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Prospects for the use of aluminum-air batteries in solar energy in Greece

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Abstract. The topic of aluminum use in the production of air-aluminum batteries, for the future development of solar energy in Greece, is being considered in this work. The article analyses different systems of vehicles in order to propose the use of air-aluminum batteries instead of lithium-ion ones.

1. Introduction

Over the last decades, climate change has become a significant environmental problem. One of its main causes is the substantial amount of carbon dioxide emitted from burning fossil fuels. Indeed, according to the conclusions of the International Panel on Climate (IPCC), the increase in industrial carbon emissions has led to an acceleration of climate change [1].

To mitigate climate change it is essential to reduce the consumption of oil as a source of energy. Instead of oil, renewable energy sources (RES) can be exploited to generate electricity or design electric vehicles. The use of "green energy", i.e., inexhaustible natural sources such as wind, water, solar energy, is environmentally friendly and has great prospects for further evolving. However, accumulating "green energy" entails problems, since *solar photovoltaic systems* (*PV*) can only generate electricity during daytime, whilst a substantial demand for electricity arises during the evening hours. Hence, without the proper design and use of batteries, the exploitation of PV systems cannot be effective.

To overcome this limitation, it is necessary to design high-capacity batteries which can store surplus of renewable energy, thus reducing the dependence on oil.

The development of solar energy systems in Greece began in 2006, and ever since the amount of energy harvested and consumed through solar panels has constantly increased. This is motivated by the high irradiation with a parallel beam of rays originating from the direction of the solar disk, i.e. insolation, which in the Mediterranean is approximately 1700 $kW \cdot h/m^2$ (figure 1).

Greece ranks 5th among all countries in terms of the amount of energy generated by PVs per unit of population, and about 7% of all electricity consumed in the country is produced by PVs [2]. Currently, the largest PV in Europe is being built in Greece, using two-sided modules with a capacity of 204 MW, which is anticipated to be launched at the end of 2021 [3].

While using PVs, the energy generated by solar panels is stored in batteries. Then, the received current is converted from DC to AC and it is distributed to households for their needs. To produce 1 kW of energy, 7-10 m^2 of solar panels are enough.

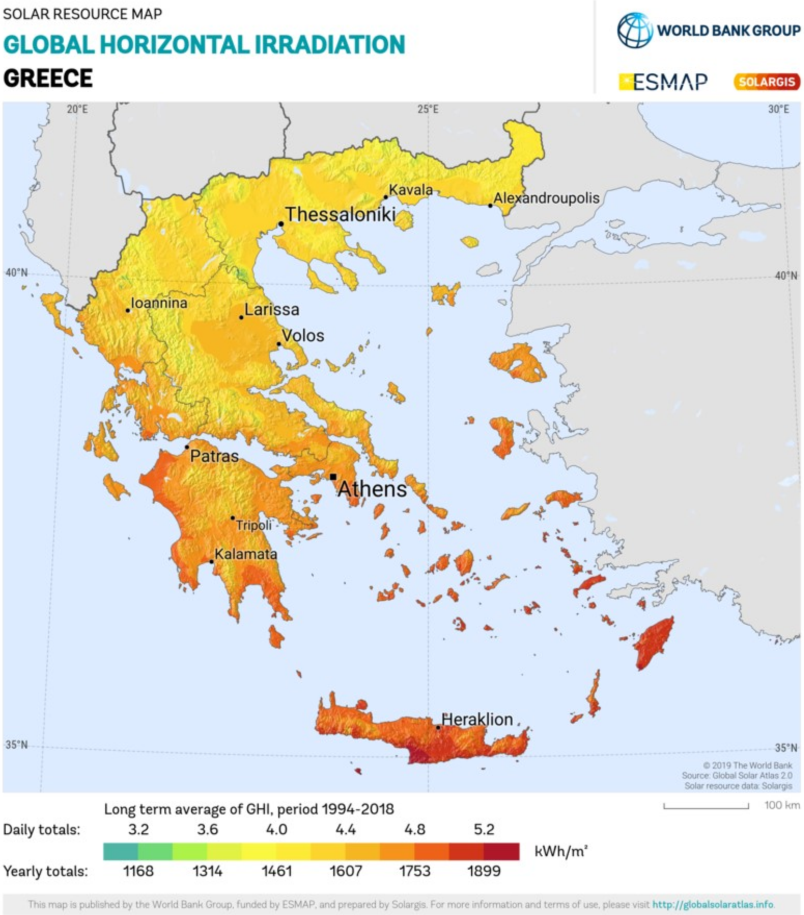

Figure 1. The level of insolation in Greece.

When tackling the problem of electricity storing, utilizing aluminum-air batteries (Al-Air) is advantageous from an environmental point of view, since there are no CO2 and NOx emissions or thermal pollution. Additionally, it is also possible to recycle aluminum by reducing Al(OH)3 to Al without further bauxite mining.

Lithium-ion batteries are widely used for energy storage in electric vehicles `and in the power industry. However, the limited resources of lithium and its uneven distribution on earth hinder the development of lithium-ion batteries for large-scale applications. In accordance with existing technologies and the growth rate of lithium production, lithium ores will be exhausted in about 25 years, and lithium reserves of proven resources associated with salt lakes will be depleted in about 50 years [4]. Therefore, a promising direction is the use of aluminum for the manufacturing of an aluminum-air accumulator.

Aluminum is the most abundant metal and the third most abundant element in the earth's crust after oxygen and silicon [5]. This, along with the highest theoretical volumetric capacity, constitutes aluminum one of the most promising anodes for electrochemical energy storage systems.

2. Materials and methods

The aim of this work is to study the prospects of the aluminum-air batteries use in solar energy systems in Greece, as well as their exploitation in the electric vehicles operation. To do this, it is necessary to consider the aspects that affect the amount of greenhouse gas (GHG) emissions, and to analyze the requirements for climate policy set forth at various international conferences and adopted protocols and agreements. As discussed later, from the analysis of the annual GHG emissions of the various economy sectors it follows that a large role is owed to the anthropogenic component.

It has been found that aluminum is the most common metal. An analysis of the aluminum use advantages revealed that it is more environmentally friendly, and that the electrical energy consumed to produce aluminum is about three to five times lower than for lithium.

In large cities, up to 90% of harmful emissions are generated by the operation of vehicles, hence, a study of the use of different vehicle types is carried out. The following types are identified:

- Internal combustion engine vehicles (ICE) of the traditional type;
- Hybrid type, a combination of an internal combustion engine with an electric drive;
- Air-based vehicles, utilizing hydrogen fuel cells;
- Battery-based vehicles.

Motivated by the analysis of these material results, a proposal to use aluminum air batteries instead of lithium-ion batteries is made.

3. Results

Air-aluminum batteries (Al-Air) demonstrate the highest energy density values among the batteries of all types; hence they are a promising technology for energy storage. This battery type has not yet become widespread, due to the high cost of the anode and difficulties exhibited in the removal of by-products when using traditional electrolytes [6].

The air-aluminum battery generates current due to the chemical reaction of the metal with oxygen from the ambient air (figure 2). The anode is an aluminum plate. The cell is coated on both sides with a porous material with a silver catalyst that filters the CO2, and the metallic elements slowly degrade to Al $(OH)_3$.

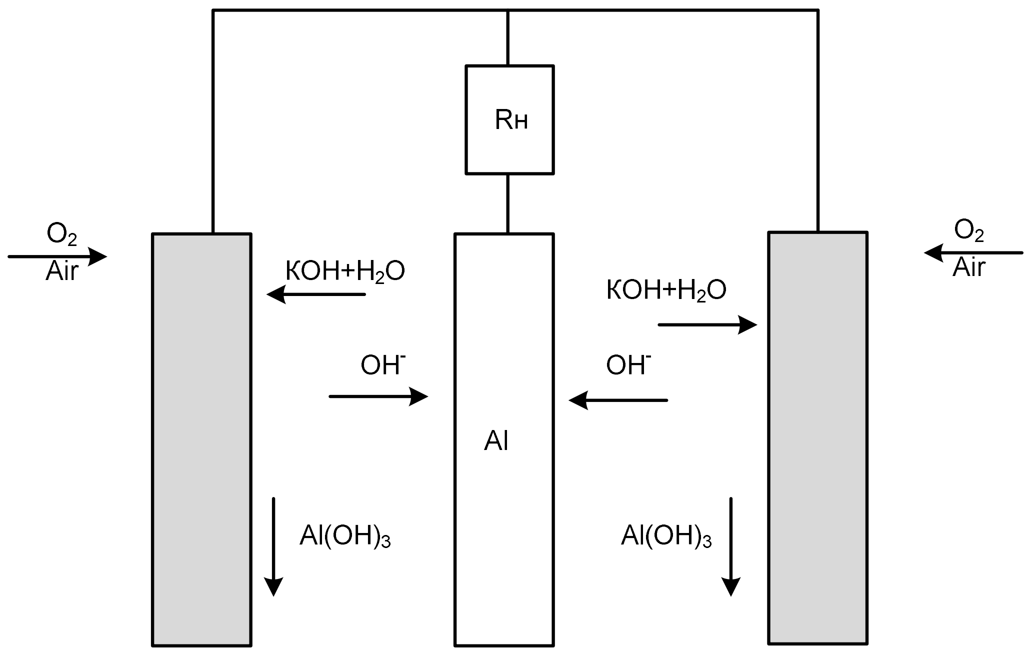

Figure 2. Air-aluminum battery (Al-Air).

The relatively high density of aluminum, which is about 2.7 g/cm2 and its trivalent ionic state, enables the theoretical volumetric capacity of aluminum to reach 8.04 A h3/cm3, which is two to three times higher than that of magnesium and lithium. This unique property makes the use of aluminum-based batteries particularly promising in devices where the available volume is limited or where

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minimizing the device size is the most important optimization criterion. Thus, aluminum-based batteries are suitable for powering portable electronics and electric vehicles, or they can be exploited to improve the home power energy consumption.

It is noted that aluminum air batteries are non-rechargeable cells. When the aluminum anode is consumed, by reacting with atmospheric oxygen in an aqueous electrolyte to form hydrated alumina, the battery can no longer generate electricity.

4. Discussion

Despite the advantages of aluminum-based batteries, the aluminum industry is responsible for about 1% of man-made greenhouse gas emissions, with about 40% coming from direct emissions - the process of aluminum production itself and about 60% from indirect emissions – the generation of electricity in power plants [7]. Approximately 1 kg of aluminum produces 5-20 kg of CO2. Hence, it is important for the increase of the aluminum production to use renewable energy in aluminum electrolysis at any aluminum-based application in order to reduce emissions. In that manner, we can consider aluminum as a promising energy source. The renewable energy is stored in the form of aluminum, and it is later distributed to the location where it will be consumed, or in regions with increased environmental stress, or in areas where there is a shortage of energy resources, such as the islands of Greece.

To produce 1 kg of aluminum, temperatures of about 1000 °C are required, as well as 9–12 kWh of electrical energy with a process efficiency at around 85 to 95% [8]. If the electrolysis of water is achieved by using "green energy", renewable energy from hydroelectric power plants, the sun, wind and so on, the functioning of aluminum energy, should not lead to an increase in the harmful impact on the environment. Theoretically, one can get approximately 5 kWh per 1 kg in an aluminum-ion battery.

For comparison, lithium, similarly to aluminum, is obtained via the electrolysis of lithium chloride at a temperature of about 500 °C [9], however, in this process the electrical energy consumption is 32–40 kWh per 1 kg.

Currently, stationary energy sources and energy technology complexes are used, for example, an experimental cogeneration power plant KEU-10 was developed, using aluminum as a primary fuel, water as a primary oxidizer, with a nominal hydrogen capacity of 10 m^3/h [10].

5. Conclusion

The problem of saving the environment is inextricable linked to the emissions of greenhouse gases, which include CO2. To preserve the planet's ecosystem and address the issue of global climate change, it is essential to use renewable energy sources, as well as to reduce the use of fossil fuels. Global development should be “green” and sustainable, decisive for economic development together with environmental problems.

When using solar energy as RES, it is necessary to resolve the issue of energy redistribution during the daily change in energy consumption. The use of air-aluminum batteries in this case is promising.

The electric energy consumption for aluminum production is about three to five times lower than that of lithium, which results to the same theoretical gravimetric or volumetric capacity of the metal negative electrode in the battery.

Therefore, it is advantageous to develop aluminum-based storage batteries for the development of solar energy in Greece and around the world. The use of aluminum-air batteries (Al-Air) in solar energy production areas will help to optimally redistribute the generation and consumption of electricity.

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