

RENEWABLES AND NEW MATERIALS

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Abstract: Different types of new materials and their application in renewable energy sources are discussed. The new materials in Solar cells like perovskite, ferroelectric, organometallic, ceramic, as well as different technologies such as tandem, multi junction or concentrated are presented. Fuel cells in particular SOFC (Solid Oxide Fuel Cell) as well as new tendencies in membranes and electrodes have been discussed. The trends to use fiber and composites for the blades in wind power, concrete towers, methods for sealing and protecting from corrosion are given, too. Some aspects of new batteries like flow batteries, zinc-air and aluminum-ion batteries, tidal and wave energy are reported.

Keywords: renewable energy sources (RES), new materials, solar cells, new batteries, tidal and wave energy.

1. INTRODUCTION

Over the last 200 years, the main proportion of our energy has come from non-renewable sources such as oil and coal. These resources are running out and affecting climate change resulting in a strong push in the scientific research community towards exploration of the potential of renewable sources of energy (RES) for the future. How can we keep supplying energy to an ever-growing population and how much will it cost [1]? There are two ways to achieve these goals:

- Increasing efficiency and reducing the demand for energy.
- Increasing the supply of renewable energy.

The solution seen by The International Energy Agency is in increase in RES, expecting electricity generation from 21 % in 2012 to 33 % by 2040, while EU targets state that 20% of energy comes from RES at 2020. It is apparent that, in order to mitigate the impact of climate change and also to ensure the energy security in the world, we must develop renewable energy sources rather than continue to rely on fossil fuel-based energy [1].

Reducing energy demand can be achieved by: economic factors, seasonal factors, temporal factors. In this respect, it is very important to identify, launch, and advance innovative research directions in renewable energy materials science. Some of promising solutions are discussed in the following text.

2. SOLAR CELLS

Solar cells remain a focal point of scientific investigation since the Sun offers the most abundant source of energy on the Earth [2]. The concern, with conventional solar cells made from silicon is their cost as well as material. Even with recent improvements, they still require a significant amount of electricity and industrial processing to be manufactured.

The answer to energy problems lies in a new generation of super-efficient, low-cost use of sunlight, i.e. the use of technological advancements underpinned by application of improved or new materials to improve efficiency and reduce the cost of PV panels per kWh. Most solar panels on the market today use crystalline silicon cells-which convert on average around 16 percent of sunlight into electricity [3]. Other panels utilize cadmium-telluride (Cd-Te) or copper-indium-gallium-selenide (CIGS) thin-films, the efficiencies of which are 12 to 15 percent. Scientists claim that with the new approaches, up to 50 percent efficiency could be reached.

One of the most promising technologies are multi-junction cells in which each layer of light-harvesters gather energy from a separate slice of the solar spectrum. The tendency is to employ super-efficient semiconductor materials like perovskite and gallium-arsenide, and use of tin solar-absorbing “quantum dots” – nanometer-sized crystals able to confine energized electrons and help them knock

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others loose [4]. Assembling the dots into a cell, however, requires a “whole other level of chemistry”. The process, called “multiple exciton generation”, can potentially recover a third of light energy normally lost as heat.

Silicon won't be replaced in solar plates soon, but it might not be too long before it gets a partner from materials called perovskites. In 2009, researchers turned attention to a class of material called “metal halide perovskites”, (MHPs)[5]. Those materials are sprayed on like paint onto solid objects. As the result, the MHPs crystallize into a thin film that can be used to capture energy in a solar cell. The researchers suggest it should be possible to make a silicon-perovskite “tandem” device that is more than 25 percent efficient. Making perovskite solar cells could be integrated into existing silicon panel manufacturing lines by adding a few steps. Within just a few years, performance of MHPs rivals conventional silicon solar cells. The ultimate goal is to make manufacturing MHPs solar cells as easy as printing newspapers, generating rolls of thin solar cell material that could be easily applied to houses, cars, or in other target applications.

One challenge with perovskite based advances is that the range of the solar spectrum the perovskite absorbs does not fully complement that absorbed by silicon. One way to solve this is to introduce cesium ions instead of certain ions, such to achieve the desired photovoltaic properties while maintaining the material's structural stability. Perovskite-based technologies face further challenges due to the material's sensitivity to moisture and air, and questions remain about whether perovskite cells can be made durable enough to survive the long lifetimes required in power systems. One significant drawback with many current MHP solar cells is that they contain lead.

Among the various types of solar materials, organometal halide perovskite has attracted scientist attention due to its optical and electronic properties. [6] Dramatic increase in the power conversion efficiency (PCE) from 3% in 2009 to as high as over 22% today, sets these solar cells as a promising next-generation energy device.

High-performance tandem devices made of semiconductors other than perovskite have already achieved efficiencies in the lab of over 40 percent, but they are extremely expensive as a result of complex manufacturing processes. Making perovskite cells is much cheaper, and they are technologically easier to manufacture.

Some material exhibit a property where, when exposed to light, their electrons take off in one particular direction without crossing from one material to another. This is called the ‘bulk’ photovoltaic effect and is in contrast to the ‘interface’ effect that occurs

in existing solar cells.[7] This phenomenon, although known since the 1970s, has been demonstrated only with ultraviolet light. The availability of a material that exhibits the bulk photovoltaic effect for visible light would simplify solar cell construction.

Another way to go around the inefficiency imposed by the Shockley-Queasier limit in interfacial solar cells is to stack several solar cells having different bandgaps [8]. These solar cells have a top layer with a high bandgap catching the most valuable photons and lets the others pass through. Next layers have lower and lower bandgaps, getting the most energy out of each photon.

A design made with a new ceramic material shows the way to provide sustainable power cheaper, more efficiently, and requiring less manufacturing time. It also reaches a four-decade-old goal of discovering a bulk photovoltaic material that can harness energy from visible and infrared light, not just ultraviolet light. A new class of ceramic materials can be understood as one material which does the work of two. The used material is ferroelectric and can thus switch polarity which is one of key traits for exceeding the theorized energy-efficiency limits of today's solar cells.

The advance, based on Solar Junction⁹ findings could help to make a solar system called concentrated photovoltaics a far more attractive way to generate electricity from the Sun [9]. Advances in solar cell efficiency have made concentrated photovoltaic systems economical in some areas. Solar Junction's cells employ fewer layers than many other ultra-efficient solar cells and are better matched to the solar spectrum. Solar cells designed for use under such high concentrations—called multi-junction cells- incorporate two or three semiconductor layers for absorbing different colors of sunlight. In an experimental trial with use of the new materials, 41 percent of the energy in sunlight was converted into electricity [10].

Organic compound cells are a current area of investigation too. The new materials for the organic photovoltaic (PV) cells based on composites of a conjugated polymer and fullerene or its derivatives are investigated for their application in solar cells. The results on some composites of the conjugated polymer MEH-PPV poly (2-methoxy-5-(2'-ethylhexyloxy)-1,4-phenylenevinylene) and P3HT (poly-3-hexylthiophen) with fullerene and metal phthalocyanines have been reported. Adding of phthalocyanine to fullerene may lead to the higher photovoltaic efficiency of the composite at the same fullerene contents.

Recently ferroelectrics have attracted attention as materials for use in photovoltaic devices. There

has been designed a series of single-phase solid oxide solutions made from low-cost and non-toxic elements using conventional solid-state methods: $[\text{KNbO}_3]_{1-x}[\text{BaNi}_{1/2}\text{Nb}_{1/2}\text{O}_{3-\delta}]_x$ (KBNNO). The KBNNO has ability to absorb up to six times more solar energy than the current ferroelectric materials what makes it very attractive for solar energy conversion and other applications [11].

Harvard physicists suggested a device which would generate electric power by capturing energy from Earth's infrared emissions [12]. Two different types of energy devices are proposed: one that is analogous to a solar thermal power generator, and other that is analogous to a photovoltaic cell. Both would run in reverse.

The first type of device consists of a "hot" plate at the Earth and air temperature, and a "cold" plate on top of it. The cold plate, facing upward, is made of a highly emissive material that cools by very efficiently radiating heat. It has been calculated that the heat difference between the plates could generate a few watts per square meter. The other proposal relies on temperature differences between nanoscale electronic components—diodes and antennas. There are investigations in new types of diodes (tunnel, ballistic) that handle lower voltages. Only a selected class of diodes can switch on and off at the 30 trillion times a second rate, which is needed for infrared signals. Increasing the impedance of the circuit components, i.e. raising the voltage to a more practical level, might contribute to finding a working solution too.

There is significant amount of research on solar cells on a global level. For example, the researchers at NREL have developed a way to create a high-efficiency, monolithic, multijunction, photovoltaic devices formed through the epitaxial lattice-matched growth of at least one high ($> 1.7\text{eV}$) sub-cell and at least one medium ($1.1 - 1.7\text{eV}$) bandgap sub-cell, followed by the growth of a lattice-mismatched low ($< 1.1\text{ eV}$) bandgap sub-cell on a compositionally graded layer. A team of Berkeley Lab researchers has invented the first vapor-liquid-solid (VLS) growth technology yielding to photovoltaics. The advance has been achieved through a new world performance record for solar cells made with "earth-abundant" materials like copper and zinc instead of indium, gallium and other so-called "rare earth" elements.

No doubt the performances of solar cells are going to improve significantly.

3. FUEL CELLS

Fuel cells (FC) offer a clean and highly efficient way to convert the chemical energy stored in

fuels directly into electrical energy [13]. They are similar to batteries as they have an anode, cathode and electrolyte, but they use fuel to create a continuous flow of electricity. Fuel cells can be about four times more efficient than a combustion engine because they are based on electrochemical reactions. There are many types of FC such as: Direct liquid fuel cells, PEM (proton exchange membrane) fuel cells, Fosforous acid FC, Alkali FC, Molten Carbonate FC, Solid oxide FC.

The solid-oxide fuel cell (SOFC) [14] is one of the most promising of these energy technologies. It is also an environmentally friendly technology. In SOFCs, the electricity is created by oxygen ions traveling through the fuel cell. SOFCs don't require the use of expensive metals, like platinum, and can work with a large variety of fuels, even with gasoline or diesel fuel. When gasoline is used for fuel, however, a carbon-based material tends to build up in the fuel cell and stop the conversion process. Some other chemicals, especially sulfur, can also poison and stop the reactions. The SOFC has certain advantages over lower temperature fuel cells. It has ability to use carbon monoxide as a fuel rather than being poisoned by it, and the availability of high-grade exhaust heat for combined heat and power, or combined cycle gas-turbine applications. The cost is the most important limit to SOFC implementation. The most important technical barriers relate to the electrodes. In terms of mitigating global warming, the SOFC results in reduction of carbon dioxide emission. Much of the R&D focuses on approaches that will increase activity and utilization of current platinum group metal (PGM), and PGM-alloy catalysts, as well as non-PGM catalyst approaches for long-term applications.

Next generation of ionic conducting membranes for fuel cell, battery, and other applications are very promising too (NREL). To improve fuel cell performance, R&D focuses on developing ion-exchange membrane electrolytes with enhanced efficiency and durability; improving membrane electrode assemblies (MEAs); developing transport models and in-situ and ex-situ experiments to provide data for model validation; identifying degradation mechanisms and maintaining core activities on components, sub-systems, and systems specifically tailored for stationary and portable power applications[16].

4. NEW BATTERIES

There is a clear need for bulk energy storage in the modern and future power systems, such as for example the storage of energy generated by wind

farms at night to be used when demand is high during the day. The conventional battery technology is so expensive that it only makes economic sense to store a few minutes of electricity.

Among many, Harvard University researchers claim to have developed a new type of battery that could make it economical to store electricity from wind farms and other sources of power. The new battery, is based on an organic molecule called a quinone - found in plants such as rhubarb that can be cheaply synthesized from crude oil [17]. The molecules could reduce, by two-thirds, the cost of energy storage materials in a type of battery called a flow battery, which is particularly well suited to store large amounts of energy.

In a flow battery, energy is stored in large tanks in liquid form. In order to make storing hours of energy, flow batteries need to cost just \$100 per kilowatt-hour instead about \$700 per kilowatt-hour today (U.S. Department of Energy). The energy storage materials account for only a fraction of a flow battery's total cost and the quinones will cut the energy storage material costs down to just \$27 per kilowatt-hour. The Harvard work is the first time that researchers have demonstrated high-performance flow batteries that use organic molecules instead of the metal ions [18]. The quinones can be easily modified, which might make it possible to improve their performance and reduce costs. So far, the researchers are using quinones only for the negative side of the battery, while the positive side uses bromine, a corrosive and toxic material. Further research is being undertaken on development of new versions of the quinones that could replace the bromine.

There is competition from other startups developing cheaper flow batteries, such as EnerVault and Sun Catalytix [19]. Sun Catalytix is developing inorganic molecules to improve performance and lower cost. Furthermore, EnerVault uses iron and chromium as storage materials and is developing ways to reduce the cost of the overall system [20]. A Swiss company claim to have developed rechargeable zinc-air batteries that can store three times the energy of lithium ion batteries, by volume, while costing only half as much (De Volt, Switzerland).

The battery designed and developed at SINTEF – a research institute in Trondheim, Norway overcomes the main problem with zinc-air rechargeable batteries – that they typically stop working after relatively few charges, Head Pumps. Geothermal power [21]. If the technology can be scaled up, zinc-air batteries could make electric vehicles more attractive. Unlike conventional batteries, zinc-air batteries rely on oxygen from the atmosphere to generate electrical current. The battery chemistry is

also relatively safe because it doesn't require volatile materials, so zinc-air batteries are not prone to catching fire like lithium-ion batteries.

Making zinc-air batteries rechargeable has been a challenge [22]. Inside the battery, a porous "air" electrode draws in oxygen and, with the help of catalysts at the interface between the air and a water-based electrolyte, reduces it to form hydroxyl ions. But after repeated charge and discharge cycles, the air electrode can become deactivated, slowing or stopping the oxygen reactions. This can be due, for example, to the liquid electrolyte being gradually pulled too far into the pores. The battery can also fail if it dries out or if zinc builds up unevenly, forming branch-like structures that create a short circuit between the electrodes. ReVolt reported it has developed methods for controlling the shape of the zinc electrode (by using certain gelling and binding agents) and for managing the humidity within the cell.

For electric vehicles, ReVolt is developing a novel battery structure that resembles that of a fuel cell. The system would be like a fuel-cell system or a conventional engine, in that the zinc slurry would essentially act as a fuel—pumping through the air electrode like the hydrogen in a fuel cell or the gasoline in a combustion engine.

The recent discovery of a fast charging aluminum-ion battery with a graphite cathode could potentially revolutionize small electronic devices, while some hopes to extend this to MW scale storage [23]. Unlike lithium-ion batteries, aluminum-ion is not prone to combustion resulting from overheating, and still offers comparable capacity to the best energy storage technology presently available. 'Fast charging' could mean almost as quick as a capacitor, but with better charge preservation to enable time shifting of power delivery.

5. WIND POWER

The wind power industry is a growing market for composite materials. Light construction and fiber composite technologies make wind energy systems very attractive and efficient, thus reducing produced energy costs.

The first rotor blades made from glass-fiber reinforced plastics (GRP) were used as early as 1957 in commercial systems sizes of a few tens of kW. Today, we are able to attain magnitudes of 8 to 10 MW and are looking towards larger scale solutions in the near to medium future. The GRP of rotor blades is increasingly being replaced by the lighter and more rigid carbon fiber-reinforced plastic (CFRP). In the wind power sector, CFRP or composites can

potentially be employed also in other components, such as the tower or generator shafts (FlexShaft) [24,25]. Rotor blades made from GRP and CFRP are finding application at an increased rate. The composites allow manufacturing large yet light structures such as the nacelle housing and long blades. High-performance composites consist of carbon, Kevlar, or glass fibers impregnated with a resin and cured into shape using various molding methods. The future is expected to involve an increased use of CFRP making it possible to create even larger and better optimized rotor blades for wind power systems. In addition, the use of metal-composite hybrid materials which combine lighter weight composites with the durability of aluminum, zinc, copper or steel can enable structural components with slightly more mass than carbon fibers but at significantly lower cost carries significant promise of delivering the required technical performance levels in this area.

There are still a range of potential optimizations that can be made in both the technologies and the materials themselves, for example, further development of material (fibers and matrices, sandwich cores) properties such as durability, quality, bird and lightning resistance, corrosion (especially in offshore situations), erosion or recycling.

The technology is still nowhere near the level of readily available 3D printed 80m long wind turbine blades, however it is expected to quickly pick up pace in this respect as sub-components manufactured with this technique are presently under evaluation.

Siemens has announced the commercial launch of a concrete wind turbine tower technology that places turbines in stronger winds at higher altitudes, thus resulting in more potential energy production [26]. The precast segmental concrete tower system is designed to be economically scalable to heights in excess of 115 meters. This concrete tower technology offers up to an additional 10% or more annual energy production compared to the typical 80 meter height, depending on climatic conditions.

Sika has presented its full range of sealants and structural adhesive solutions for wind turbines from the tip of the blades to the base of the foundation - which include the unique SikaForce-7800 Red & Blue two-component polyurethane structural repair adhesives and SikaDur Blade Repair Kits [27]. Many resins used in high-performance composites have molecular make-ups that result in a thick or semi-solid product at room temperature. Emerging classes of smart materials include self-healing materials, sensing materials, and shape memory materials, each of which has many potential applications what has been demonstrated recently in windmills.

Increased vibration levels can loosen some

tower fasteners resulting in a need for regular or requires occasional re-tightening and resulting costly maintenance. To mitigate this and similar risks most trends are oriented toward looking for better ways to measure tension (rather than torque) and prevent corrosion. Other trends are toward lighter tools and a future trend is collaboration between construction workers and turbine engineers that will build design features that make it easier to tighten bolts outside the hub – a more purpose designed and ease of maintenance driven technological solutions are required.

There is a discussion how to design the best way to produce or measure bolt tension. Standard procedure has been to measure pressure in hydraulic tools or current in electric tools. Those parameters indicate that a torque that corresponded to a required bolt tension has been reached. It is noted that actual bolt tensions can vary as much as $\pm 40\%$.

The offshore wind installations are encouraging development of bolt coatings with the purpose to protect industrial structures and equipment in corrosive conditions in which saltwater and high humidity corrode unprotected steel. Chemists are giving attention to zinc flake materials [28].

The turbine blades at the leading edge gradually wear away due to dirt in the air along with crop dust and rain. When this effect does not receive proper attention, the blade can and will deteriorate to the point of needing a replacement, which is a very costly process. Coating developer Hontek has developed a new series of blade coating for the wind turbine blades to address this issue and prolong blade lifetime in this respect [29].

Siemens officials have recently stated that the magnets to be used in Siemens direct-drive wind turbines will contain reduced levels of heavy rare earth elements (HREEs), such as dysprosium. In collaboration with Siemens Wind Power, Molycorp and Shin-Etsu are looking at improving the magnet material to reach zero HREEs.

6. GEOTHERMAL ENERGY

The shallow ground or upper 4 m of the Earth's surface maintains a nearly constant temperature ($10^{\circ} - 16^{\circ}\text{C}$). Geothermal heat pumps can use this resource to heat and cool buildings. The heat removed from the indoor air during the summer can also be used to provide a free source of hot water. Some geothermal power plants use the steam from a reservoir to power a turbine/generator, while others use the hot water to boil a working fluid that vaporizes and then turns a turbine

Many technologies have been developed to

take advantage of geothermal energy such as: Geothermal Electricity Production, Geothermal Direct Use and Geothermal Heat Pumps. Geothermal power plants, however, use steam produced from reservoirs of hot water found a couple of miles or more below the Earth's surface. There are three types of geothermal power plants: dry steam, flash steam, and binary cycle [30].

Dry steam power plants draw from underground resources steam. The steam is piped directly from underground wells to the power plant, where it is directed into a turbine/generator unit. Flash steam power plants are the most used. They use geothermal reservoirs of water with temperatures greater than 182°C. This water flows up through wells in the ground under its own pressure while some of the hot water boils into steam. The steam is then separated from the water and used to power a turbine/generator. Any leftover water and condensed steam are injected back into the reservoir, making this a sustainable resource.

Binary cycle power plants operate on water at lower temperatures of about 107°-182°C. By using the heat from the hot water, a working fluid, usually an organic compound with a low boiling point, is vaporized in a heat exchanger and used to turn a turbine. The water is then injected back into the ground to be reheated. The water and the working fluid are kept separated during the whole process, so there are little or no air emissions.

Small-scale geothermal power plants (under 5 megawatts) have the potential for widespread application in rural areas, possibly even as distributed energy resources. Distributed energy resources refer to a variety of small, modular power-generating technologies that can be combined to improve the operation of the electricity delivery system.

7. WAVES AND TIDE

Waves are produced by winds blowing. Because waves travel across the ocean, their arrival time at the wave power facility may be better predictable than wind. Conversely, tidal energy, which is driven by the gravitational pull of the moon and sun, is predictable much longer in advance. The technologies needed to generate electricity from wave and tidal energy are at a nascent stage.

There are three main types of wave energy technologies [31]. One type uses floats, buoys, or pitching devices to generate electricity using the rise and fall of the ocean level. The second type uses oscillating water column (OWC) devices where the rising water drives air out of the top of the shaft,

powering an air-driven turbine [32]. The third type employs a tapered channel, or overtopping device that can be located either on or offshore; they concentrate waves drive them into an elevated reservoir, where power is then generated using hydropower turbines as the water is released.

Until recently, the best model for tidal power facilities included erecting a tidal dam, or barrage, with a sluice across a narrow bay or estuary [33]. As the tide flows in or out, the sluice is opened and water flows through low-head hydro turbines to generate electricity. For a tidal barrage to be feasible, the difference between high and low tides must be at least 5m.

Several other models for tidal facilities have emerged in recent years, including tidal lagoons, tidal fences, and underwater tidal turbines, but none of them are commercialized. Perhaps the most promising is the underwater tidal turbine. Several tidal power companies have developed tidal turbines, which are similar in many ways to wind turbines. These turbines would be placed offshore or in estuaries in strong tidal currents where the tidal flow spins the turbines, which then generate electricity.

8. CONCLUSIONS

One of the greatest challenges of mankind is to provide sufficient amounts of clean energy which would be available, affordable and accessible. The solution is expected to be found in new types of energy sources which will invariably require new technological advances. The major issue to further breakthrough in this context is the availability of new materials that can underpin further technological advancement in power generation device design.

There is no doubt that research in new materials in the energy sector will help solve many existing energy problems. Certainly, the main object is to improve efficiency, and to reduce CO2 emission by using sun energy.

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ОБНОВЉИВИ ИЗВОРИ ЕНЕРГИЈЕ И НОВИ МАТЕРИЈАЛИ

Сажетак: У раду се разматрају различите врсте нових материјала и њихове примјене у обновљивим изворима енергије. Презентују се нови материјали у соларним ћелијама као што су перовскит, фeroелектрични, органометални, керамички, као и различите технологије као што су тандемске, вишеспојне или концентроване. Расправља се о горивим чланцима, посебно SOFC (Solid Oxide Fuel Cell), као и новим тенденцијама у мембранама и електродама. Предочени су такође трендови да се користе влакна и композити за оштрице у вјетротурбинама, бетонски торњевци, методе за заптивање и заштиту од корозије. Извјештава се о неким аспектима нових батерија као што су flow батерије, цинк-зрак и алуминум-ион батерије, као и плимској и таласној енергији.

Кључне ријечи: обновљиви извори енергије (ОИЕ), нови материјали, соларне ћелије, нове батерије, плимска и таласна енергија.

