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o obnovljivim izvorima
električne energije

The 4th International Conference
on Renewable Electrical
Power Sources

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FOREWORD

The world population growth reaching over 7 billion people causes the increasing global energy demand, especially electricity demand. Non-renewable energy sources are depletable and environmentally unacceptable (environmentally unfriendly), since they cause various forms of pollution, as well as one of the biggest challenges in the human history – climate change and global warming. In order to mitigate this, the use of fossil fuels must be reduced, and as long as coal, oil and gas are primary energy sources, the world will not make that necessary step forward. Therefore, a significantly higher share of renewable energy sources is required, and these sources are not only renewable, but also much more environmentally acceptable (environmentally friendly).

As a result, it is believed that renewable energy sources will be increasingly used in Europe, which will lead to the reduction of greenhouse gas emissions and less dependence on oil. Searching for such solutions, the European Union set an ambitious goal – Directive 2009/28/EC, which prescribes the reduction of total energy by 20%, the increase of the share of renewable energy in the total energy by 20% and the reduction of greenhouse gas emission by 20%. The European Union has been making large investments in order to reduce carbon emission, achieve competitive prices and protect the environment.

The main goal of the 4th international conference on renewable electricity (electric power) sources is to analyse the comparative advantages and disadvantages of modern solutions in the field of renewable electricity sources used globally and in this country, and to provide the constructive exchange of competent opinions and ideas related to the development and use of these sources.

This international conference is for the fourth time organised by the Society for Renewable Electricity Sources within SMEITS (Serbian Union of Mechanical and Electrical Engineers and Technicians).

Belgrade,
October 2016

PREDGOVOR

Porast broja stanovnika u svetu na preko 7 milijardi uslovljava da svetske potrebe za energijom, posebno električnom, postaju sve veće. Neobnovljivi izvori energije su iscrpivi, nisu ekološki prihvatljivi, jer izazivaju razne oblike zagađenja, kao i jedan od najvećih izazova u ljudskoj istoriji - klimatske promene i globalno zagrevanje. Da bi se to ublažilo korišćenje fosilnih goriva se mora smanjiti, jer dok god su ugalj, nafta i gas primarni energetski izvori, svet neće napraviti taj neophodan korak napred. Zbog toga se zahteva znatno veće učešće obnovljivih izvora energije koji su pored toga što su obnovljivi, i ekološki znatno prihvatljiviji.

Zbog toga se veruje da će se obnovljivi izvori energije u Evropi sve više koristiti, što vodi smanjenju emisije gasova sa efektom staklene bašte i manjoj zavisnosti od nafte. U traganju za takvim rešenjima, Evropska unija je postavila ambiciozan cilj – Direktivu 2009/28/EC koja propisuje da se do 2020. godine ukupna potrošnja energije smanji za 20%, da u ukupnoj potrošnji energije obnovljivi izvori učestvuju sa 20%, kao i da se emisija gasova sa efektom staklene bašte smanji za 20%. Evropska unija ulaže velika sredstva u ostvarenje ciljeva smanjenja emisije ugljenika, postizanja konkurentnih cena i zaštite životne sredine.

Osnovni cilj 4. Međunarodne konferencije o obnovljivim izvorima električne energije jeste da se analiziraju uporedne prednosti i nedostaci savremenih rešenja u oblasti obnovljivih izvora električne energije u svetu i kod nas, i da se obezbedi plodotvorna razmena kompetentnih mišljenja i ideja vezanih za razvoj i primenu ovih izvora.

Ovaj međunarodni skup po četvrti put organizuje Društvo za obnovljive izvore električne energije u okviru Saveza mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS).

U Beogradu,
oktobra 2016

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UPOTREBA NOVIH FOTONAPONSKIH TEHNOLOGIJA ZA INTEGRISANE SISTEME U ZGRADAMA

THE USE OF NEW PHOTOVOLTAIC TECHNOLOGIES IN THE BUILDING INTEGRATED SYSTEMS

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Danas sistemi obnovljive energije imaju značajan uticaj na okolinu, stoga su razvoj resursa obnovljive energije i korišćenje obnovljive energije od ključnog značaja. Jedna od najperspektivnijih tehnologija obnovljive energije jeste fotonaponska (FN) konverzija energije. FN konverzija energije predstavlja direktnu konverziju sunčeve svetlosti u električnu energiju. Korišćenje fotonaponskih panela u zgradama se istražuje već više od dve decenije i deklarisano je kao glavni faktor eksploatacije fotonaponskih panela i smanjenja emisije CO_2 *u zgradama. Komercijalni FN materijali koji se najčešće koriste za FN sisteme uključuju silikonske (Si) solarne ćelije, kadmijum telurid (CdTe), bakar-indijum diselenid (CIS) i solarne ćelije izrađene od drugih tankoslojnih materijala. Fokus mnogih istraživača danas je istraživanje novih tehnologija tankoslojnih fotonaponskih folija, trenutnog stanja na tržištu i budućih izazova koji dolaze sa rastućom potražnjom FN panela. Prednosti tankoslojnih fotonaponskih tehnologija za integraciju u zgradama će takodje biti istaknute u ovom radu.*

Ključne reči: *Fotonaponski paneli, Solarne ćelije, Nove fotonaponske tehnologije, Fotonaponski paneli integrisani u zgradu*

Today, the renewable energy systems have a significant impact on the environment, so the development of renewable energy resources and the use of renewable energy are essential. One of the most promising renewable energy technologies is photovoltaic (PV) energy conversion. PV energy conversion represents the direct conversion of sunlight into electricity. The use of PV in buildings is under investigation since more than two decades, being recognized as a main factor for the exploitation of PV and the reduction of the CO_2 *emissions of buildings. Commercial PV materials commonly used for PV systems include solar cells of silicon (Si), cadmium-telluride (CdTe), coper-indium-diselenide (CIS) and solar cells made of other thin layer materials. Nowadays focus of many researchers is on investigation of new thin film photovoltaic technologies, actual market situation and future challenges arising with growing PV demand. Also the advantages of the thin film photovoltaic technology for building integration will be pointed out in this paper.*

Keywords: *Photovoltaic, Solar cells, New PV technology, Building integrated photovoltaic*

INTRODUCTION

Photovoltaic (PV) is one of the most prominent renewable energy technologies. Solar photovoltaic technologies are an attractive option for clean and renewable electricity generation – it is the direct conversion of sunlight into electricity without any heat engine to interfere.

Starting from 1990 industry of photovoltaic conversion of solar irradiation shows constant annual economical growth of over 20%, and from 1997 over 33% annually. In 2000 total installed capacities worldwide have surpassed 1000 MW, and in developing countries have overreached more than million house-holds which are using electrical energy generated by means of the photovoltaic systems. It is predicted that PV will deliver about 345 GW by 2020 and 1081 GW by 2030 [1]. Over the last five years, the global PV industry has grown more than 40 % each year.

Silicon is still a leading technology in making solar cell because of its high efficiency. But many researchers, due to its high cost, are trying to find new technology to reduce the material costs for production of solar cells and thin film technology can be seen as a suitable substitution. However, the efficiency of solar cells based on this technology is still low, and researchers are intensively making an effort to enhance the efficiency. Commercial PV materials commonly used for PV systems, besides silicium (Si), include solar cells of cadmium-telluride (CdTe), coper-indium-diselenide (CIS) and solar cells made of other thin layer materials [2].

Very important perspective of new thin film PV technology is use of flexible modules, with possibility of their simple integration in roofs and buildings facades. Flexible modules are light-weight and suitable for applications where weight is important, and they offer a much faster payback than products based on conventional photovoltaics [3]. It is expected that they will play a very important role in the world PV market in the near future. In this paper the advantages and perspective of the flexible thin film photovoltaic technology for building integration are also pointed out.

THIN FILM (TF) PHOTOVOLTAICS

Thin-film Si solar cells have few important advantages compared to crystalline cells: the thickness of Si can be drastically reduced to 50 μm, thin films can be deposited on low-cost substrates, thin films can be fabricated on module-sized substrates and in integrally interconnected structures, etc. Crystal-line Silicon on Glass (CSG) is technology which involves the direct deposition of silicon onto glass and solid-phase crystallization for fabrication mini-module with efficiency of 8.0%, [4].

Three materials that have been given much attention under thin film technology are amorphous silicon, CdS/CdTe and CIS, but researchers are continuously putting in more effort to enhance the efficiency. However, all of these materials have some bad impact on the environment. Another solution for thin film technology has been carried out by researchers by using polymer organic as a solar cell material. Polymer materials have many advantages like low cost, light weight and environmental friendly, but they have very low efficiency compared to other materials with just 4–5%.

In this chapter, we will analyze current commercial and potential future TF PV technologies, with a special focus on their related prospective and challenging manufacturing issues.

Amorphous-silicon based PV

Commercial solar cell devices based on hydrogenated amorphous silicon (a-Si:H or a-Si) are typically made of a dual-junction with micro (μc-Si) or nano-crystalline (nc-Si) Si, (micromorph tandem) [5,4].

The Si layers are deposited by plasma-enhanced chemical vapor deposition (PEC-VD) incorporating gaseous mixtures of H_2 and SiH_4. The design of the cells optimizes the collection of current by having very thin n- and p-layers, with an intrinsic intermediate layer, the thickness of which is enough to absorb almost all the incident light, to give a p-i-n structure. However, the physical properties of the i-layer degrade under illumination, because Si-H bonds are destroyed under visible light. This effect can be reduced (but not eliminated) by careful control of the deposition process, decreasing the thickness of i-layer, and using multiple junctions. As in the case for c-Si, a-Si technology was rapidly commercialized in the early 1980s.

These devices rapidly surpassed 10% efficiency, but suffered from light-induced degradation that leads to a reduction of the solar cell efficiency. The possibility to deposit a-Si at temperatures below 200^0 enables the fabrication of light-weight, flexible laminates on temperature sensitive substrates, which is a unique feature that provides a competitive advantage in markets such as consumer products and BIPV, [5].

The best initial efficiencies of 13.7 % and 9.8 % were achieved on triple-junction cells and modules, respectively. However, stabilized efficiencies are still low, around 6–7% for the best commercial modules. Nevertheless, at present, about 8–10% of the worldwide PV production uses a-Si technology, [2].

Cadmium-telluride

This material can produce high efficiency, more than 15 % and is also known to give an ideal band-gap (1.45 eV) since the direct absorption coefficient is very high. A layer of cadmium sulphide is deposited from solution onto a glass sheet coated with a transparent conducting layer of thin oxide. Standard CdTe-based devices, so-called "super-strate configuration", comprising a glass substrate, the TCO, usually SnO_2:F (FTO) and/or $(In_2O_3)_{0.9}(SnO_2)_{0.1}$ (ITO), the n-type window layer (CdS), the p-type CdTe absorber, and finally the back contact (ZnTe/Cu/C or Mo) [5,4].

CdTe solar cells have been used as low cost, high efficiency, thin-film photovoltaic applications since 1970. With the forbidden zone width of 1.5 eV and the coefficient of absorption 105 cm^{-1}, which means that a layer thickness of a few micrometers is sufficient to absorb 90 % of the incident photons, CdTe is almost an ideal material for solar cells manufacturing. CdTe solar cell is sensitive in the wave length of 0.3–0.95 mm and maximum of its sensitivity is in the wave length range of 0.7– 0.8 mm. Laboratory CdTe cells have the efficiency of 16 %, and commercial ones around 8 %. Great toxicity of tellure and its limited natural reserves diminish the prospective development and application of these cells.

The key issues with respect to large-scale CdTe manufacturing are the aforementioned perceptions concerning Cd toxicity and Te availability. Testing of modules fate during fires or leaching of Cd from broken CdTe modules did not reveal non-neglibile threats to the human body or the environment so far, nevertheless module designs have been improved, [6]. The issue of Te availability will require substantial observation and fundamental research, whereas recycling may play a major role, not only regarding the toxicity of Cd but also regarding the re-use of Te, [5].

Copper–indium–gallium–selenide/sulphide

The first copper chalcopyrite PV devices were introduced in 1976 in the form of copper-indium-di-selenide ($CuInSe_2$ or CIS). Consequently, the abbreviations CIS, CIGS, CIGS or CIGSSe are generally used to describe this material, depending on how many elements are involved. Its direct band gap can be as high as 1.68 eV with slight modification with Sulphur (S). The CIGSSe system with up to five elements and numerous binary and ternary phases, presents much greater complexity than the other commercial PV technologies, [5].

The basic structure of CIGS devices fabricated by current manufacturing schemes begins with the deposition of a Mo back contact followed by the p-type CIGS absorber (1–3μm), a thin buffer layer (50–100 nm), and a doped ZnO serving as the transparent front contact.

CIGS is the only commercial TF technology that has continually reported efficiency improvements of its record cells during the last decade, with efficiency at present of 13 % for modules and 20 % for cell [7]. Today, several companies are producing commercial CIGS modules in the range of 10–50 MW/year with Japanese manufacturer Solar Frontier on the forefront selling 14.5% efficient modules from GW-scale production. Substrates include soda lime glass, metal foils, or high temperature polyimide that aroused substantial interest for BIPV and portable power applications, [5].

Organic solar cells

Single-junction OPV devices are generally comprised of a hetero-junction between an electron donor molecule (e.g. P3HT, poly (3-hexylthiophene) and an electron acceptor molecule (e.g. PCBM, phenyl-C61-butyric acid methyl ester) [5]. Similar to CIGS, OPV has made great leaps in terms of performance in the past decade [8] with German company Heliatekbeing the first taking the 10% hurdle, reporting a 10.7% efficient organic tandem cell. The more or less infinite number of candidates for organic semiconductor materials may be categorized as either solution-processed (polymers, den-drimers, oligomers, or small molecules) or vacuum deposited (small molecules or oligomers).

Another main issue that has to be solved with organic solar cells is the stability regarding chemical, physical and mechanical degradation predominant in organic materials and devices. Major issues include photo-degradation and the sensitivity to oxygen, requiring the use of ultra-barriers for encapsulation. Since organic PV

(OPV) relies on carbon based semiconductors, low cost high volume manufacturing of flexible solar modules without any raw-material concern appears feasible [5].

Dye-sensitized solar cells

Due to some problems with efficiency, production cost and environmental related issues of some solar cell materials, researchers have come up with ideas to produce new material technology call dye-sensitized solar cell. Dye-sensitized solar cells (DSC or DSSC) were first introduced in 1991 by Gratzel and O'Reagan. A device is typically composed of organometallic dye molecules adsorbed to a mesoporous titania nanoparticle film, with the pore space filled by an electrolyte. In such a structure light is absorbed by the dyes injecting electrons into the TiO_2 network, which transports these to the front contact. If connected to an external load, the electrons return to the platinized back contact, where they reduce redox couples, which in turn diffuse through the electrolyte and regenerate dye molecules to complete the cycle. Gratzel's group rapidly optimized the device to more than 10% efficiency within a few years of its introduction, [5].

A beneficial feature of DSSC is that they exhibit improved performance at diffuse and low light conditions, motivating their use indoors and without direct solar exposure. In combination with the feature that devices can be fabricated in a number of colors and levels of transparency, this makes them an attractive candidate for consumer products and BIPV applications.

Unfortunately, record cell efficiencies are stagnant at about 11% since more than 15 years, and further optimization of any main component of DSSC devices is not likely to yield significant efficiency improvements [7].

Third- generation for PV solar cell

Other than searching for new material to improve solar cell output, new technology in processing PV solar cell has been ascertained. Nanotechnology or sometimes referred as ''third- generation PV'' is used in order to help increase conversion efficiency of solar cell since energy band-gap can be controlled by nanoscale components [9].

Nanotubes (CNT), quantum dots (QDs) and ''hot carrier'' (HC) solar cell are three devices used in nanotechnology for PV cell production. The advantages of using this technology are: (I) Enhance material mechanical characteristic, (II) Low cost, (III) Lightweight and (IV) Good electrical performances.

2.6.1. Carbon nanotubes (CNT)

Carbon nanotubes (CNT) are formed by hexagonal lattice carbon. One research team has invented photo diode solar cell from CNT and successfully improves efficiency and current output from that solar cell. Although the efficiency for solar cell is still low (3 – 4 %), many research will be carried out in this technology to improve the electrical output [10].

2.6.2. Quantum dots (QD)

Quantum dots (QD) can be described as a material that is built with many forms of material thus makes it a special semiconductor system with an ability to control band-gap of energy. Voltage output can be increased as band-gap energy size increases but on the other hand, smaller band-gap can also increase current output.

As a solution, QDs are used since they can vary light absorption and emission spectra of light [11]. Efficiency of solar cells based on QD are easily influence by the defects on them.

2.6.3. Hot carrier solar cell (HC)

Hot carrier (HC) is a challenging method compared to CNT and QD because it needs selective energy contacts to convert light into electrical energy without producing heat. Its efficiency reaches 66% which is three times higher than existing cell made from silicon. But to this date, due to lack of suitable material that can decrease carrier cooling rates, HC has never been commercialized but remain an experimented technology [12, 13].

FLEXIBLE SOLAR CELLS AND MODULES

Very important perspective of thin film PV technology is flexible modules with strategic space and military use, integration in roofs and buildings facades, etc. The ultimate advantage of thin-film technology is roll-to-roll manufacturing to produce monolithically interconnected solar modules leading to low time for energy payback because of high-throughput processing and to low cost of the overall system, [3].

A-Si flexible modules

Flexible a-Si solar cells are likely to be very popular and in demand for applications in the low to medium range of power, since they can be made in different shades (even semi-transparent), shapes, and sizes.

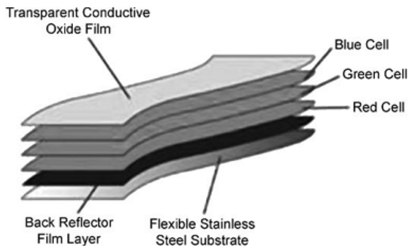
At Fig. 1.a schematic of a triple-junction structure containing amorphous silicon is present, [14]. Digital photograph of a-Si cell device deposited on patterned Al substrate is shown at Fig. 1.b, [15].

The world's leading companies in a-Si TFPV manufacturing are undergoing rapid expansion from an annual production capacity of about 30 MW to 300 MW by 2010, to apply this technology as widely as possible and drive the expansion of its market share by applying its products to free-land applications and building-integrated photovoltaics (BIPVs) [14].

Flexible CdTe cells

Also, CdTe is one of the leading candidates for the solar cells due to its optimum band gap and the variety of film preparation methods.

Fig. 2.a shows flexible CdTe solar module configuration, [16] and Fig. 2.b shows photograph of flexible CdTe solar module. Lab efficiency on plastic foil achived 11.4% (single-junction cell), and on metal foil 8% (single-junction cell), [2].



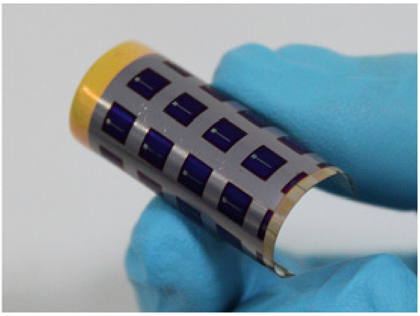
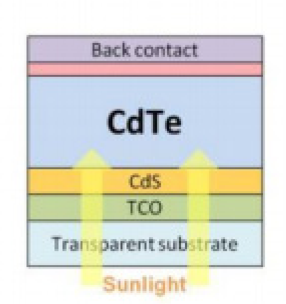


Figure 1. Flexible a-Si solar module

a) Schematic view of a-Si thin-film cell layer structure, [14]

b) photograph of a-Si cell device deposited on patterned Al substrate, [15]

These devices allow building integration in structures, which cannot take the additional load of heavy and rigid glass laminated solar modules. The flexible solar modules can be laminated to building elements such as flat roof membranes, tiles or metallic covers without adding weight and thus, the installation costs can be reduced significantly, [17].



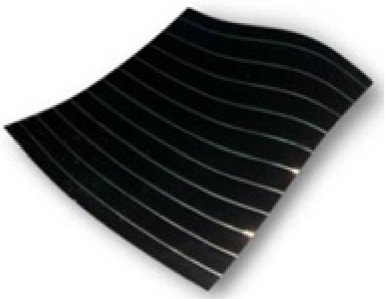


Figure 2. Flexible CdTe solar module

a) Schematic view of CdTe thin-film cell layer structure, [16]

b) photograph of flexible CdTe solar modules, [17]

The Swiss laboratory for thin films and photovoltaics EMPA is involved in the development of flexible CdTe solar cells on polymer films and metal foils. Thay have demonstrated 13.8% efficient CdTe solar cells on flexible polyimide films, [18].

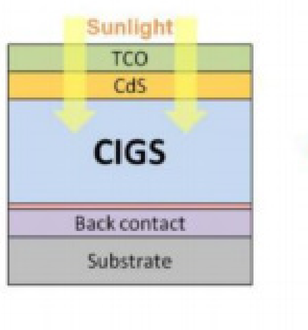
Flexible CIGS cells

A large number of activities on highly efficient, stable, and flexible thin-film modules based on CIGS has recently drawn much interest for flexible solar cells on metal and plastic foils. Apart from the expected high efficiency and long-term stability for terrestrial applications, flexible CIGS has excellent potential for space application because of their tolerance to space radiation, being 2–4 times superior to conventional Si and GaAs cells. Flexible CIGS cells can be grown on polymide and on a variety of metals, e.g., stainless steel, Mo, and Ti, [19]. The basic schematic cross-section of a monolithic module on a polyimide substrate is shown in Fig. 3.a, [16], and flexible prototype mini-module developed on polymer foil is shown in Fig. 3.b, [17].

These devices allow building integration in structures, which cannot take the additional load of heavy and rigid glass laminated solar modules. [17].

Scientists at Empa, the Swiss Federal Laboratories for Materials Science and Technology, have developed thin film solar cells on flexible polymer foils, based on CIGS with a new record efficiency of 20.4% for converting sunlight into electricity. The technology is currently awaiting scale-up for industrial applications, [18] .

Flexible CIGS solar cells have the ability to both realize their potential as the most efficient thin film technology and to dominate the building-integrated photovoltaics (BIPV) market in the future, [16].



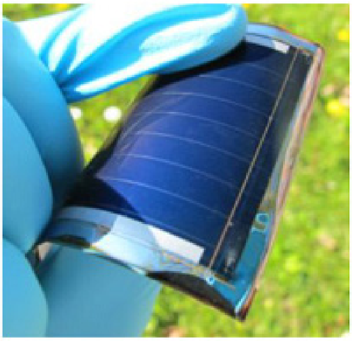


Figure 3. Flexible CIGS solar module

a) Schematic view of CIGS thin-film cell layer structure, [16]

b) photograph of flexible CdTe solar modules, [17]

CONCLUSION

The Building integrated Photovoltaics (BIPV) market, which got increased political support during the last years is still one of the big hopes for TF technologies. In this context, these modules have many advantages compared to c-Si ones: strongly reduced weight for the application to the building stock, see through property, adjustable optical transmittance, excellent building appearance, potential capability for applying flexible substrates, and less sensitivity to the degradation of light intensity and increasing temperature of the module.

Also, compared to traditional Si-based photovoltaics, flexible TF PV technologies offer a unique versatility that architects and engineers will harness to renew the facades of existing buildings, as well as in the construction of new buildings and in the development of power-generating products.

One of the main tasks of researchers is to develop highly efficient thin-film solar cells. They focus on novel concepts to improve the performance of solar cells, to simplify production processes and to improve the device structure of next generation solar cells with higher efficiency at lower cost. Flexible thin film technology is suitable for production of attractive modules which can be realized to be able to match not only traditional architectures, but also the most innovative tendencies, and also cost-effective PV integration.

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Under the hypothesis that all the cost increases occur at the same time, for the scenario of 95% RE contribution with PV + PHS technology IRR remains above 16% which is still good result from the investment point of view.

5 CONCLUSIONS

RE harvesting technologies for power systems in remote islands are highly recommended solution from both environmental and economic point of view. Even the CAPEX for installing them may be higher than in mainland, they become profitable on mid term run.

The multi-criteria approach, which includes technology, economy, environment, and local labour capacities is very useful to avoid future gaps in system implementation and operation.

The most suitable technology does not depend only on the resource availability but rather on the binomial resource availability- technology cost. In this way, we come to the conclusion that the PV technology is the most suitable even the wind resource on St. Helena Island appears to be more abundant.

Even the battery technology progress results in a significant cost reduction, PHS remains the most interesting solution for small to mid size self-sufficient systems.

Achieving 100% RE self-sufficient system, with intermittent sources, requires an important oversizing of the system, both for power production and for storage. Seems much more reasonable to target 80-95% RE system, maintaining a part of existing diesel capacities as a manageable back-up of the system, for the eventual situations of prolonged RE resource lack.

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BOSCH nudi liniju kolektora izuzetnh performansi, kao i setove opreme koji obuhvataju sve što je potrebno za izvođenje jednog solarnog sistema

Inženjerska komora Srbije, Beograd

Viessmann predstavlja kolektor sa ThermProtect – patentiranim "inteligentnim" premazom apsorberskog sloja koji se, sa promenom u svojoj kristalnoj strukturi u zavisnosti od temperature, automatski prilagođava promenama Sunčeve svetlosti i trošenju toplote

Weishaupt nudi solarne kolektore koji su idealni za dopunu kondenzacionog sistema ili toplotne pumpe. Kolektori su robusni i otporni na vremenske uticaje. Pogodni su kako za zagrevanje sanitarne tople vode, tako i za podršku grejanju. Do 30% godišnje potrošnje goriva se može uštedeti kombinovanim sistemom sa podrškom grejanju/zagrevanjem sanitarne vode.

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