END-OF-LIFE MANAGEMENT: SOLAR PV STORAGE IN BRAZIL

Rodrigo Latuf de Andrade – rodrigolatuf@alsolenergia.com.br
Gustavo Malagoli Buiatti – gustavo@alsolenergia.com.br
Barbara Ferreira Viegas Rubim – barbara.rubim@alsolenergia.com.br
Alsol Energias Renováveis S.A
Arfa Karani – arfakarani@hotmail.com
Lalitha Mahalingam – lalitha.priyadarshini@gmail.com
Samuel George Hanna Gabra – samuel@aucegypt.edu
University of Cambridge

Abstract. *The purpose of this template is to evidence of the benefits of recycling batteries. The research focused on the recycling process of industries located in Brazil. As known is an activity of environmental risk and public health, but that carried out with safety and responsibility, it brings economic, environmental and social benefits, within the limits of the legislation. In this sense the lead-acid batteries, although it is a technology in transition process to give way to other types of battery, in some cases still the best cost-benefit ratio. For solar applications, what has been done over the last few years are adaptations or structural modifications over conventional batteries in order to improve their behavior in the operating conditions of solar systems.*

Key words*: Storage, batteries, management*

1. INTRODUCTION

The autonomous photovoltaic solar systems have found a growing market, thanks to the reduction of manufacturing costs and the improvement of the quality of the photovoltaic modules and storage technologies, which today already reach a high degree of technical development. In this sense, several projects and programs have been implemented in our country in the last decade, not only with the objective of universalising the electricity service from solar technology, to rural areas or difficult access, benefiting several communities, but also to interactions with the grid in order to optimize the energy produced. Since power systems, which incorporate renewable technologies such as photovoltaic solar, have been introduced as energy alternatives for electricity generation for various applications in the solution of electrification deficiencies, power supply for telecommunications systems, navigation and signaling, the use of these batteries was the option found for the storage of the electric energy generated, adapting the intermittent generation to the demand, and thus guaranteeing a reliable and constant supply of energy. The choice of these batteries was and is determined by the cost and the availability, being a technology apparently of easy adaptation to this application.

The battery for PV applications should have as main characteristics: cycling capacity, high energy efficiency, long service life, low maintenance and low cost. Combining the characteristics of the batteries described in the previous items with the conditions imposed by the PV systems, it is easily concluded that the conventional batteries do not adapt satisfactorily. With a correct sizing and system control strategy it is possible to achieve better operating conditions, but there is still an unpredictable factor that is the user of the system, which can completely change the condition of use of the battery. In practice what is observed is that the battery life is shorter than expected.

Although there are technologies in development, and some have even been very promising, today they still have a high cost for the amount of accumulated energy required in renewable energy systems. Examples are nickel, lithium and vanadium (Rydh, 1999).

2. BATTERIES IN PHOTOVOLTAIC SYSTEMS

Storage offers one possible source of flexibility, absorbing or releasing energy to smooth intermittent generation patterns and demand variability. It can also help to manage the implications of potentially more variable patterns of consumption for the grid, offering an alternative to conventional network reinforcement. The function of these elements in photovoltaic systems is to store energy produced by the photovoltaic generator and deliver it to the load when generation is zero (as at night), insufficient (as in periods of low irradiance), or required (required by the grid). The batteries can be formed by an electrochemical cell, or by a group of them, connected in series or in parallel, constituting a complete electrochemical storage system. The different means of energy accumulation found so far are shown in Tab. 1.

Table 1 - Energy Storages Technologies

Chemical	Hydrogen
	Synthetic Natural Gas
	Biofuels
Electrochemical	Primary and Secondarycell or battery
	Reserve cell
	Fuel cell
Electrical	Capacitor and Supercapacitor
	Superconducting magnetic
Mechanical	Flywheel System
	Pumped Hydro
	CAES
Thermal	Sensible heat system
	Latent heat system
	Absorption and adsorption system

According to Jossen et al. (2004), lead-acid batteries are the type of technology most used in systems that use photovoltaic generation and battery storage, despite the current trend of replacing this type of technology. A comparison of storage systems shows that the main drawback of lead-acid batteries is their specific energy, confronting the main advantages of a low specific cost and high recycling capacity. At Tab. 2 is a comparison of lead-acid technology with lithium batteries.

Table 2 - Comparison between storage technologies where ++: very good; +:good; *: satisfactory e -: bad

Characteristics	Lead-acid	Lithium-ion
Safety	+	-/*
Specific energy	-	++
specific power	+	+
Specific costs	+	*
Recyclable	++	*

Due to the current state of development of the batteries and the current storage market in Brazil and worldwide, two batteries were the focus of the analysis. These batteries are ‘Lead-acid’ which is the most deployed battery in Brazil at the moment and ‘Lithium-ion’ battery, which is considered to be the future of the energy storage field, Lithium-ion costs have droped 65% since 2010 accoding to the Rocky Mountain Institute. A comparison is showed in Fig. 1 and Fig. 2.

Figure 1 - Characteristics of lead-acid battery

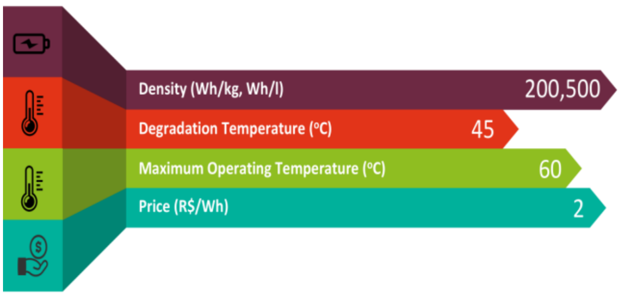

Figure 2 - Characteristics of lithium-ion battery

2.1 Parameters that affect battery behavior

The energy storage system shall operate continuously in charge and discharge cycles of varying intensity and duration depending on the intermittent generation of energy and various types of consumption. A seasonal cycle (determined by the generation and consumption profiles) superimposes a seasonal cycle, which depends on the evolution of solar radiation throughout the year. According to the application a daily cycle can range from superficial (cycling depth about 15%) to deep (greater than 80%). Thus, batteries in photovoltaic applications can undergo changes in their useful life under conditions of irregular loads and discharges, long periods at low load or overload and under variations in temperature. This varies greatly depending on the location of the system and the demand.

3 PERICULOSITY, TOXICOLOGY AND LEGISLATION

Batteries contain substances that pose physico-chemical hazards and toxicological effects, in various levels and shapes. The following criteria or parameters are used to determine the hazardousness and toxicity of batteries and therefore the classification as hazardous or non-hazardous waste at the end of their useful life. The legislation requires the determination of battery waste, based on hazard criteria represented by: flammability, corrosivity, reactivity and toxicity, the latter determined by leaching or percolation characteristics in the environmental system. The main routes of exposure to lead are oral, respiratory and cutaneous. However, the toxic effects are the same regardless of the route of exposure.

3.1 Brazilian Legislation

The Brazilian government was a pioneer in Latin America, in establishing the regulation for the management of exhausted batteries, through Resolution CONAMA 257, 06/30/99 and in force as of July 22, 2000, complemented by Resolution nr. 263 of 11/12/99. Amongst the different types of batteries and batteries (Resol 257, Art. 2), those containing lead, cadmium, mercury and their compounds must be returned (Art. 1), and accepted (Art. 3) by merchants, manufacturers or importers, or by the collection network that should be created by them (Art. 6). In the focus of this work are presented in Tab. 3 the types of discard for the storage technologies previously mentioned.

Table 3 - Battery final disposal

Storage type	Usual aplication excluding PV	Destination
Lithium-ion	Notebooks, cellphones	domestic waste
Lead-acid	Industries, automotive	return to the manufacturer or importer

The modes of operation of the members are available on the page of ABINEE and MMA. Therefore, the orientation for the consumer is to refer exhausted batteries as the form of collection adopted by the industries and validated by MMA. Battery management schemes vary in type, scope, responsibilities, and performers, especially when considering different continents. The main focuses of regulatory actions for the implementation of management system are industrial and automotive batteries and among portable batteries, those whose components make them classified as hazardous waste after the end of their useful life.

3.2 Hazard and toxicology

Batteries contain substances that pose physico-chemical hazards and toxicological effects, in various levels and shapes as presented in Tab. 4..

Table 4 Some toxic substances that make up the batteries

Substance	Contamination type	Quantity	Efect
Mercury	Touch and inhalation	Extremely toxic even in small quantities.	Stomatitis, kidney damage, affects the brain and neurological system. It accumulates in the body.
Cadmium	Touch and inhalation	Highly toxic even in small quantities.	Accumulates in the body. Causes kidney dysfunction and lung problems.
Lead	Touch and inhalation	Extremely toxic even in small quantities.	Renal dysfunction and anemia when absorbed by skin or lung.

4 LEAD PROCESSING METALLURGY

Metallurgy is defined as the set of techniques and processes used for extraction, processing and industrial processing of metals. In general, it distinguishes itself in metallurgy, mining and metallurgy for the preparation of metals to form alloys and various products. In industrialized societies, importance of scrap recovery and recycling processes obtains remarkable economy in relation to the extraction from the mineral.

In the metallurgy of preparation of the metals (processes), the minerals are extracted from the concentrated, refined, alloyed and prepared to meet the specifications. In choosing the most appropriate method for each case cited above for the preparation of metals, a number of factors are considered, including the chemical nature of the concentrate. In general it is an oxide (in the case of iron and aluminum, for example), sulphide (eg copper, zinc and lead = non-ferrous metals), or a carbonate or a silicate. At this stage, the three commonly applied processes are: pyrometallurgy, which uses heat; electrometallurgy, which uses electricity; and hydrometallurgy, which uses water.

4.1 Pyrometallurgy

Pyrometallurgy is the extractive process in which the reactions are processed at high temperatures with the aid of a reducing agent. The heat is supplied normally by fuels such as coke, oil and gas, or by electricity. In most of the cases, fire has a chemical and physical function because it releases certain components of the ore. Generally applied to large quantities of ore and in high temperature, pyrometallurgy operates the reduction of oxides by carbon, a Typical example is the blast furnace for cast iron.

Machado (2002), specifically describes the secondary process of pyrometallurgy of lead-acid recycling (automotive battery), explaining th eobtaining the lead from the metal fraction previously separated from the casing of the battery (Grid and pulp), being composed of approximately 40% of alloys of lead and 60% of lead oxide, called slag. The scrap metal is (type flip-flops, rotating, vertical or electric) through a conveyor belt metal or machinery, at a temperature above 1000 ° C and atmosphere together with the fluxes and that after casting the lead compounds are reduced to elemental lead. From the furnace the lead in the liquid form and the effluent gaseous. The lead goes to the refining unit and from there to the molding and finally stocked. The gaseous effluent passes through an incinerator followed by a heat exchanger and then goes to the filter unit (residue solid returns to the process), finally being routed to the chimney and released into the atmosphere. Some advantages of this process are: Ability to process a wide variety of materials and speed in the modification of the composition of the load.

4.2 Electrometallurgy

Electrometallurgy is the process that uses electrolysis, that is, an electric current applied to a solution (aqueous or fused salts) containing the metal. This is the most recent of the metallurgical processes, since it was possible from the supply of electricity. This is the method used in the extraction of aluminum from cryolite as well as copper, zinc and much of magnesium. Machado (2005), also briefly describes the process, based on the dissolving the metal in an electrolytic cell containing an electrolyte. The negative electrode if depositing in the form of neutral atoms attracts the metal dissolves in the form of cations, which undergo an applied electric current through electrodes immersed in the electrolyte. This process had industrial origins approximately 150 years, and was used by James Elkington for refining of copper, around 1903, this method of extraction was also used in refining of lead (Dennis, 1964).

4.3 Electrohydrometallurgy

The electrohydrometallurgical process is to reduce the particles of lead compounds and leaching them with a acid solution of ferric fluoborate. At this point, lead is dissolved with ions ferrous ions are reduced to ferrous ions. The solution resulting from the leaching is pumped into the cathode compartments of an electrolytic diaphragm cell in which metallic lead is deposited on stainless steel cathodes in a compact and pure form. The solution is impoverished in Pb2 + ions, it is then sent to Anodic compartments of the same cell, on the surfaces of anodes occurs oxidation of ferrous to ferrous ions, which return to the leaching stage. Schematically represented in the electrohydrometallurgical process diagram, where the lines correspond to the circulation of the anolyte and the catholyte. In the steel cathode lead is deposited in the anode and the solution of iron fluoroborate II is oxidized, which then passes to the leach reactor where it dissolves the lead compounds. At metallic impurities are decanted chemically and filtered before returning to the solution feeder tank. This work system can be observed in the Fig. 3

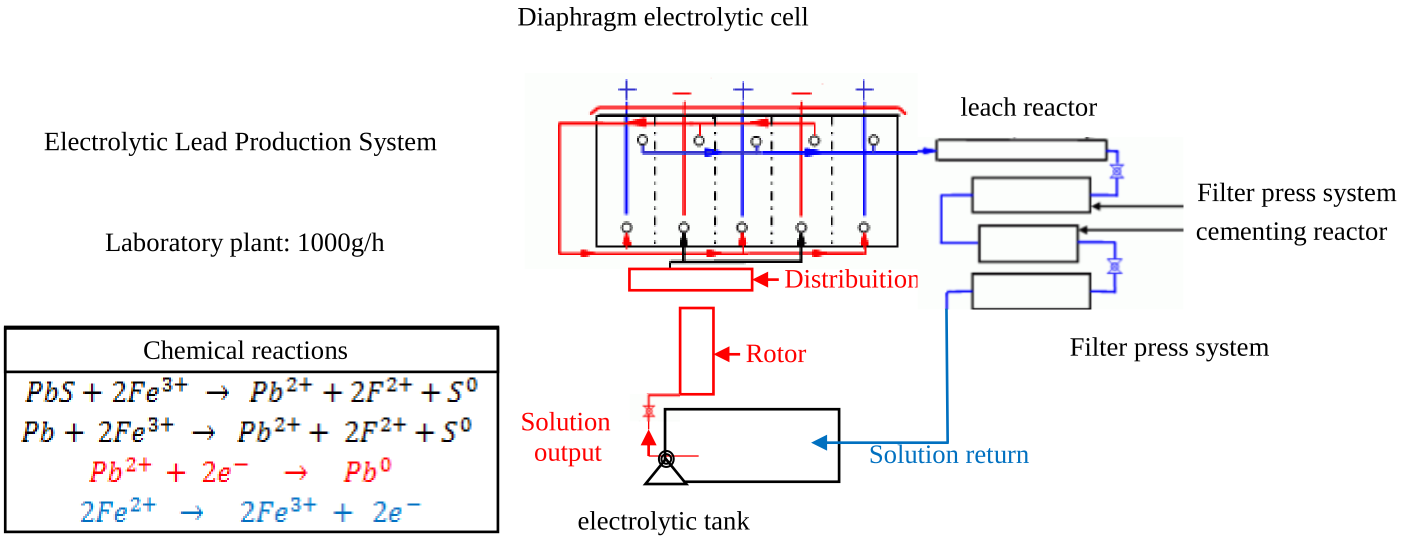

Figure 3 Schematic of the electrohydrometallurgical process of lead production (Electrolytic cell in Polyvinyl chloride machined - Electrolyte tank - Polyvinyl chloride pipes)

5 CONCLUSIONS

Promoting solar photovoltaic (PV) off-grid solutions for poor rural areas without access to electricity is a good thing. The benefits of lighting and electricity for education and health, and clean energy as an enabler for income-generating activities cannot be emphasised enough. Therefore, the Sustainable Development Goal 7 ‘Affordable and Clean Energy’ promotes renewables such as solar PV and mini grids as one of the quickest ways to scale up rural electrification rates in developing countries and to end energy poverty.

When people talk about off-grid solar PV, they often only talk about solar panels, but forget that for solar to work in off-grid areas one also needs storage technologies - batteries. Also, what is so far not considered in the roll-out of solar PV panels and batteries, are the end-of-life issues associated with the technologies.

Some organisations are beginning to understand the looming challenges associated with the energy transition in rural areas and are exploring solutions to the emerging problems

The amount of lead-acid batteries that will be needed for storage is staggering. Currently, for every 6 kilowatts of installed solar PV about 8 units of batteries (400 Amp, 48 V) are needed. A back-of-the envelope calculation shows that for 30,000 megawatts (MW) about 40 million batteries will need to be installed initially. The typical lifetime of a battery is only about three years, compared to 20-25 years average lifespan of the PV panels. For 30,000 MW solar PV capacity this would mean over the lifetime about 280 million batteries will have to be installed, replaced, recovered and then recycled. Most of the batteries can be expected to be lead acid batteries as lithium-ion batteries are slow to enter the off-grid market in developing countries.

Lead recycling is big business with global dimensions. Lead-acid batteries are one of the most recycled consumer products in the world. In 2013 the worldwide production of recycled lead was 6.7 million tons, more than half of total global lead production.

It is clear that current practices and recycling methods are not sufficient to deal with the emerging challenge effectively. In the first place, policies and regulations on international and national level are needed to establish certified collection and recycling centres operating with environmentally sounds practices and adhering to health and safety standards to protect workers.

To manage the recycling challenge of lead acid batteries from solar PV, the solar industry stakeholders including manufacturers, developers and distributors will need to come together to set up take-back schemes, collection and recycling systems. Extended producer responsibility is one of the key concepts that need to be applied in practice. With regard to environmental benefits, we can mention the reduction of extraction of mineral reserves, non-contamination of soil, rivers (water), air, reduction of space for landfills. As well as fostering the importance of recycling and the formation of environmental awareness. Time for action is now, it is still possible to avoid solar PV battery waste becoming a new toxic wave.

Acknowledgement

Thanks to the company Alsol Energias Renováveis and University of Cambridge for working together and contributing to provide the necessary information to the elaboration of this work. This article was developed within the scope of Strategic Call 21/2016 of the Technological R&D Program of the Electric Energy Sector regulated by ANEEL.

REFERENCES

Basel Convention on the control of transboundary movements of hazardous wastes and their. Milestones in the Convention's History. Disponível em: <http://www.basel.int/convention/basics.html#9>.

Bateria de hidreto metálico de níquel. Disponível em: <http://pt.wikipedia.org/wiki/ bateria_de_hidreto_met%C3%A1lico_de_n%C3%ADquel>.

Bateria de íon lítio. Disponível em: <http://pt.wikipedia.org/wiki/bateria_de_%C3% ADon_de_l%C3%ADtio>.

Battery history. Disponível em: <http://www.europulse.com/battery_history.htm>.

LEMOS,Idelton.Fontes alternativas de energia na geração de eletricidade Aplicações e perspectivas da células fotovoltaicas e outras fontes de energia,Minas Gerais-UFLA,Monografia,2005.

Jacob B, Ritz B, Heinrich J, Hoelscher B, Wichmann HE. The effect of low-level blood lead on hematologic parameters in children. Environ Res 2000; 82:150-9.

Machado, Iraci Pereira. Avaliação Ambiental do Processo de Reciclagem de Chumbo. Dissertação (Mestrado em Engenharia Mecânica) – Faculdade de Engenharia Mecânica, Unicamp, São Paulo, 2002. Disponível em: <http://libdigi.unicamp.br/document/?code=vtls000252297>.

Sanhueza, Abel E. Chacon; FONTANETTI, A. R. Novos processos de reciclagem de chumbo. Revista Matéria, v. 11, n. 2, p. 146-154, 2006. Disponível em: <http://www.materia.coppe.ufrj.br/sarra/artigos/artigo10627>.

Santos, R.R dos, 2002, Procedimentos para eletrificação rural fotovoltaica domiciliar no Brasil: uma contribuição a partir de observações de campo. Tese de doutorado. PPG em Energia da USP, 238p.

Torcheux, L., Lailler, P., 2001, A new electrolyte formulation for low cost cycling lead acid batteries. Journal of Power Sources, 95, p.248-254.