The History of Using Solar Energy

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***Abstract*—The energy received on Earth from the Sun is plentiful and totally renewable. Basically, the sun enabled life on our planet, and our life cannot be imagined without it. The sun is directly or indirectly at the origin for nearly all the energy resources on Earth, as fossil fuels (coal, natural gas and oil), hydro (global water circulation is due to the sun), wind, waves, biomass, etc. The sunlight was used as an energy resource already by ancient civilizations. Since than a lot of innovative technologies and advancements were performed in this field. The paper presents the main milestones of the developments performed in this important field of energy conversion.**

Keywords—solar energy; science history.

I. Introduction

The energy requirement of the mankind is continuously growing. It is forecasted that by the middle of our century the global energy demand will at least double. This huge energy necessity and the actual environmental challenges will be possible to be covered by the increasing electrical energy conversion from renewables, among them solar energy [1].

The annual solar energy potential of the Earth is 23,000 TWy. 1,600 TWy should be the world energy consumption for 100 years (computed with the yearly consumption in 2009), as it is illustrated in Fig. 1. For comparison, the Earth's total finite energy resources (coal, uranium, petroleum and natural gas) are of 1,655 TWy and the most optimist estimations of the energy that can be converted yearly from non-solar renewable resources (wind, ocean, biomass, hydro and geothermal) is only 94 TWy [2].

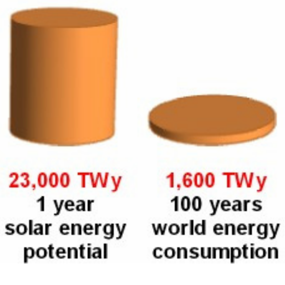

Fig. 1 The solar potential vs. energy consumption

Almost all the energy forms used in electrical power generation are of solar origin. Oil, coal, natural gas and woods were originally produced by means of photosynthesis. Wind and waves are due to temperature differences [3], [4], [5]. Throughout the history, each new applied energy form contributed to the development of the society [6].

The use of the very clean solar energy is not a new discovery of the scientist of our days. It was used in diverse scopes since a lot of centuries. Therefore, the history of solar energy conversion is long, various and exciting.

The paper will deal with the most important and interesting milestones of the developments performed in this field of energy conversion.

II. Ancient Ages

The sun has a vital role in the life on Earth. This was recognized and celebrated by all the cultures already in the ancient ages. Peoples of those days admired the Sun, and even frequently personified and worshipped it as a deity [7].

Egyptian pharaoh *Akhenaten IV* (≈1353 BC - ≈1336 BC), husband of the more famous *Nefertiti* queen, forced religious reforms concerning monotheistic state religion instead of traditional polytheism religious conviction of the ancient Egyptians. He deified himself as a god, who alone could worship *Aten*, the single god accepted that time. *Aten* was the sun disk in the Egyptian mythology, and originally an aspect of the god *Ra*, the Egyptians' sun god. The contact with *Aten* was possible through the sunrays, as shown in Fig. 2 [8].

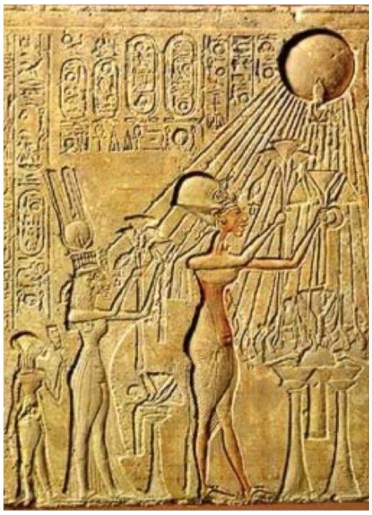

Fig. 2 Pharaoh *Akhenaten IV* in the sunrays being in contact with *Aten*

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In several scripts of the ancient Egypt is stated that Great Pyramid, the last remaining construction from the list of the Seven Wonders of the Ancient World, was built as a stairway to the sun [3].

Almost all of the ancient cultures around the world had their god of Sun, which represented the power and force of the star of our solar system. Some of these gods were: *Amaterasu* in Japan, in Greece *Helios* and later *Apollo* (this last was also sun deity in Rome), *Surya* the Hindu sun god, etc. [9].

Given the immense abundance and usefulness of the solar energy, it slowly moved from the metaphysical approach to more practical applications [7], [10].

The first such applications were connected to architecture. 6000 years ago, the Neolithic Chinese people had their sole opening of their homes facing south to catch wintertime the low sun rays for assisting the warm of the houses. Suspended thatched roof was used to keep away the high summer sun from the houses. This technology was used thousands of years later also by the ancient Egyptians and Greeks [7]. *Aristotle* (384 BC-322 BC) was teaching how to use of the winter sun for heating, and how to keep the house in shade during summertime. This approach was the pioneer of present passive heating and cooling techniques [11].

The proper house orientation was taken from the Greeks by the famous Roman architect *Vitruvius* (≈80 BC - ≈15 BC), author of *De architectura*, one of the basic books in the field. The technology was further developed by applying large transparent single pane windows (*fenestra* in Latin) of mica, translucent marble or clear glass. These windows were acting like solar heat traps, admitting the sunlight and keeping the accumulated heat inside [11], [12].

Since prehistory, the sun was used to dry and preserve food [3]. Food processing was a crucial avocation of mankind. The ancient Egyptians used specific dehydration technology to dry grains, formerly storing them in seal silos. This technology enabled them to keep the stored grain for several years.

Fig. 3 Ancient Egyptians drying meat [13]

Salting was vital in food preparation and conservation, too. The sun was used to evaporate sea water to obtain salt [3]. The saltwater was collected in solar ponds, and after the water was evaporated the salt remained at their disposal. This very simple technology is still used around the world (see Fig. 4).

Fig. 4 Salt pans in Marakkanam (Tamil Nadu, India)

Ancient people early recognized that the concentrated waves of the sun can be used for lighting fire. Already in the 7th century BC magnifying glasses were used to focus the sunrays. Upon a more advanced approach in the 3rd century BC the ancient Greeks and Romans used mirrors to concentrate the sunbeam for lighting torches [14].

One of the most controversy stories of the ancient history is related to this kind of solar energy use. Upon this, the Greek scientist *Archimedes of Syracuse* (≈287 BC - ≈212 BC) lit Roman enemy wooden ships by concentrating sunrays. The "burning mirror" was probably an angled hexagonal giant mirror, or a system of mirrors, focusing the so-called "heat ray", or "death ray" by *Archimedes* on the approaching ships (see Fig. 5).

Fig. 5 *Archimedes* lighting Roman warships

III. MIDDLE AGES

The early middle ages (5th÷10th century), the so-called "dark ages" was the period in Europe following the collapse of the Western Roman Empire. It was the epoch of intellectual and economic darkness, when superstition and illiteracy ruled. Scholars were few, and reason and logic was marginalized by bigot belief and religion. This time period was not suitable for technology progress [15].

The Europe of the 12th÷14th century became more open for technical advancements. But these were either based on long-established techniques originating from Roman and Byzantine cultures, or adapted from Eastern civilizations, as the Islamic world, China or India. At that time, frequently the revolutionary aspect did not lay in the act of invention itself, but in its technological refinement and application to local conditions. During this period, European people continued to satisfy their energy needs almost exclusively with renewable energy [16].

During the Renaissance (literally "rebirth") era (14^{th}÷17^{th} century) in the medieval Europe the number of new inventions and innovations was radically increased. This period can be considered as the bridge between the dark middle ages and modern history.

Leonardo da Vinci (1452–1519), the "Renaissance Man", was an Italian polymath and the most well-known inventor of that age. Beside his famous paintings, like the Mona Lisa and the Last Supper, he had forward showing contributions in a large diversity of science fields, as engineering, chemistry, mathematics, physics, etc. [17]. Seemly he was already at that time aware about environmental issues, since he worried about the destruction of the earth's huge forests. Hence he performed several studies concerning the use of the solar energy for heating purposes.

He investigated the geometry of the reflections of parallel sunrays on a curved metal plate (see Fig. 6). He obtained a geometric relationship which was independent from the curve of the plate. It is believed that *Leonardo da Vinci* proposed the first industrial application of a concave mirror solar concentrator to be used for a water heater. He also proposed a technology to weld copper using concentrated solar radiation, and technical solutions to heat bathing installations or to operate textile machines.

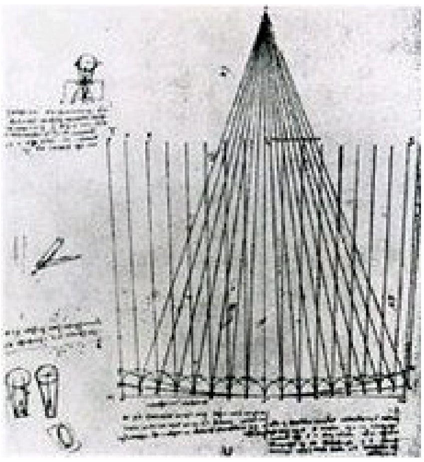

Fig. 6 Drawing of *Leonardo da Vinci* concerning sunray concentration

The Age of Discovery, also named as the Age of Exploration, (15^{th}÷18^{th} century) was characterized by broad overseas exploration. The emerging colonialism and mercantilism resulted in an empowered and rich Europe. Technical innovations had again the necessary background of interest and financial support.

After the decline of the Roman Empire, the use of transparent glass almost disappeared since these years. The rich citizens living in this age wanted to enjoy tropical fruits also at home. South-facing glass covered greenhouses were built to trap the solar heat, necessary for the growth of exotic plants in Europe, having colder climate. In some cases, a greenhouse was attached to the south-side of houses, from where the hot air was conveying into the interior of the building [11].

The architecture of that age used also more common approaches to fructify the thermal energy of the sun. Carefully designed passive systems applied insulation, south-facing glass, and massive floors and walls, naturally assisting heating, cooling and lighting. In more advanced active solar heating and cooling systems, liquids or air were circulated through pipes or channels to move the heat to where it was necessary [3].

Several innovations were proposed for the collection, storage and control of energy converted from the sun, mainly due to reawake of the glass awareness to trap solar heat.

In 1767, the Swiss polymath *Horace-Bénédict de Saussure* (1740-1799) built his so-called "hot box" plate collector, known as the world's first solar energy collector. It was a rectangular box made of wood, insulated with black cork and covered by glass. Inside the box was a smaller similar glass-covered box, as shown in Fig. 7. When the box was placed in the sunlight, the water from the inner box could boil. The hot box became the prototype for solar thermal collectors used also in our ages [18].

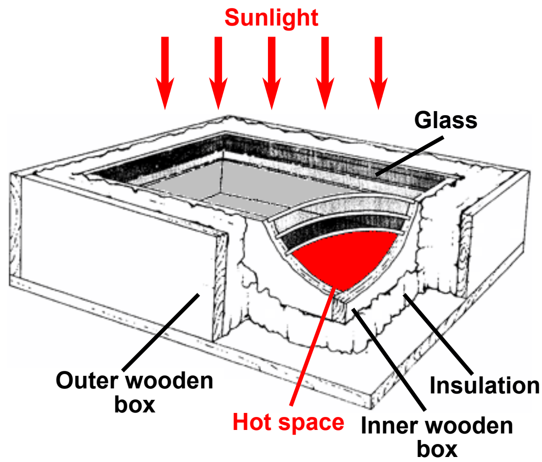

Fig. 7 *Saussure*'s hot box [18]

In the next decades *Saussure*'s invention was further improved. Significant contributions in this filed had *John Frederick William Herschel* (1792-1871) and *Samuel Pierpont Langley* (1834-1906) [19].

IV. From Industrial Revolution Age Up To Now

During the Industrial Revolution (began in Britain in the 18^{th} century) the agrarian and handicraft based economy was changed by industry and machine manufacturing.

The technological feature characterized the Industrial Revolution, beside socioeconomic and cultural ones. The technological advances due to the increasing application of science to industry were connected to [20]:

- enlarged use of iron and steel;
- new energy sources, including both fuels (coal, electricity, petroleum) and motive power (steam and internal combustion engine);
- radically improved productivity due to the invention of new machines

– important advancements in transportation and communication (steam locomotive and ship, automobile, airplane, telegraph, radio, etc.).

In this age, also numerous, solar energy related industrial achievements and innovations were reported. Here only some specific ones can be mentioned.

The sun collector of *W. Adams* was more efficient than all the previously constructed variants. The oven made by him had 8 symmetrically placed silvered glass mirrors forming an octagonal reflector, as shown in Fig. 8. The sunlight was concentrated by the mirrors into a glass covered wooden box, in which the pot with the food to be boiled was placed.

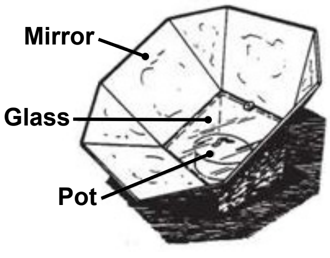

Fig. 8 Adam's solar oven [18]

The box had to be rotated by hand to align with sunrays. As it was related, the temperature in the box could exceed 200°C. This was the first mass-produced solar oven, very popular both in India and the United States of America [18], [19].

In this age, sunray concentrators were developed for solar furnaces, capable of melting iron, copper and other metals. They were made of polished-iron, glass lenses or mirrors [3].

The record holder at that time in this field was the Frenchman *Antoine Lavoisier* (1743-1794), the greatest chemist of the 18^{th} century and an accomplished polymath. He could attain in his furnace 1750°C. The furnace used two lenses of 1.32 and 0.2 m diameter, made from curved sheets of glass, having their internal space filled by vinegar, as shown in Fig. 9 [3]. This world record was not beaten for more than a hundred years. *Lavoisier* was also concerned about the environmental issues connected to burning fuels; therefore, he intended this way to clearly generate the heat needed for his experiments.

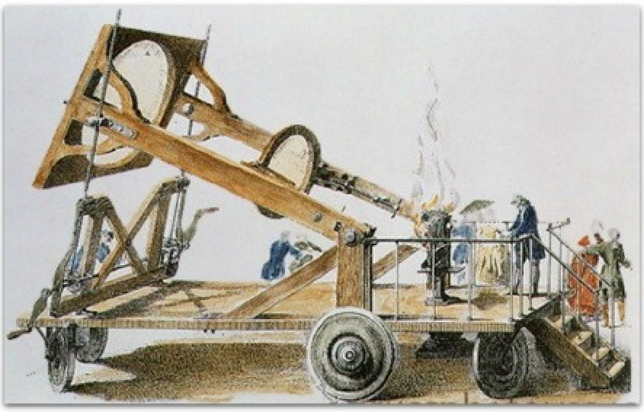

Fig. 9 The solar furnace built by *Antoine Lavoisier* [21]

During the 19^{th} century the technology evolved to a level where it became possible to directly convert the solar energy into other forms, mainly in low-pressure steam, needed in the very wide-spread steam engines.

The French mathematics professor and inventor *August Monchot* (1825-1911) pioneered this field by developing diverse sunray powered devices, as ovens, stills, pumps and ultimately the first solar steam engines. The greatest such engine, given in Fig. 10, was made of a silver-coated metal plate of 5.4 m diameter, having a total collecting area of 18.6 m^2. Its moving parts were of 1400 kg [3].

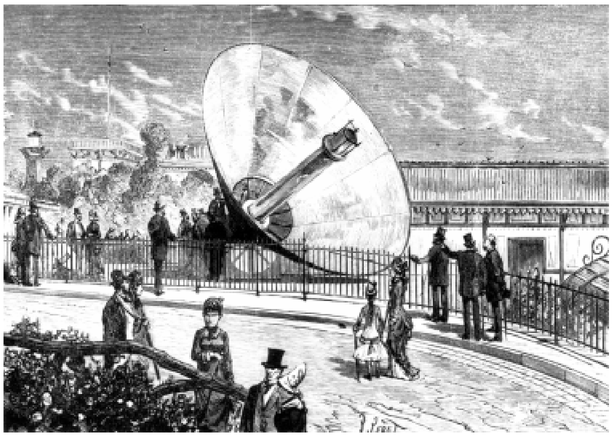

Fig. 10 *Monchot*'s largest sun machine [22]

Monchot's researches were catalyzed by his conviction that there are no sufficient resources needed by the extremely growing industry, and only solar energy conversion can solve this crisis.

The developments of *Monchot* were continued by his assistant, *Abel Pifre* (1852-1928). His solar collectors were parabolic reflectors made of very small mirrors. They shape was slightly similar to *Mouchot*'s truncated cones given in Fig. 10 [3]. His best-known solar steam engine was constructed in 1882. He used a concave 3.5 m diameter mirror having in its focus a cylindrical steam boiler. The generated steam actuated a small vertical engine of about 300 W, which was driving a printing press (see in Fig. 11).

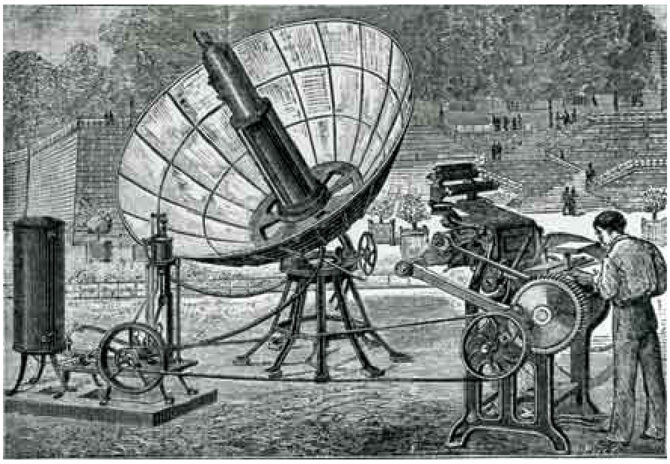

Fig. 11 The sun-powered printing press of *Abel Pifre* [23]

John Ericsson (1803-1889), a Swedish-American inventor was also devoted to the development of useful power from solar energy. In 1873 he invented a displacer type (so-called Stirling) engine (shown in Fig. 12), which was working upon the sunrays collected by a parabolic reflector. By this engine he demonstrated that power can be produced by solar energy alone, without the intervention of steam.

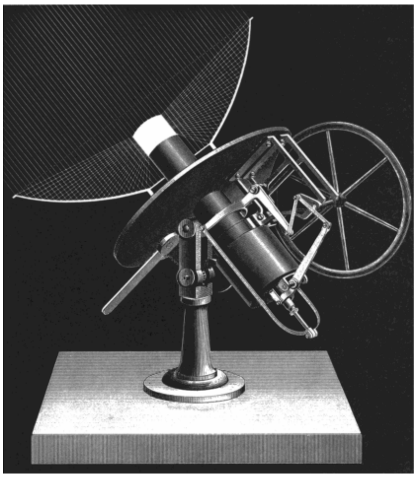

Fig. 12 The solar Stirling machine of *John Ericsson* [24]

The development of the sun collectors continued also at the beginning of the 20th century. The most significant milestones are given below.

In 1901 *A.G. Eneas* installed a 10 m diameter focusing collector, which powered a water pump in California. The device comprised of a great umbrella-like structure having inside it 1788 mirrors. The water inside the boiler placed in the the collector was heated, and the produced steam acted a conventional compound engine and centrifugal pump [3].

In 1912 *Frank Shuman* (1862-1918), an American solar energy pioneer, built the world's first solar thermal power station for a pumping plant in Meadi, Egypt (see it in Fig. 13). The system was using several 62 m long cylindrical-parabolic shaped cylinders to focus sunlight onto an absorbing tube. The cylinders covered totally more than 1200 m^2 area. The solar engine was able to develop 37÷45 kW power continuously for a 5 hours period [3]. It enabled the pumping of more than 20,000 L water per minute from the Nile to the adjacent agricultural fields.

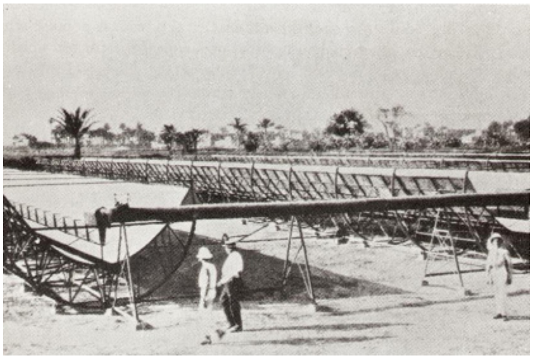

Fig. 13 The world's first solar thermal power station [22]

During the last 50 years, a lot of sunray focusing collector variants were designed and constructed. Two primary solar technologies were used: with the central and distributed receivers. Central receiver systems are based on heliostats (two-axis tracking mirrors) to focus the sunlight onto a single tower-mounted receiver. Distributed receiver technology applies diverse approaches, as parabolic dishes or troughs, Fresnel lenses, etc. [3].

The world's first commercial concentrating solar power plant, the *Planta Solar 10*, was set up in 2004 near Seville, Spain. The sunlight is reflected by 624 large movable mirrors (so-called heliostats) to the top of a 115 m high tower, where a solar receiver, a steam turbine and a generator can produce 11 MW of electrical power (enough for 5500 homes).

The world's largest such power plant was opened on February 13, 2014 in Ivanpah Dry Lake (California, USA). The *Ivanpah Solar Electric Generating System*'s nominal power is 377 MW (enough to power 140,000 homes). Here over 300,000 software-controlled mirrors are tracking the sun in two dimensions, and reflect the sunlight to the boilers placed atop of three 140 m tall towers, as it can be seen in Fig. 14.

Fig. 14 The power plant in Ivanpah Dry Lake

Another, now very widespread application area of sun concentration is the water and house heating. These became extensively used in the 1940s when they began to replace heating systems mainly based on coal burn boilers [3].

But this warming approach is rather older. The first such water heaters were practically black painted tanks filled with water. Their major disadvantage was that it took a long time to be warmed up, and they rapidly cooled down when the sun was not shining, since they were not insulated or did not have other heat retention system [25].

The first commercial product which overcame these disadvantages was the *Climax Solar Water Heater*, marketed beginning 1891 by his inventor, *Clarence Kemp* (see Fig. 15). They became very popular at that time on the West Cost of the USA. Further improvements were made at the beginning of the 20th century by incorporating sun exposed pipes and remote insulated storage tanks in which the warm water entered. All these enabled people to enjoy hot water all the day and night [22].

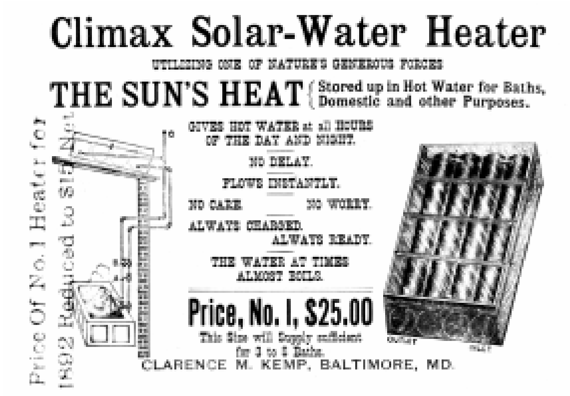

Fig. 15 Commercial for the *Climax Solar Water Heater*

V. The History of Photovoltaics

Probably the most significant breakthrough in the use of solar energy was the discovery of the photovoltaic effect. The photovoltaic cells (often called also solar cells) can convert the sunlight directly into electricity based on the operating principles relying on the photovoltaic effect [26], [27].

The "photovoltaic" term comes from the Greek "phos" meaning light, and from "volt", the unit of electro-motive force.

The photovoltaic effect was discovered by the French physicist *Alexandre-Edmond Becquerel* (1820-1891). In 1839, at the age of 19, experimenting in his father's laboratory, he built the world's first photovoltaic cell. In his experiment, he placed silver chloride in an acidic solution. While illuminating it, he observed voltage on the connected platinum electrodes. His discovery was reported in his "*Mémoire sur les effets électriques produits sous l'influence des rayons solaires*" [28].

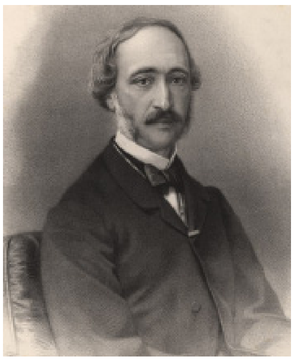

Fig. 16 *Alexandre-Edmond Becquerel*

A.E. Becquerel also had pioneering works in the field of photography. He discovered in 1840 the photosensitive properties of the silver halides, which allowed the development of daguerreotypes and other similar photographic materials. In 1848 he could produce color photographs.

Willoughby Smith (1828-1891), an English electrical engineer, first observed and reported in 1873 the light sensitivity of selenium: exposed to sunlight its conductivity increased.

Fig. 17 Selenium bars used in the experiments of *Willoughby Smith*

Two British scientists, *William Grylls Adams* (1836-1915) and his student *Richard Evans Day* proved that light shone on selenium bars produces a flow of electricity.

An American inventor *Charles Fritts* (1850-1903) is recognized as the creator of the first working photovoltaic cell. In 1883 he sandwiched selenium between an iron plate and a semi-transparent gold top layer. Although these devices had very low efficiency (under 1%), they were the starting point of one of the nowadays most dynamically developing areas of engineering [29].

Charles Fritts was also the pioneer of using solar panels. He connected several selenium modules, and placed the test array on a New York rooftop in the mid 1880s. He was very optimistic concerning the end of the steam engines and the related pollutions [11]. But the practical widespread applications of the photovoltaic devices had to wait until the 1950s.

Few people know that *Albert Einstein* (1879-1955), the famous theoretical physicist, was awarded the Nobel Prize in Physics in 1922 "for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect", and not for his new theories of general and special relativity, as that time those were considered still somewhat controversial.

An American engineer, *Russell Shoemaker Ohl* (1898-1987) patented the modern junction semiconductor solar cell in 1946. He is also the discoverer of the P-N barrier (the so-called "P–N junction").

In 1954, while experimenting the newly-discovered silicon transistors, three American scientists working for the *Bell Laboratories*, *Daryl Chapin* (1906-1995), *Calvin Fuller* (1902-1994) and *Gerald Pearson* (1905-1987) developed a solar cell that could convert enough solar energy into electricity to run any usual electrical equipment. They proposed a diffused silicon P-N junction based cell having 6% efficiency. The New York Times eulogized the discovery "as the beginning of a new era, leading eventually to the realization of one of mankind's most cherished dreams – the harnessing of the almost limitless energy of the sun for the uses of civilization" [11].

The conversion efficiency of solar cells begun to slowly increase up to 11% in 1958, and 14% in 1960, but they price was prohibitively high (about 1000 USD/W) [3].

Researchers discovered in the 1960s also other photovoltaic materials, such as gallium arsenide (GaAs). These could operate at higher temperatures than silicon, but were still expensive [3].

Due to high costs and low efficiency, at the beginnings of the photovoltaic era solar cells were used only in toys and other minor applications. Their first important applications were in space exploration. *Vanguard I*, launched by the USA in 1958, was the world's first solar-powered satellite. The 165 mm diameter and 1.47 kg aluminum sphere spacecraft had 6 solar cells of ≈100 cm^2 total surface, which produced only a few tens of mW, and was supplying one of its two transmitters (see Fig. 18).

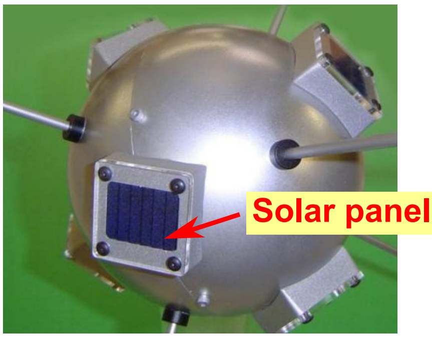

Fig. 18 Full-scale *Vanguard I* satellite model

Since then, large solar arrays resembling wings, are a typical feature of the satellites. In practice the solar cells were adequate for this application, since their small efficiency and high costs were balanced by their high power-to-weight ratio, a very important issue in aerospace industry.

The success of the solar cell in aerospace photovoltaics radically changed the general vision on their applications also on Earth. First those remote terrestrial applications were targeted, where there was no possibility for connection to a public electricity grid. Hence, solar cells were used for supplying offshore navigation horns and lights, microwave repeaters and other telecommunication devices. Step by step beginning with the mid 1980s photovoltaics become the prime electrical energy source for remote applications [22].

A significant breakthrough in the field in the 1970s was catalyzed by the very rapidly growing semiconductor industry. As the technology evolved, the price of solar cells fell together with the price of the integrated circuits (see Fig. 19).

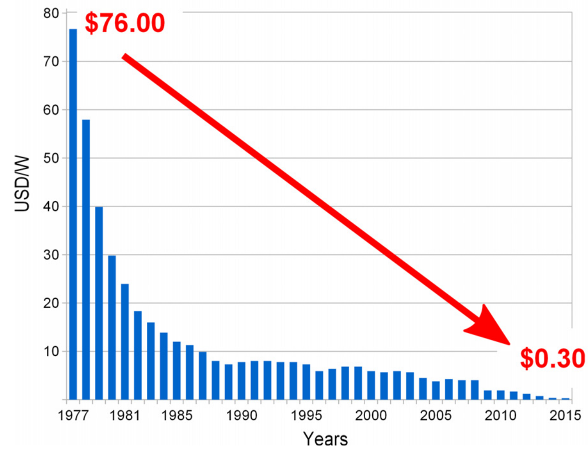

Fig. 19 Price history of crystalline silicon solar cells [30]

Meanwhile, due to the intensive research efforts round the world the efficiency of the solar cells slowly increased, as it can be seen in Fig. 20 [31]. It must be mentioned, that the efficiencies from Fig. 20 are research paper reported values, and not of commercially available solar cells.

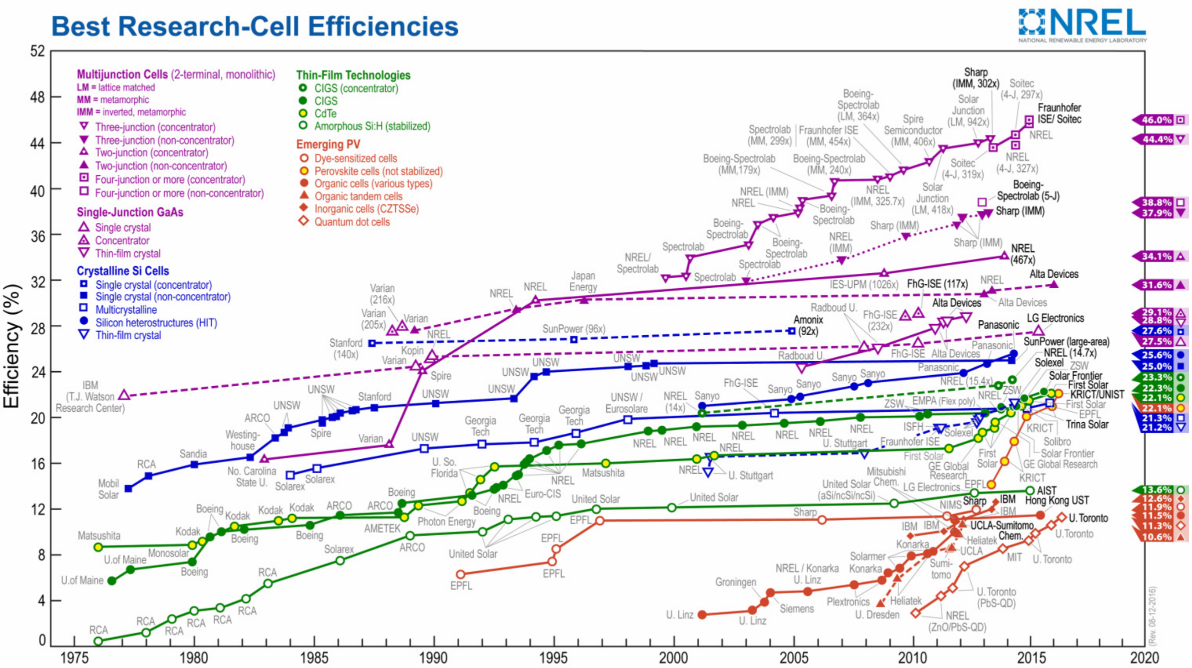

Fig. 20 Efficiency history of solar cells (research data) [31]

As it can be seen, the most promising technologies, as efficiency is concerned, are the multi-junction cells. Most photovoltaic cells use only the visual light spectrum to generate electricity. The unused photons of ultraviolet and infrared light do not have enough energy to dislodge the electrons in the P-N junction, and are absorbed as heat. In multi-junction cells each layer is specifically doped to take advantage of a certain wavelength, hence these can covert a wider spectrum of the solar energy [32]. This is the secret of their higher efficiency.

The multi-junction cells are made of various layers of different semiconductor materials. Practically, they consist of some single-junction cells stacked upon each other. They can be fabricated either by mechanical stacking of independently grown layers, or each semiconductor layer can be monolithically grown on top of the other, as one single piece. Although nowadays the multi-junction solar cells have the highest theoretical efficiency as compared to other photovoltaic technologies, yet their price is excessively high (around 150 times more than that of silicon solar cells).

VI. CONCLUSIONS

The Sun is not only the center of our Solar System, but also the greatest energy source in it. The Earth receives more energy from the Sun in an hour than the entire world energy uses for a year.

The humans are using this free and clear energy source since thousands of years. Basically, there are three solar technologies having a very long history: passive solar, solar thermal and concentrated solar. All of them are intensively used also nowadays. In the last decades, a new technology was developed, the photovoltaics, which enables electricity direct conversion from solar to electrical energy. The permanent innovations in this field resulted in increase of efficiency, and size and cost reduction, making it more prevalent throughout all the human society.

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