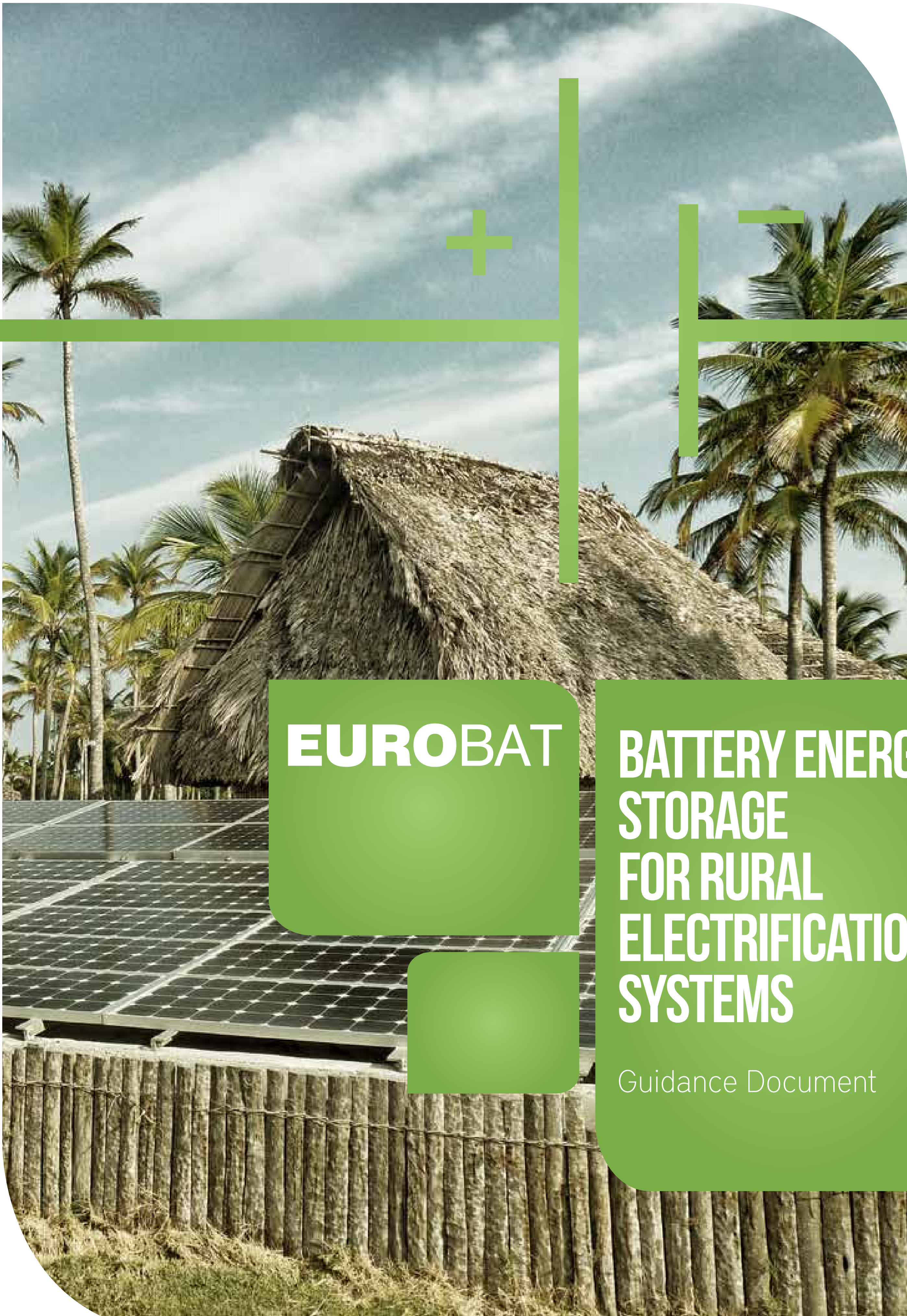

EUROBAT

BATTERY ENERGY STORAGE FOR RURAL ELECTRIFICATION SYSTEMS

Guidance Document

EUROBAT, the Association of European Automotive and Industrial Battery Manufacturers, acts as a unified voice in promoting the interests of the European automotive, industrial and special battery industries of all battery chemistries to the EU institutions, national governments, customers and the media. With over 40 members comprising over 90% of the automotive and industrial battery industry in Europe, EUROBAT also works with stakeholders to help develop a vision of future battery solutions to issues of public interest in areas like e-mobility and renewable energy storage.

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Disclaimer

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EUROBAT is a proud member of the Alliance for Rural Electrification, and thanks them for their input on this report

Cover picture: PV system on Yandup Island, Panama 2011. Picture: Phaesun

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BATTERY ENERGY STORAGE FOR RURAL ELECTRIFICATION SYSTEMS

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INTRODUCTION

The European Battery Industry represented by EUROBAT has put together this Guidance Document for installers and operators of rural electrification systems, or public authorities with a vested interest in the area.

The document provides general guidelines on optimised battery selection for use in off-grid and mini-grid systems installed to provide rural electrification. It aims to enhance the knowledge about the combination of functions that Lead, Lithium, Nickel and Sodium-based batteries can provide across different types and sizes of rural electrification system, and across varying environmental conditions.

Used correctly in off-grid and mini-grid systems, Battery Energy Storage can improve the reliability of power supply from renewable and conventional sources, increase overall system efficiency, and provide economic savings across the system life cycle. To take advantage of these benefits, system operators must ensure that their battery sizing is fitted with the system's technical, environmental and situational requirements.

Power supply for mountain hut, German Alps 2011. Picture: Phaesun

What is Rural Electrification?

Rural Electrification refers to any process of bringing electrical power to rural and remote areas. In this report, EUROBAT focusses on all market segments in which electrical power can potentially be provided most cost-effectively and sustainably through off-grid or mini-grid systems, rather than through grid extension. This can include:

- Isolated rural areas, notably in developing countries
- Peri-urban areas, notably in developing countries
- Small islands separated from the national grid

In these market segments, the extension of transmission lines is often too costly to make economic sense, especially with large distances to be covered, or when difficult terrain must be traversed. A critical mass of potential electricity users is also required to ensure financial viability. This is often not present in small and dispersed rural settlements.

On the other hand, stand-alone off-grid systems are easily accessible, relatively inexpensive and simple to maintain. With power generation usually close to the load, there are also no additional transmission or distribution costs. Mini-grid systems offer similar advantages, and provide local level electricity generation to an entire community through independent distribution networks.

Although this paper primarily focuses on their importance in electrifying rural dwellings or communities, off-grid and mini-grid systems also have several other applications in both developed and developing countries, including:

- Remote telecommunications installations
- Water purification and/or pumping
- Street Lighting
- Security systems
- Cathodic protection for the oil and gas industry

Batteries are an essential component of all stand-alone off-grid and hybrid mini-grid rural electrification (RE) systems, and are used to provide renewable energy storage and increased efficiency.

Off-Grid system for Eritrean church in Adi Beza 2010. Picture: Phaesun

INTERNATIONAL CONTEXT

" off-grid and mini-grid systems with BES are essential for achieving universal energy access

In 2013, the international impetus to increase energy access in isolated rural areas, especially in developing countries, has never been greater. After its 2012 "Year of Sustainable Energy for All", the UN has committed to a number of 2030 targets, including ensuring universal access to modern energy services and doubling the share of renewable energy in the global energy mix; while the European Commission's 2011 "Agenda for Change" makes energy a priority area for European Union (EU) development aid.[1]

The problem such policies engage with is significant. The International Energy Agency (IEA) estimated in 2011 that globally, over 1.3 billion people were without access to energy.[2] Of these, 84% lived in rural areas and 95% were in either Sub-Saharan Africa or developing Asia. These types of locations are geographically isolated and too sparsely populated for extending the national grid to make economic sense.

Recent studies such as the IEA's 2011 Energy for All report have quantified that off-grid and mini-grid configurations using Battery Energy Storage (BES) are often the most efficient and sustainable mode to electrify isolated rural areas. In order to achieve universal energy access by 2030, the IEA estimates that a further 379 TWh of on-grid electricity generation will be needed, along with 399 TWh from mini-grid systems and 171 TWh from off-grid systems.

Off-grid or mini-grid systems using BES will also become increasingly popular in isolated areas of developed or developing countries where electricity supply is costly during peak periods. This is often the case in island grids without mainland interconnection, where peak production relies on relatively expensive fossil fuel powered generation. EURELECTRIC has projected that the share of diesel in electricity generation on European islands will fall significantly from 76% in 2012 to 31% in 2020, with a clear tendency towards the installation of off-grid or mini-grid renewable energy sources.[3]

1 "Agenda for Change" – European Commission DG Development and Cooperation, October 2011
2 Energy for All: Financing Energy Access for the Poor – IEA World Energy Outlook 2011, www.iea.org/papers/2011/weo2011_energy_for_all.pdf
3 EU Islands: Towards a Sustainable Energy Future" – EURELECTRIC, June 2012

EXIDE technologies

COMMITMENT OF THE EUROPEAN BATTERY INDUSTRY TO RURAL ELECTRIFICATION

Stand-alone off-grid systems are increasingly designed to take primary energy from local renewable energy resources – for example wind, solar and biomass – rather than conventional fuels. Hybrid mini-grid systems are powered by a combination of fossil fuel (usually diesel gensets) and local renewable energy resources. These renewable energy sources are intermittent, and so storage technologies are required for short-term power balancing or long-term energy management, ensuring that electricity can still be generated when energy supply is low (for example night time, low winds).

“ Battery Energy Storage is the most effective storage technology for rural electrification applications

Battery Energy Storage is the most effective storage technology for rural electrification applications, and has already been implemented globally in numerous off-grid and mini-grid installations. Batteries can also be used as a supplement to diesel systems to improve their reliability and increase their efficiency. Unlike other storage technologies, BES systems are highly flexible and can be adapted to high power and/ or high energy applications. When correctly selected or tailored, they are also highly efficient during both use and at stand-by; resulting in economic savings across the system lifecycle.

This document provides guidance to ensure that off-grid and mini-grid RE systems are equipped with the battery system that best fits their specific requirements, ensuring optimised performance at the lowest lifecycle cost. The European Battery Industry understands the challenges facing isolated rural and island areas across the globe, and sees recent international pressure as an opportunity to position a technology which can contribute to more efficient and sustainable solutions for improving energy access.

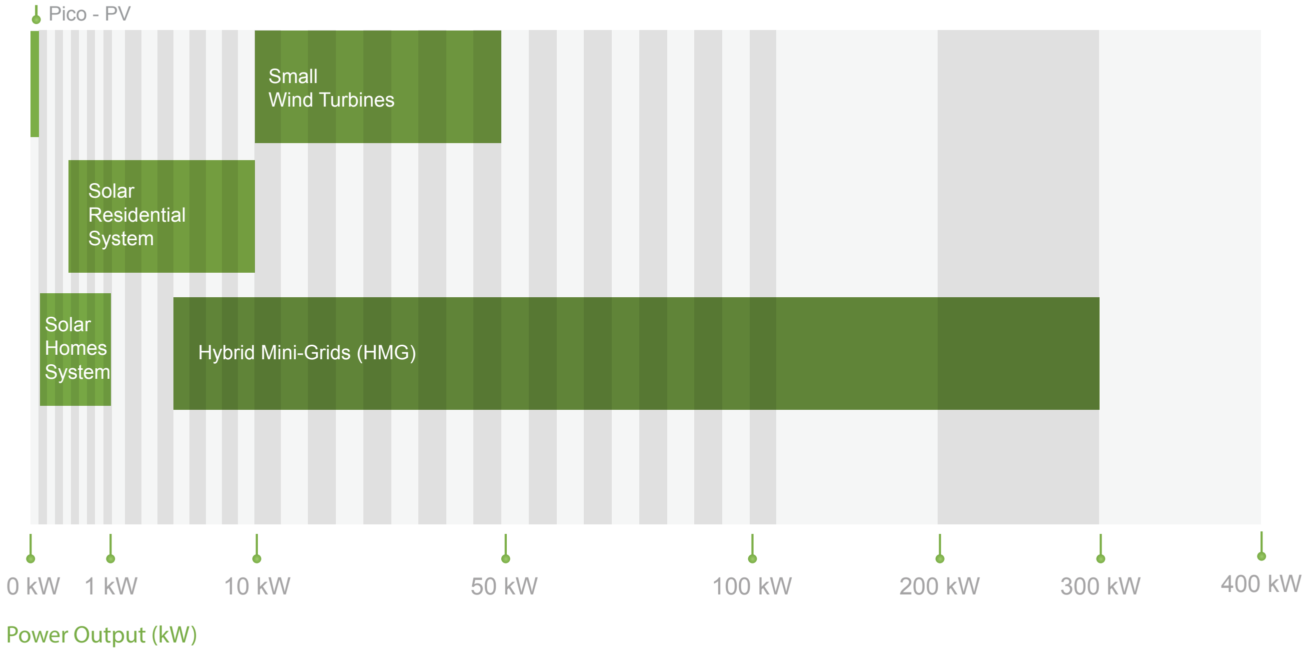
2

OVERVIEW OF RURAL ELECTRIFICATION SYSTEMS

There are several different types of off-grid and mini-grid systems, with each giving different options to end-users in isolated rural areas and small islands. These range from electricity home systems for individual households, to village or island hybrid mini-grids; with each capable of harnessing Renewable Energy Sources (RES) including photovoltaic energy and wind.

Battery Energy Storage is used across the entire range of off-grid and hybrid mini-grid systems, and provides a permanent source of electricity that is independent from variable power generation. It is used to store energy from RES and release it when needed at times when RES production is not sufficient. BES is typically sized to keep supplying power for up to 4-10 days. This is necessary to ensure that the application will always be powered should RES be limited for an extended period of time.

Power ranges for different Rural Electrification Systems



Stand-alone off-grid systems

Pico-PV Systems (PPS)

Pico-PV systems are very small Solar Home Systems with a typical power output between 1-10W. They are primarily used for lighting as a replacement for kerosene lamps or candles. PPS are powered by a small PV panel, with a battery that can be integrated into the lamp or connected separately.

Solar Home Systems (SHS)

Classic Solar Home Systems provide power to an entire household, with an output of between 250W - 1000W. A larger PV panel siphons energy to the solar charge controller, which governs overall energy management. SHS power various DC loads with the potential to integrate AC loads using a DC/AC inverter.

Small Wind Turbines (SWT)

Small wind turbines usually have a diameter of less than 15m with a power output below 50kW; and are placed high on a pole to escape ground turbulence. They are economically viable in areas with average wind speeds of over 5m/s, and have the potential to produce 300kWh per square meter rotor surface annually. The SWT provides similar functions to SHS, with its DC voltage allowing for battery charging.

Solar Residential Systems (SRS)

Solar Residential Systems provide electricity to residential communities or large commercial installations including hotels, hospitals, schools or factories; and typically include an inverter to allow the use of AC loads. SRS have a typical range of 500W to 10kW output power.

Hybrid mini-grid systems

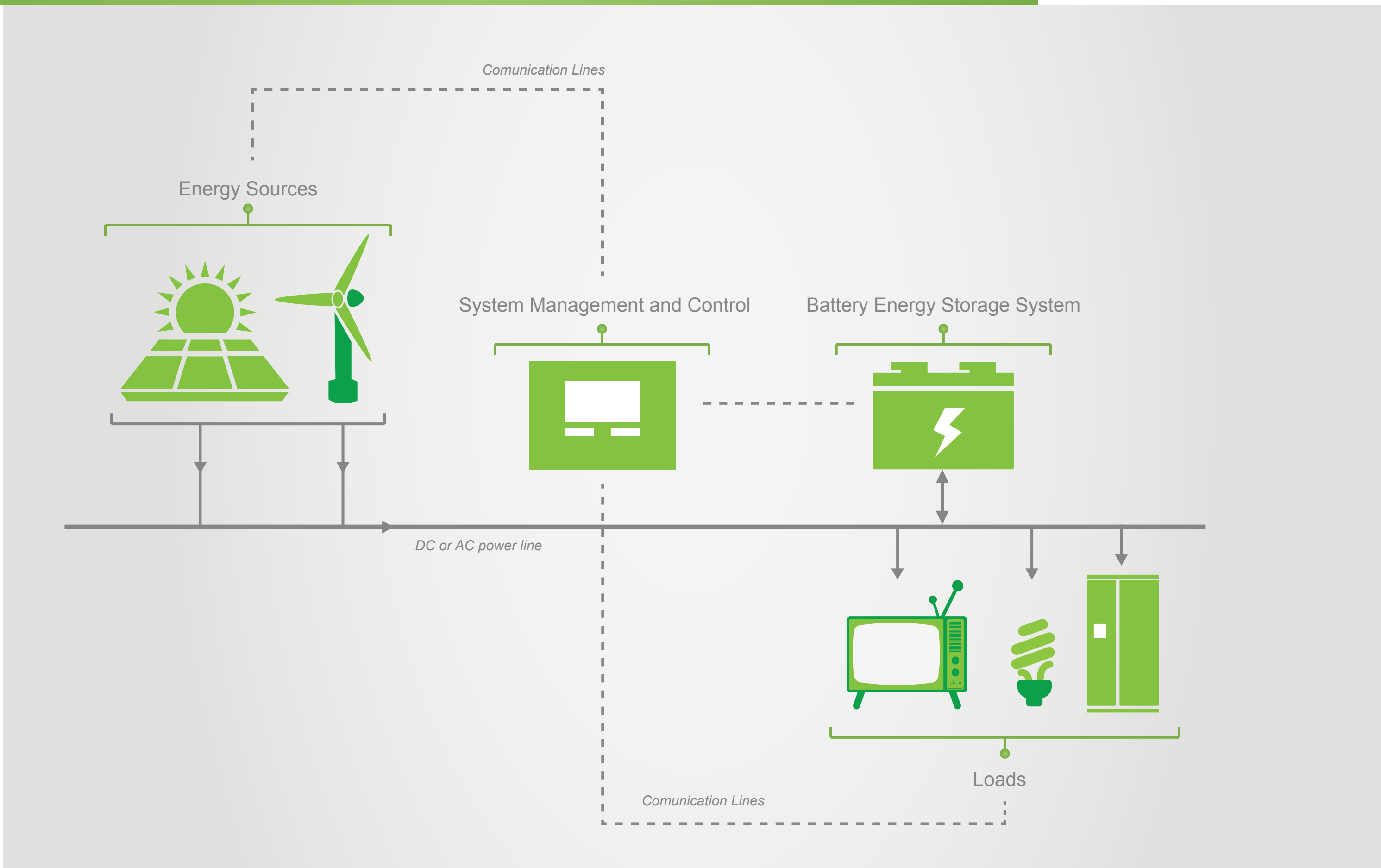
Hybrid Mini-Grids

Hybrid Mini-Grids provide electricity generation at the local level, using distribution networks that are not connected to the national grid, but can provide electricity supply to an entire community. Usually, a mini-grid will use low AC voltage (230 to 400V) with centralised production and storage, and will have an installed capacity of between 5 and 300kW.

Hybrid mini-grids typically use renewable energy as a primary source and a conventional genset (diesel/gasoline/LPG) as a back up source. They vary in complexity, but are capable of providing enough power to rural villages or dwellings to satisfy all modern domestic needs, public services and the development of a local economy. Battery Energy Storage is essential for effective and reliable bridging between the different power sources, ensuring continuity of supply as one generator ramps up while the other ramps down.

Common System Setup for Rural Electrification

Diagram of typical rural electrification system



List of system components

Energy Sources

A variety of energy sources are used to generate electricity within off-grid and mini-grid systems, including: Gensets (usually diesel-powered), Photovoltaic panels, Small Wind Turbines, Combined Heat and Power (CHP), Fuel Cells, Hydropower.

Although diesel gensets remain the most prevalent energy source in global rural electrification systems, increasing amounts of renewable energy sources are being implemented as a consequence of rising fuel prices and increased technological competiveness. Several energy sources can also be combined to generate electricity in the same system, with hybrid mini-grid systems using renewable energy as a primary source and a genset as a backup resource.

DC/AC Power line

The power line can either be AC (alternating current) or DC (direct current), and is used to transfer electricity from the energy sources either directly to the loads, or to the battery system for storage and later release.

The most common setups use AC due to commercially available loads. With DC power lines, a DC to AC converter can be used to power individual loads. The typical voltages for each are as follows:

- AC – 400V 50Hz for a 3 phase system or 230V 50Hz for single phase systems,
- DC – 12V, 24V, 48V (with higher voltages possible)

In case of long DC transmission lines, higher DC voltages are recommended to reduce the transmission resistance losses.

System Management and control

Energy management systems are an important component in rural electrification systems to coordinate battery, generator and load management. Their tasks include load management, control of energy generation, and operational control of the battery energy storage system; allowing for consumption needs to be harmonised with energy generation and storage capacity.

System management is crucial to ensure that all energy from available renewable sources is efficiently harvested.

Communication line

In most off-grid and mini-grid systems, a dedicated communication line is used to transmit data between the different system components, optimising the overall efficiency and performance of the system at all times.

In certain cases, Power line communication (PLC) or Radio Frequency (RF) technologies can instead be employed. These avoid the costs of a dedicated line, which can be high when system components are far apart.

Battery Energy Storage System

As mentioned throughout this paper, the integration of a rechargeable battery energy storage system (BESS) is necessary to provide short-term power balancing and/or long-term energy management. Lead-based, Lithium-based, Nickel-based or Sodium-based deep cycling industrial batteries can be used depending on system requirements. The battery storage setup should ideally include a two way power flow converter to enable the transfer of electricity to and from the DC or AC power line.

A battery management system (BMS) is necessary to control the power flow in and out of the battery within its acceptable capacity. This is essential to ensure reliable operation and to guarantee the expected lifetime of the battery. The BMS can usually communicate with the system management in order to ensure that the battery operates within its buffer range.

Loads

The AC or DC loads comprise the different applications that will be powered by the off-grid or mini-grid system. Typical loads usually have a run time of several hours or days, and can include: Water pumps, Lighting, Various appliances, Communication equipment (mobile phones, PCs)

Although DC loads are becoming more common (widely used already in caravans and yachts), their startup costs might still be substantially higher due to their production volumes. Most standard AC electronic equipment is powered from a switched mode high frequency power supply, and can therefore also run from a DC source voltage of at least 110V DC.

Although it is not expected that each load will have communication/control circuitry, some sort of basic on/off control function will be useful in case of load shedding.

3

GUIDANCE ON BATTERY SELECTION FOR OFF-GRID AND MINI-GRID SYSTEMS

Studer

This section gives general and technology-specific guidance on battery selection for off-grid and mini-grid systems. Incorrect battery selection has a significant impact on the system's performance, total cost of ownership, and safety, and so EUROBAT recommends that the following information is taken into account when selecting a battery for rural electrification application.

"Incorrect battery selection has a significant impact on the system's performance, total cost of ownership, and safety.

General Guidelines for Battery selection for off-grid and mini-grid systems

Often, the temptation when installing off-grid or mini-grid systems on a limited budget is to simply choose the battery available with the lowest up-front cost. However, the cheapest batteries are not always the most cost-effective option over the total cost of ownership, and might not be optimised for the application's performance requirements. EUROBAT emphasises that battery selection must be tailored to each system according to its size and the specific requirements of the application.

Across all battery technologies, there are several fundamental guidelines that need to be taken into account when selecting batteries for use in off-grid and mini-grid RE systems:

Automotive batteries of any type are NOT suitable for use in off-grid or mini-grid RE systems

An automotive battery is designed for providing high current for a short duration, for example to crank an internal combustion engine . It is not designed to supply current for a long duration. Thus, an automotive battery should NOT be used for off-grid energy storage.

Automotive batteries in off-grid and mini-grid systems would have a short lifetime and so have to be regularly replaced, comprimising their cost-effectiveness.

All batteries used in off-grid or mini-grid systems must be specifically designed for deep cycling application

Deep-cycle industrial batteries designed specifically for long run times, and optimised for deep discharge and recharge cycles are highly recommended for rural electrification systems. Off-grid and mini-grid RE systems operate on a daily basis in various states of charge, and such a challenging operating mode requires deep-cycle industrial batteries to provide high reliability and the lowest life cycle cost to users.

The cost per cycle of deep cycle batteries is much lower than shallow cycle batteries, making them more cost-effective across the life-cycle.

Battery selection should be informed by relevant performance testing according to international standards

Relevant international standards for battery cells and applications set performance testing requirements which test the battery's ability to perform optimally in off-grid and mini-grid systems where the battery is frequently operated at partial states of charge.

The key international standards for batteries used in off-grid and mini-grid RE systems are listed in Section 5 of this paper. EUROBAT recommends that only batteries that have been tested to these cell-specific and application-specific standards by an independent laboratory (with results readily available) should be selected for use in off-grid and mini-grid RE systems.

After following these fundamental guidelines, project developers must carefully evaluate the specific requirements of their off-grid or mini-grid RE system in order to determine the optimal battery technology that should be used.

OVERVIEW OF DIFFERENT BATTERY TECHNOLOGIES

The four main battery technologies represented within EUROBAT - Lead, Lithium, Nickel and Sodium – each have individual characteristics that fulfil a clear role across the different segments.

Battery Technologies	Characteristics
Lead based (Pb)	Proven in application, low production cost
Nickel based (Ni)	Proven off-shore & harsh environments, long life
Lithium based (Li)	High energy density, small and light
Sodium based (Na)	High energy density, light

When selecting batteries for use in off-grid or mini-grid RE systems, project developers should consider which battery technology best fulfils the system's specific technical and environmental requirements.

The following sections catalogue the different Lead-based, Nickel-based, Lithium-based and Sodium-based battery technologies that have been manufactured for optimal use in off-grid and mini-grid RE systems, with summaries of their key performance characteristics to aid selection.

No cycle performances or lifetimes are referenced in this guide, because both are dependent on the battery chemistry and its depth and rate of discharge. Cycling profiles are different in each IEC cell-specific standard, thus it is not meaningful to compare across technologies. In the future, An application specific standard like IEC 61427-1 could be used as a benchmark, but this is still under development.

EUROBAT recommends for the user to approach the system manufacturer for selection of battery type and a specific sizing. Please reference Chapter 5 for guidance on which information is required to allow for this.

Lead-based Batteries

Lead-based batteries are the most widely used electrochemical system globally, with proven safety, performance and low cost. Currently, over 90% of industrial stationary and motive applications are covered by lead-based batteries, with a strong European manufacturing base.

Lead-based batteries are already prevalent as a "low Total Cost of Ownership" component in existing small to large-sized rural electrification applications. They have the following advantages:

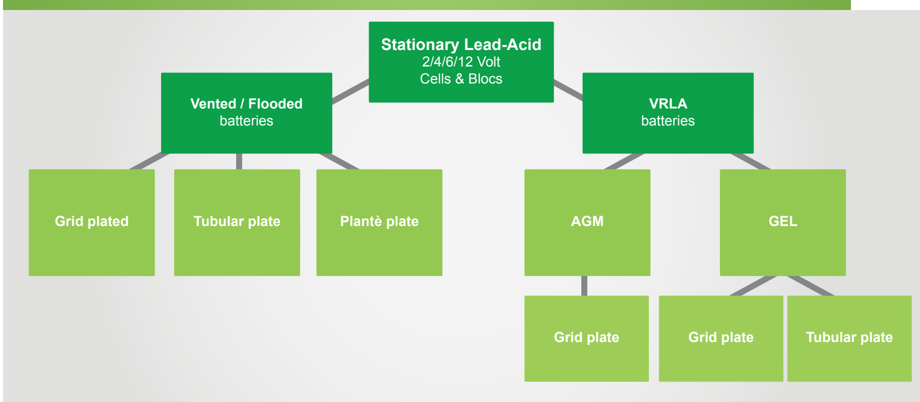
- Low cost/kWh
- Proven technology in stationary applications
- Robust design
- High resource efficiency and recyclability

Lead-based batteries comprise a wide range of models (1 up to 1000s Ah). This allows for flexible scalability in rural projects depending on system requirements. Both vented/flooded and VRLA batteries can be used in rural and remote applications, although VRLA remain the most prevalent due to their limited maintenance requirements and excellent performance/cycles/price ratio.

Tubular plates are especially recommended for rural applications requiring a high number of cycles and good deep-discharge behaviour. Cycle performance can be optimised by correct dimensioning with respect to site-requirements and conditions. As a common rule, continuous high-temperature environments impact cycle-life. In general, the usage of gel and tubular plates improves the resistance against high temperature and harsh environments.

EXIDE Technologies

Tree chart of Lead-based Battery types



Notes	
Flooded/vented batteries	Need maintenance for refilling water etc.
VRLA	Sealed maintenance-free Valve Regulated Lead-Acid batteries
AGM	Electrolyte absorbed in Glass
Gel	Electrolyte fixed thixotropic gel

Nickel-Cadmium Batteries

Nickel-Cadmium (Ni-Cd) batteries have been used for several decades as a niche alternative to Lead-based batteries in specialised industrial applications. They are set apart by:

- Long calendar life (typically over 20 years),
- High cycle life in cycling applications
- Superior reliability and sturdiness
- Gradual loss of capacity when aging
- Excellent ability to take mechanical and electrical abuse
- Ability to operate at extreme temperatures

Ni-Cd batteries are especially well-suited for rural electrification systems under extreme environmental conditions. Although acquisition costs are slightly high compared with conventional batteries, their robustness begins to reduce the Total Cost of Ownership for the operator.

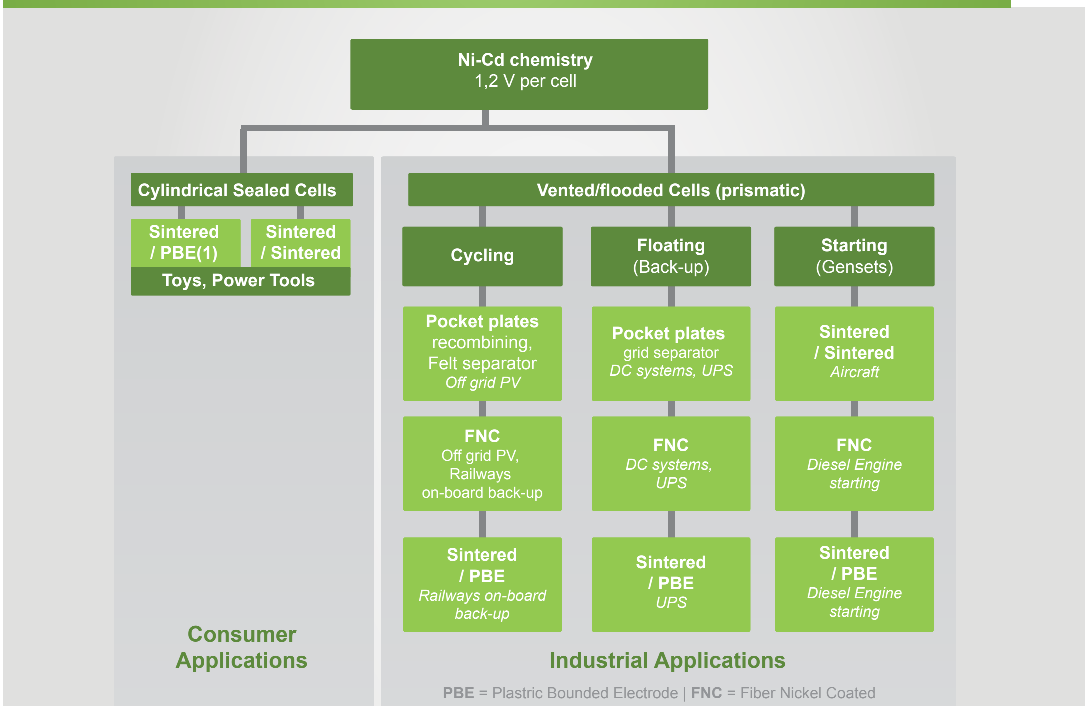
Ni-Cd are built with different electrode designs, which are listed in the table below. The positive electrode contains nickel hydroxide and the negative one cadmium hydroxide. The electrolyte is only used as a means of transport for OH-ions, ensuring their good temperature performance and robustness.

Different types of cell are designed for different application duties: floating, cycling, and engine starting. Industrial NiCd batteries designed for cycling are most appropriate for use in stand-alone off-grid and mini-grid Rural Electrification systems.

N.B. Nickel-Metal Hydride (Ni-MH) batteries also exist for use in niche off-grid systems. They are primarily used in remote small PV applications such as buoys, navigation aids and beacons; where they are set apart by improved energy density (up to 40% greater than NiCd batteries) and the fact they are maintenance free.

Hoppecke

Tree chart of Nickel-Cadmium Battery types



Lithium-ion Batteries

Lithium-ion batteries are a well-established technology for Consumer portable electronics, and are the technology of choice for use in Electric Vehicles. Since 2000, they have begun to enter industrial markets, where they feature:

- High energy density
- High energy efficiency
- Maintenance-free design
- Lighter weight
- Excellent charge acceptance
- Long calendar and cycle life time

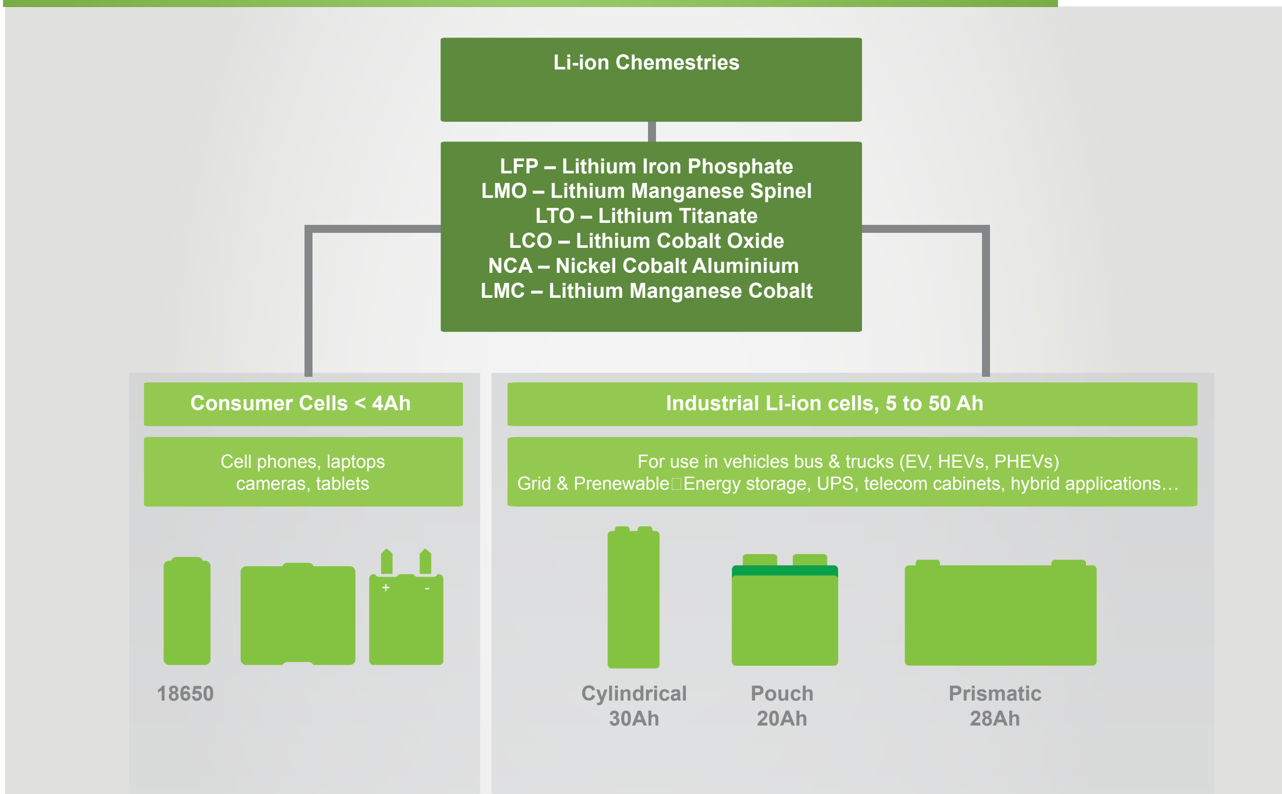
For rural electrification systems, these characteristics make Li-ion batteries most competitive when volume, weight, cycling performance, energy efficiency and remote monitoring are more of a driving factor than initial cost.

Industrial Li-ion cells come in different shapes and sizes: cylindrical, prismatic and pouch cells. There are several different Li-ion chemistries, each depending on the material choices of anode (graphite, carbon, lithium titanate) and cathodes (LMO, NCA, LFP, LCo). The electrolyte can be either liquid organic solvents or polymer, with the nominal voltage consequently varying according to the chemistry. Each offers different performance characteristics, and so so the ideal choice should be selected of the application.

Saft

Lithium-ion battery systems require sophisticated control electronics to avoid overcharge, monitor cell temperature, and perform cell balancing. Although this increases the complexity of the technology, it also offers precise remote monitoring of the battery state of charge, health and other operating conditions.

Tree chart of Lithium-ion Battery types



Sodium Nickel Chloride Batteries

Sodium Nickel Chloride ($NaNiCl_2$) batteries are a relatively new technology, and were originally introduced in the market for Electric and Hybrid-Electric Vehicle such as buses, trucks and vans. Today the use of the technology has been broadened to include telecom and back-up markets and on/off grid energy storage systems for stationary application.

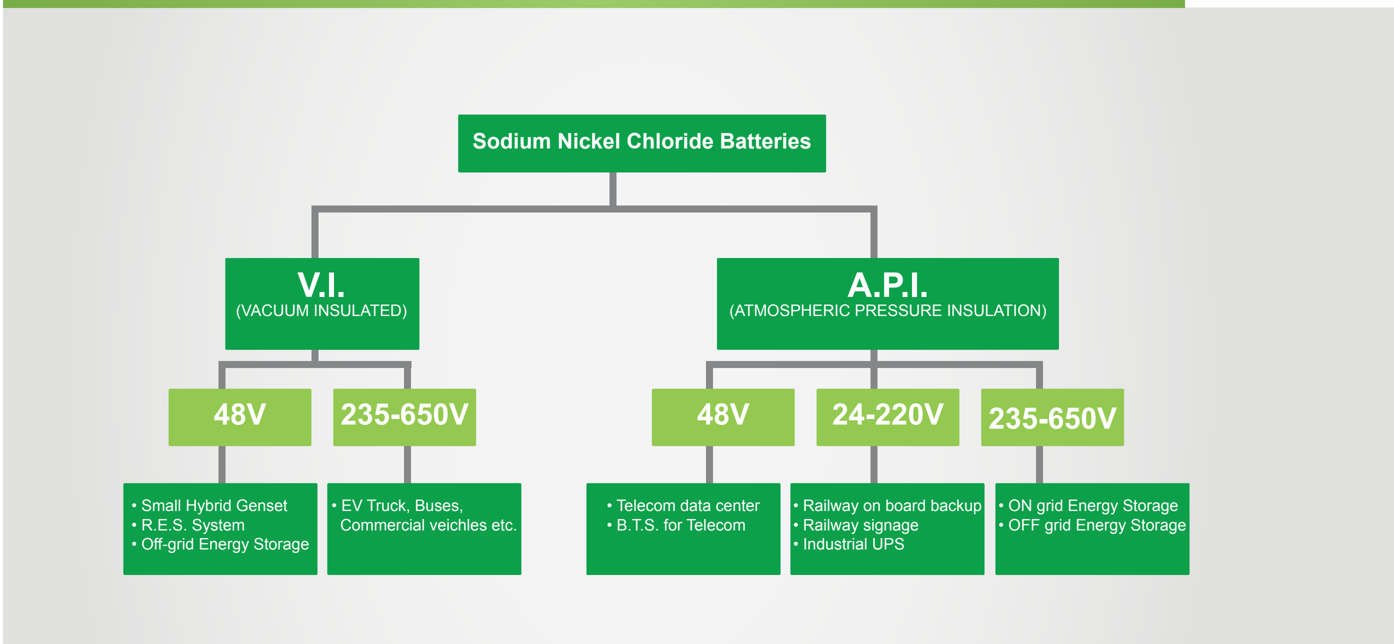
In industrial applications, they feature:

- High specific energy
- Constant performance and cycle life in harsh operating environments (-40°C to +60°C)
- Low maintenance requirements

Because their cycle life remains constant despite external temperature, Sodium-based batteries are best suited for rural electrification installations characterised by harsh ambient systems. They also have a good level of safety in operation, and are recyclable within existing industries for the production of stainless steel and road paving.

FIAMM

Tree chart of Sodium Nickel Chloride battery types



End-of-Life Batteries in Rural Electrification systems

Batteries reach end-of-life when they are no longer able to fulfill the initial requirements set for them (i.e. 80% of initial capacity/runtime/autonomy)

In the European Union, the Batteries Directive (2006/66/EC) sets mandatory targets to guarantee that automotive and industrial batteries placed on the market are collected and recycled at their end of life. Other EU legislation and industry best practice ensures the sustainability of this process in respect to human health and the environment.

Outside of the European Union, the extensiveness of local legislation for the end-of-life treatment of batteries differs from country to country. Regardless of local legislation, batteries are usually collected for recycling or recovery at end-of-life because of the intrinsic financial value of their components and materials, and in respect of the environment. EUROBAT members have established local battery collection points across the world to facilitate this process. Recycled or recovered substances are usually supplied to local industries.

In certain developing countries, the informal recycling of battery technologies can be an issue, because it is sometimes conducted under lower conditions of safety, health and environmental performance. EUROBAT recommends that battery recycling is conducted by authorised battery recyclers or battery retailers that return used batteries to secondary smelters; and that local policies are put in place to minimise population exposure from informal industries.

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4

GUIDELINES FOR OPTIMISED BATTERY SIZING

To optimize battery performance in off-grid systems, it is important to select the battery technology and battery sizing that best fits the specific requirements of the application

In this section, EUROBAT provides information on the different technological, environmental and situational parameters that can impact on battery performance.

Taking all of these parameters into account will allow for battery selection that is optimized for the particular system configuration, including:

- Battery cycle life and calendar life
- Total Cost of Ownership (TCO)
- Reliability and safety

EUROBAT therefore recommends that installers, operators, or owners of off-grid systems should only select their battery system once they have decided upon these parameters. By integrating this information, a specialised battery expert will be able to recommend the optimal battery type and sizing to be used.

Environmental Parameters

- **Typical loads** – Max, min, average site temperature
- **Atmospheric conditions** – Typical weather, humidity levels etc.
- **Space/weight considerations** – The space that will be available for the BES system, and any limitations on its total weight.

System Parameters

- **Typical loads** – The required energy and power that the battery will be required to deliver over a specified period of time to fulfil demand of different loads.
- **Duty cycle** – Required activity of the battery during this time period
- **Daily PV and/or Wind Production** – The amount of electricity expected to be generated from PV panels or wind turbines. Dependent on prevailing weather conditions and technical specifications of PV panels and wind turbines
- **Total available power** – The amount of electricity that will be generated per day by the entire system
- **Gen Set Power** – The amount of electricity that will be generated per day by Gen Set (usually diesel-powered).
- **Expected autonomy time without charging** – The total time the battery will be expected to operate autonomously in the system between charges

Situational Parameters

- **Human presence or remote site** – Whether personnel will be on hand for regular maintenance of the battery and wider system.
- **Accessibility of site** – To estimate how easy it will be to replenish depleted genset, or otherwise provide extra support or parts.

Hybrid System Subihiyah Oasis in Kuwait 2011. Picture: Phaesun

By integrating these parameters together, the battery specialist will be able to select an appropriate battery type and system sizing for their particular requirements. This will include decisions on the following categories:

- **Battery type and design**: See section 3.
- **System setup:** the number of batteries, parallel and/or series connection, wiring technology etc.
- **Dimensions and weight**
- **Energy storage capacity**: the amount of energy that the battery can store under certain conditions (kWh).
- **Response time**: the time needed for the battery to respond to stimulus.
- **Charge/discharge rates**: measure of power indicating the rate at which energy is added or removed from the battery system.
- **Lifetime**: measured either through cycle life (number of cycles the battery can be charged or discharged before the battery's nominal capacity falls below 80% of its initial capacity) or calendar life (number of years before the battery's nominal capacity falls below 80% of its initial capacity.).
- **Roundtrip Efficiency**: measure of energy loss across the storage cycle (charge and discharge of battery).
- **Operating temperature range**: the minimum and maximum temperatures under which battery performance, lifetime and safety can be maintained.
- **Initial capital cost**: the total cost for the battery system's acquisition and installation.
- **Operating costs**: the cost and demands of ongoing operation and maintenance to the battery system

EUROBAT emphasises that selection of battery technology and system sizing should always be undertaken by a battery specialist. Failing to take these parameters into account risks the selection of a battery that is not optimised to the requirements of the system and its environment; potentially impacting on its performance and cost-effectiveness.

5

BATTERY STANDARDISATION

Battery selection for off-grid and mini-grid systems should always be informed by relevant performance testing according to presiding international standards. A broad international standardisation framework governs the safety and consistency requirements for RES off-grid systems. Implemented by the International Electrotechnical Committee (IEC) or International Organisation for Standardisation (ISO), individual quality standards target each system component, including PV panels, wind turbines, charge controllers and inverters.

These standards are the authority in the renewable energy community, and are respected by all EUROBAT members. Any programme or project design should integrate their requirements in order to ensure optimised system solutions. They set the minimum requirements for safeguarding a sufficient quality of system components.

The relevant international standards for batteries are as follows:

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"Incorrect battery selection has a significant impact on the system's performance, total cost of ownership, and safety.

IEC 61427: Secondary Cells and Batteries for Photovoltaic Energy Systems (PVES) General requirements and methods of test

Batteries of all technologies used in off-grid PV systems are primarily regulated by *IEC 61427: Secondary Cells and Batteries for Photovoltaic Energy Systems (PVES) – General Requirements and methods of test*. This standard gives general information relating to the requirements of the secondary batteries used in photovoltaic energy systems (PVES) and to the typical methods of test used for the verification of battery performance. It deals with cells and batteries used in photovoltaic off-grid applications.

IEC 61427 is applicable to all types of secondary batteries - including lead-based, lithium-based, nickel-based and sodium-based batteries - and aspires to inform and assist the PV system designer in properly identifying, selecting, sizing and recycling the most suitable batteries according to the specific requirements of the off-grid system. However, it does not include specific information relating to battery sizing method of charge or PVES design. The standard is separated into three parts:

1 General information on batteries and their operating conditions, including:

- Autonomy
- Typical charge and discharge current,
- Maximum storage period

As outlined in Section 3, battery selection for off-grid and mini-grid systems should always be informed by relevant performance testing according to presiding international standards.

- Operating range of temperature

2 General requirements for battery performance, including:
- Mechanical endurance
- Charge efficiency
- Deep discharge protection and safety

3 Functional characteristics, including:
- Rated capacity
- Endurance in cycling
- Charge retention
- Endurance in cycling in photovoltaic application

N.B. *IEC 61427* is currently being updated within the IEC, with the intention to divide into two parts:

- *IEC61427-1: Secondary cells and batteries for Renewable Energy Storage – General Requirements and methods of test – Part 1: Photovoltaic Off-grid application*

- *IEC 61427-2: Secondary cells and batteries for Renewable Energy Storage – General Requirements and methods of test – Part 2: On-grid application*

Other IEC standards applicable to Battery Energy Storage in off-grid systems

The basic terms for batteries of all chemistries are defined in *IEC 60050-482*: Primary and secondary cells and batteries. In addition, safety requirements for Battery installation and operation are set by *EN 50272-2 (IEC 62485-2): Safety requirements for secondary batteries and battery installations. Part 2: Stationary batteries*.

Chemistry-specific battery standards applicable to Battery Energy Storage in off-grid systems are as follows:

Lead-based batteries

- *IEC 60896-11: Stationary lead-acid batteries – Part 11: Vented types – General requirements and methods of test.*
- *IEC 60896-21: Stationary lead-acid batteries – Part 21: Valve regulated types – Methods of test*
- *IEC 60896-22: Stationary lead-acid batteries - Part 22: Valve regulated types - Requirements*

Nickel-Cadmium batteries

- *IEC 60623: Secondary cells and batteries containing alkaline or other non-acid electrolytes – Vented nickel-cadmium prismatic rechargeable single cells*
- *IEC 62259: Nickel-Cadmium prismatic rechargeable single cells with partial gas recombination*

Nickel-Metal Hydride batteries

- *IEC 62675: Secondary cells and batteries containing alkaline or other non-acid electrolytes - sealed nickel-metal hydride prismatic rechargeable single cells*

The IEC has also developed a technical standard to aid battery selection for off-grid systems in developing countries: *IEC 62257-8-1 TS : recommendations for small renewable energy and hybrid systems in rural electrification. Part 8-1 selection of batteries and battery management systems for stand-alone electrification systems – Specific case of automotive flooded lead-acid batteries available in developing countries*. This was updated in 2011.

IEC 62093: Balance-of-system components for photovoltaic systems - Design qualification natural environments establishes requirements for the design qualification of balance-of-system (BOS) components used in terrestrial photovoltaic systems. Batteries used in off-grid systems are included in its coverage.

6

CASE STUDIES

SOLAR RESIDENTIAL SYSTEM FOR MADAGASCAR VILLAGE

EXAMPLE WITH A NI-CD BATTERY

This system provides Maravoto's residents with clean, safe energy for about six hours a day

Located in Madagascar, the facility installed in 2009 provides Marovato's 120 residents with clean, safe energy for around six hours per day – mainly in the evenings – as an alternative source of energy to the kerosene and hand-gathered wood traditionally used by the villagers. It generates peak power of 1,400 W: for comparison, the village currently uses only 490 W.

The 24 V Ni-Cd battery system, comprising eighteen 920Ah cells, stores energy generated in the daytime by 24 photovoltaic panels with an average output of 7 kWh.

Case study and photos provided by Saft

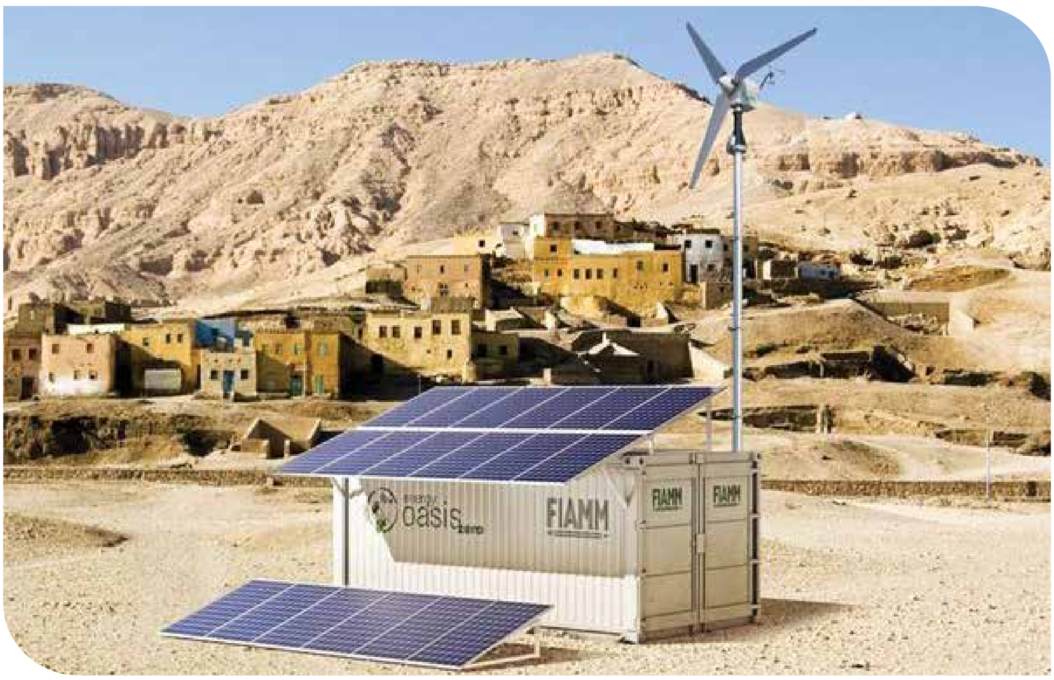
OFF-GRID SYSTEM FOR SCHOOL IN IRAQ
EXAMPLE WITH A SODIUM BASED BATTERY

This off-grid PV system is under installation in school in Iraq and is designed to fulfil power requirements throughout the day. A Sodium Nickel Chloride battery is used for energy storage because of the high temperature conditions in which the system must operate. Sodium-based batteries are able to ensure a long calendar and cycle life despite these high temperatures, providing an expected lifetime of longer than 10 years.

The study of the consumption profile (peak power, distribution across the hours etc...) and the estimation of the available PV generation results in a battery pack sizing of about 55 KWh (nominal size):

Day light energy consumption (PC, printer, lights, refrigerator, AC)	45 KWh/day
Night time energy consumption	11 KW/day
PV average production (13 KWp)	55 KW/day
Battery capacity	44 KWh @ 80%

The system aims to reduce significantly the school's gasoline consumption, with the combination of photovoltaic panels and a battery energy storage system also allowing for an important reduction of ambient air pollution.



Case study and photos provided by FIAMM

CASE STUDIES

HYBRID GENSET FOR OFF-GRID TELECOMMUNICATIONS EXAMPLE WITH A LI-ION BATTERY

A 48V 3,7 kWh Li-ion battery module delivers effective energy storage for a Hybrid genset, providing reliable power for off-grid telecom Base Transceiver Station (BTS).

The diesel generator, operating 24/7, simultaneously charges the battery and powers the site load. When the battery has been fully charged, the generator shuts down and the battery takes over as the primary source of power.

The genset power is 9 kW and the peak power is 16 kW. 6 modules of 48V, 3,7 kWh connected in parallel are necessary to provide the duty.
By reducing the genset runtime down to a typical 4 hours per day, this approach offers major savings in fuel consumption – typically 74 percent compared with a standard genset.

It also improves the environmental impact by reducing CO_2 emissions while increasing refueling and service intervals. Such a solution not only ensures continuity of Power supply, but also minimizes the TCO (Total Cost of Ownership).

The system saves 74% of total fuel consumption compared with a standard genset

Case study and photos provided by Saft

OFF-GRID SYSTEM IN WALALKARA, SOUTH AUSTRALIA WITH A LEAD-BASED BATTERY

This off-grid system provides electricity to community buildings in Walalkara, a protected area in South Austrialia.

The system comprises a solar remote power system consisting of 32 solar panels, a small genset, and specialised Lead-based batteries.

In the absence of direct solar energy during off-peak periods, the Lead-based batteries are used to provide 48Vdc 29kWH of power to the area's houses, school and clinic buildings. When undergoing battery selection, reliability was of the utmost importance due to the remoteness of the community and the high cost of any service calls.

Case study and photos provided by EXIDE Technologies

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