-industrial uses of hydrogen to attain the same level of routine safety.

### 11.5.3 Fast Charging & Opportunity Charging

Fast Charging. Fast charging systems use high-output chargers that deliver energy at a much greater rate than conventional chargers. Instead of swapping batteries during shift changes, operators can rapidly recharge the same battery during breaks or at scheduled intervals throughout the day. This approach reduces the need for large battery inventories and eliminates battery change-outs, but it can generate additional heat in the battery and may shorten service life if not carefully managed. Proper charger programming, temperature monitoring, and ventilation are essential to maintain battery health and ensure safety during fast charge cycles.

Opportunity Charging. Opportunity charging refers to topping off the battery during short, naturally occurring breaks in a shift—for example, while an operator is on lunch or between tasks. Unlike fast charging, opportunity charging does not aim to deliver a full recharge in one session. Instead, it extends the usable time of a battery by adding incremental energy throughout the day. When managed correctly, this method can keep lift trucks running continuously across multiple shifts with fewer batteries per truck. However, successful implementation requires disciplined charging practices and chargers designed with appropriate profiles to prevent overcharge or undercharge conditions.

Operational Considerations. Both fast charging and opportunity charging reduce downtime and can eliminate the need for large battery rooms, but they require investment in specialized chargers, upgraded electrical infrastructure, and close attention to battery management. While the life expectancy of batteries in these applications is often shorter (3–5 years compared to 5–6 years in conventional charging), the overall productivity gains and reduction in battery handling can offset the cost. Facilities should weigh operational needs, energy availability, and long-term fleet management goals when deciding between—or combining—these charging strategies.

### 11.5.4 Lithium Ion Batteries

Lithium-ion (Li-ion) batteries are an emerging alternative to lead acid batteries for material handling equipment. They offer several advantages: higher energy density, faster charging, and no need for watering or equalization. Unlike lead acid batteries, Li-ion systems can be opportunity charged at any time without damaging the battery, making them well suited for multi-shift operations.

Li-ion batteries maintain a more consistent voltage throughout the discharge cycle, which translates to stable performance for lift trucks. They also generate less heat during use and charging, improving efficiency and reducing ventilation requirements. While the upfront cost of Li-ion batteries is significantly higher, the extended cycle life, lower maintenance needs, and elimination of battery change-outs can make them cost-effective over time.

Operational considerations include compatibility with existing equipment, charger requirements, and battery management systems that monitor temperature, voltage, and charge cycles to ensure safety. Facilities evaluating Li-ion technology should weigh the long-term total cost of ownership against initial capital investment and consider fleet size, duty cycles, and energy costs.

## 11.6 Battery Modernization

The future holds a lot of advances in technology both to batteries and forklifts. Fuel cells are an interesting addition to the forklift environment. So far, they have not made a significant impact because of power limitations, the inability to supply high rates for short periods of time, and costs. As costs come down and technologies improve the fuel cell may be a viable option for some companies, but only time will determine the reliability and the cost of ownership.

Automated Guided Vehicles (AGV's) are another technical advancement that has brought about significant changes to how warehouses operate. An AGV only needs to stop working long enough to charge its battery, or in some cases change its battery. AGV are changing the way

warehouses staff people and get work done. They are increasing efficiencies which in term cuts costs. Battery life on an AGV is still undermined, because the application for some of the AGV is very hard on batteries which causes a shorten battery life. Each application will need to be evaluated to determine if AGV are a good fit for your application.