REPORT NO.
AUA/ERC-94/__

ENGINEERING RESEARCH CENT
ՃԱՐՏԱՐԱԳԻՏԱԿԱՆ ՀԵՏԱԶՈՏՈՒԹՅՈՒՆՆԵՐԻ ԿԵՆՏ

A SURVEY OF SOLAR ENERGY RELATED ACTIVITIES IN ARMENIA

by

Artak Hambarian

Report to: ENGINEERING RESEARCH CENTER

AUGUST 1994

COLLEGE OF ENGINEERING
AMERICAN UNIVERSITY OF ARMENIA
YEREVAN, ARMENIA

Engineering Research Center

SOLAR ENERGY IN ARMENIA

by

Artak Hambarian

Abstract

This report is devoted to the development of solar energy in Armenia. Here in the form of short separate reports are described the current state of affairs, the principal players and their roles, technical and other difficulties that exist, and prospects for full development and implementation of solar energy for residential, commercial and urban utilization. Each report is devoted to a concrete group of researchers working in universities, institutions or firms. Although the analysis is not complete, it includes all major groups and gives an overview what's going on in Armenia in the field.

AUA-ERC April 1994

American University of Armenia

Table of Contents

1. Introduction

Today's critical situation in Armenia, related to the blockade, dictates severe attention to alternative energy options. In western countries exist the following approach to solar energy: It is known that today the price of one kilowatt-hour (kWh) of "solar" electricity exceeds the price of 1 kWh obtained from conventional sources of energy by a factor of 3 to 10 (depending how it is implemented) [1]; the price of 1 kWh of "solar" electricity decreasing, approximately ten times each decade. At that rate one can conclude that a few years later from now solar energy options will become the cheapest form of energy and this will require a gradual transition to more wide utilization of the solar energy than today.

In the case of Armenia one can say without any doubt that even today solar energy is cheaper then any other option. When you are not always able to transport it through the border it means that always the price of fossil fuel can increase unfounded. With environmental safety and independence, any doubts one may have in priority of solar energy will disappear.

There are a lot of problems. The most serious is the problem of capital investments. Today's energy system was created by the help of capital investment that took place during at least 50 years. In order to replace the old system a capital investment over billions of dollars may be needed. Another problem concerns the required surface area that is necessary to give for solar collectors. Simple calculation shows that with 10% efficiency all needs of Armenia (taking into account the forecast for year 2005 which is approximately equal to 30 gW) would be covered if that area will equal to 1% of Armenia's total surface. In order to clear up whether it is a large number or not it is necessary to carry out a monitoring investigation. Finally, the problem is to store the energy collected in the summer period. Experience concerning such seasonal accumulators of that scale is unknown today in the world (see section 6). But are there any alternatives? As there is no any final conclusion, solar energy must be regarded as at least one of them. Consolation is that it isn't necessary to replace all existing energy systems overnight, but the process if it will take place will occur gradually.

This report is devoted to the description of the current state of affairs, the principal players and their roles, technical and other difficulties that exist, and prospects for full development and implementation of solar energy for residential, commercial and urban utilization.

In sections 2 - 9 are described the major places, where the pursuit is solar energy (universities, institutes, firms). Results, discussion, and conclusions are given in sections 11 and 12. In the appendices are shown some transactions, brochures and more other information about described work presented.

2. Solar Institute

In 1959 in the Energy Institute was organized a Division of Perspective Energetic, which later on became known as the Solar Institute. Before 1978 main topics of study were concerned with high temperature materials' science, and accelerated wearing out under intense ultraviolet radiation. Since 1978 there has been a shift to production of photoconverters.Now the main interests are:

1. water heating (*);
2. photoelectricity (*);
3. materials' science;
4. accelerated artificial aging;
5. photoelectrolysis(*).

(*) solar energy options are water heating, photo electricity, and photoelectrolysis.

2.1 Water Heating:

Now in the Solar Institute they are producing water heating solar panels with approximately same characteristics as other similar devices. Actually they consists of pipe formed in a "S" shaped pattern welded with a sheet of iron, painted black, and covered with glass. The new director, Dr. Hrayr Melkonian, who was appointed seven months ago, says: "Many people try to solve Armenia's problems through PV power. I have a different approach: water heating panels can provide with hot water, and they are much more important today, when such diseases as dyfterisis and others are attacking Armenia. I know that PV electricity is also important , but the same money will work much more efficient being invested in solar water heating panels. Now we build a bath house for the bus park workers. It will have 20 square meters of panels, will be able to provide hot water for 50 people daily, and will cost $1,500. We can produce such installations and place them in villages."

2.2 "AREVIK":

This is a private enterprise, which was appeared on the basis of the Solar Institute in collaboration with a Tchech firm "Ecosolar". They produce Solar Showers, which use large flat and black plastic bags for absorption of the solar radiation. The system has following traits:

- there is no electric pump;
- sun tracking is easy to do by hand;
- construction is easy to dismantle and assemble;
- absorbers' area: 2.8 square meter;

- weight: 32 kilograms;
- volume of the tanks: 140 liters;
- the mixture cold water consumption (in the case of continuous use): 140 liters/hour;
- capacity in sunny weather (Armenia): 70 liters/hour;
- price: $250.

"Part of our production we send back to Tchechia, but there are also a lot of buyers here in Armenia", says Onik Gasparian, the head of the enterprise. The advertising brochure of "Arevik" is attached.

2.3 Photovoltaic Converters, "CONTACT A":

On the basis of the Solar Institute (SI) photo electricity department, recently has organized a society, "CONTACT A", with limited responsibility. Dr. Afyan Victor, the head of this society and of the SI's photo electricity department, have designed a "laminator", the main facility for solar panel production.

"We are oriented towards the concrete buyer as we are without any governmental support, which is not the case in any developed country. We can enlarge our production, but we are not confident in today's Armenian market".

Now they are producing mainly 3-watt solar panel + a flash with daylight & filament bulbs. The light converting photo voltaic (PV) semiconductor (silicon) wafers, as well as the lantern (flash) and the battery are purchased in Russia. It was produced and sold over six months about 100 kits ($15 each) . The buying activity now is very low (several kits per month). They also produce 30-watt panels utilizing the same PV wafers. As they are relatively expensive (more then $90 each) in order to produce them they must be paid in advance. More powerful panels, nickel - cadmium batteries, inverters are optional.

"We could utilize PV wafers produced in Armenia (e.g. in "Transistor", "Sirius" or elsewhere). But in order to sign a contract we must be confident in the market in Armenia, Iran, or Syria. Now we are buying the main component - PV wafers in Russia, for about $1.5 per watt (by the way they are going to increase the price up to $2.5). In the case of production of these wafers in Armenia we could pay less and easier find market in our neighbor countries", says Dr. Afyan.

Starting from June 1994 "CONTACT A" works upon an order got from the "Fund of Armenian Relief". The small photovoltaic installation must have 1.2 kW of peak power, and must be installed in Gyumri, providing electric power to the central barber's shop. The project costs $10,000, $5000 (this numbers are to be justified) of which is spend on PV panels' order. All works will be finished at the end of October.

2.4 Photoelectrolysis

It is well known that hydrogen production is one of those important concerns that occupies many famous minds in the world. Many famous scientists relate with hydrogen the future of the world energy system. It is known that the cheapest and more efficient way to get hydrogen is electrolysis, but in order to get hydrogen by electrolysis one must have another source of electricity. That other source can be PV electricity or any other environmentally benign source of power, otherwise hydrogen production will not make sense.

In 1972 Japanese researchers for the first time in the world achieved a photoelectrochemical reaction, when in the result of photocathalysis, by illuminating a TiO_2 (rutile) wafer immersed in water (or a special solution), water was decomposed into free (gaseous form) oxygen and hydrogen.

Here the key point is the price of the hydrogen got by the help of photoelectrolysis. It is known, that efficiency of electrodes must be more than, or equal to 5%, in order to be economical to produce hydrogen in this way.

"We already passed that threshold," says Dr. Melkonian, "this is because of our independent and stubborn approach. We did efficiency measurements and got celebrated 5.5% for the process efficiency on the laboratory scale installation. We use focused (by Fresnel lenses) solar radiation, sun tracking system, and special, very cheap technology for rutile electrode production. We were independently working upon this project since 1978, the works were stopped in 1991, but we retrieved everything now. In the case of having investment equal to $1.8M we can construct a power plant which will deliver hydrogen equivalent to 800 tons of carbohydrate fuel. Collectors of the plant will cover just 6.5 hectares of area. To illustrate that our technology is cheaper I can bring the following example: Our price of 6 square meter installation is $250, whereas in the west you will see the price for the same installation not less then $1,800."

2.5 Materials' science

Although this is not an energy related activity, but interesting enough to mention about that.

Using focused solar radiation in the Solar Institute they managed to produce $\beta - Al_2O_3\langle Na\rangle$. This material is used in extraordinarily high power accumulating batteries (i.e. 10 kW, 400 kWh), having rather small dimensions. The monopoly on the world market is after Siemens Co., but Solar Institute's production is of higher quality and purity (99.3%), and costs less.

3. Polytechnic Institute

Since 1976, in the Department of Semiconductor Technology, 1986 in the Department of Physics, 1991 Center for Small Energy Systems.

Main topics:

1. Solar Conversion Of Water To Hydrogen
2. Photovoltaic,
3. Solar Thermal,
4. Wind,
5. Wind & Insolation Monitoring,
6. Biogas.

3.1 Solar Hydrogen Conversion:

In 1976 in the Department of Semiconductor Technology of the Yerevan Polytechnic institute the Japan's experiment (see previous section) was successfully repeated. One of the initiators of this work was Joseph Panossian, Ph.D. . He managed to interest the Moscow firm "Quanta" in that work and they invested money in order to continue experiments. The work started with two main objectives: to increase the efficiency of the process and to provide chemical resistance and reliability for semiconductor electrodes [2].

Unfortunately Dr. Panossian was compelled to leave Polytechnic Institute in 1978. Fortunately he was invited with his group to Yerevan State University to continue his work. Here the study became more fundamental [3].

From 1986 the work again was continued in the Polytechnic Institute, now in the Physics Department [4]. During the time span from 1976 to 1991 the researchers' group received 21 patents on photolysis and related topics.

In 1986 in the Physics Department of the Polytechnic Institute a collaboration started with Californian firm **Arco Solar** (now **Siemens Solar Industries**). Mutual understanding and helping each other are the two things that makes the connection between them. Representatives from Siemens Co. want to open a division in Armenia.

In 1991 the Center for Small Energy Systems of the Polytechnic Institute was organized. The center has the following three departments: heliotechnics; wind; solar & wind monitoring. The Center now actively collaborates with the **Solar Energy Research Institute** (*SERI*, now *NREL (National Renewable Energy Labs),* Golden, Colorado).

3.2 Photovoltaic & Solar Thermal:

1) Photovoltaic:

Here main topics are: development of a new technique for making electrodes on the front surface of the semiconductor (silicon - Si) wafers by the help of powerful laser pulses (a research work); completing PV panels from PV cells (Si wafers). In order to perform the second objective Dr. Kennel Touryan of NREL helped in purchasing and transportation the "laminator", actually the main facility ("SPI", $10,000 cost). "Unfortunately today's conditions do not allow to complete the work ", says Dr. Panossian, "it's pity, but this equipment has been idle for more than one year. In order to complete we need an estimated $100,000. With that funding we would be able to use PV cells produced in "TRANSISTOR" or elsewhere in Russia and start production. In regard to marketing of panels: we are able to find buyers".

2) Solar - thermal:

Investigation in the area of the solar - thermal option again relates to cooperation with American firms. PSAR, a small Californian firm is interested in testing of his parabolic solar collector in Armenian conditions. Now four sections of mirrors are installed on the roof of one of Polytech buildings, and are capable to provide Polytech with steam heated up to 120°C (equivalent power is 2.5 kW).

Another Californian firm, AET, is interested in testing of it's flat solar collectors. these collectors are similar to those produced by the SOLAR INSTITUTE in Yerevan and costs approximately $125 per square meter.

3.3 Wind:

Leonid Manoukian, Ph.D., the head of the Center for Small Energy Systems says: "We had installed and are now running three wind systems: The first set, near Tsakhkahovit on the slope of mount Aragats, consisting of five wind - powered generators. Four of them are small soviet wind - generators (4 kW) and were installed 10 years ago, the fifth one, the powerful (150 kW), manufactured by Chase Corp., was installed in 1991. The second set is a so called wind - mechanical system, with direct connection of the fan with a water pump (WINDBARON, capability: 3 - 5 liters per minute of water pumped from a well 300 meters[max.] deep). It is installed in Derek, near a small village not far from Tsakhkahovit. A similar wind - mechanical system must be installed nearby, in the village of Melick. A third one is installed not far from Shorjha (opposite shore of the lake Sevan)". It is a very small system (1kW), connected with a system of batteries.

Energy & Fuel Ministry is now hoping to install a 10 MW wind station by the end of 1995 in Pushkin's Mountain Pass. The energy blockade and lack of financing may delay all the works. Particularly WINDBARON agrees to sell in the European market all the solar production made in Armenia (leaving for Armenia the CIS market), but it's unknown when it will be possible to start production here.

3.4 Wind & Insolation Monitoring:

Dr. Manoukian says: "Unfortunately the station in Tsakhkahovit, which is our basic station where we perform our research work, is not situated in the best place", he continues, "we just were driven by the scarce information provided by already existing meteorological stations' network. That is why it is necessary to do monitoring all over Armenia. Now we have four monitoring stations: One in Yerevan, the second in the Tsakhkahovit station, and two of them in Pushkin's Mountainous Pass. The pace of information recording is: a record every ten minutes, which is the average of 60 observations performed with 10 second intervals. This is only the start, and in order to complete the work we must have many more monitoring stations" (approximately 100 stations).

3.5 Biogas:

"We are just starting this work. The only thing we have completed is this: we purchased a biogas system this year from a Ukrainian firm in Zaporojhie and installed it in a village. Using manure of four cows its capable to provide with gaseous methane to a four - person family", finished Dr. Manoukian.

3.6 In the result of the annual Armenian International Energy conference ...

(held from April 26 to may 2)

...appeared two Memorandums and a joint venture:

- *Memorandum 1:* "Sea West" Co. and Ministry of Energy and Fuel of Armenia agree to cooperate in solar and wind monitoring works. Center for Small Energy Systems will be the executor, works begin at 1st of October 1994, and will last one year. Based on results, Sea West Co. will make a decision concerning to a wind power plant setting in Armenia.
- *Memorandum 2:* "American Energy Technologies", Inc., (AET) and Ministry of Energy and Fuel of Armenia agree to cooperate in solar thermal collectors' manufacturing in Arm Atom. This is a company in the system of the Ministry of Energy and Fuel of Armenia. Again the core of this project is the Center for Small Energy Systems.
- *Joint venture:* Starting from August 4, "WINDBARON of USA" and Center for Small Energy Systems together bring to existence a new joint venture, "WINDBARON of Armenia". The aim is to produce alternative energy products as following:

1) wind generators having power less then or equal to 1.2 KW;
2) PV panels;
3) hybrid installations of wind generators and PV panels;
4) wind-mechanical pumps (similar to one that is installed in the village Derek);
5) hybrid pumps (mechanical pumps driven by hybrid installations described in the third point);
6) inverters and other electronic appliances related with alternative energy.

Production of the PV panels already started. They cost $4 per watt and arranged in 30 watt panel size. Efficiency is about 12%. Also they are going to sell 2,000 watt installations based on that panels. Technical characteristics of these installations are attached.

4. Yerevan State University:

Semiconductors' & Insulators' Physics' Department (S&IPD) of the Radiophysics Faculty has a long term experience concerning to the interaction of light with semiconductors. In regard with solar energy the main topics are:

1. Solar Hydrogen Conversion,
2. Thin Film Semiconductor Solar Converters.

4.1 Solar Hydrogen Conversion:

In 1978 at S&IPD work started on solar hydrogen conversion, with the transition of a group of researchers from the Polytechnic Institute (see section 2). One of the major enthusiasts of the research in the area of solar hydrogen conversion is Dr. Albert Sargssian. . He was in the group of Dr. Panossian, when they came to S&IPD in 1978. The technology used is different from the one used in Solar Institute. Until now his main pursuit is solar hydrogen conversion.

"Now we have the following situation: For chemically stable rutile electrodes we have 2% efficiency (for unstable ones efficiency is known to be up to 14%). In order to make the hydrogen production economically feasible we must reach at least 5% of efficiency. We have some new ideas concerning to utilization of some superconducting materials (operating in non superconducting mode). When we started this work, the efficiency of rutile electrodes was 0.1%. Using ceramics form of that material and optimizing other parameters we reached 2%. And now everywhere in the world this figure grows very slowly", states Dr. Sargssian.

Some results of the work in this field are shown summarized in [5].

4.2 Thin Film Semiconductor Solar Converters:

It is well known that the major part of the price of any semiconductor solar converter can be attributed to the semiconductor materials' cost. That is why thin film converters are among of the most promising solar energy options. Although the conversion efficiency is difficult to improve over 10 - 12%, this option has the cheapest price of semiconductor solar converters per each unit of output power (e.g. per 1 watt). In addition, they are less degradable for the basic material is polycrystalline instead of monocrystalline. In the case of successful performance the production of photoreceivers based on these properties, it would be possible to provide people with cheap enough sources of energy.

In 1992 Dr. Vladimir M. Haroutyunian[1], proposed to carry out R&D with the photosensitive receiver films based on junctions $CdS-CuInSe_2$, (or $CdTe-CuInSe_2$ or similar). In the literature there was just information about the general principles

[1] Associated member of Armenian Academy of Sciences, Dean of the S&IPD.

of the technique, but no details or description of apparatus. In order to develop the technological chain, it's necessary to develop and construct a special vacuum scattering installation. It must be able to coat the base (usually molybdenum or any metal covered with it) first with the basic material, i.e. $CuInSe_2$, then with CdS. A five member research group managed to construct a computer controlled, laboratory scale installation.

"Approximately 90% of the work is completed now", says Dr. Hakob Markarian, "we hope to complete the work upon construction of this installation after three or four months. After getting the first results we will start to optimize the process of vacuum scattering in order to gain maximum efficiency and low technological cost. And we know that real difficulties will start at that time".

"We are not aware of what is going on in the world in this area last two years", says another member of the group Dr. Vachagan Melicksetian, "we just know that until 1988 work was going on intensively. The scientific literature starting from that year on is practically non existant for us (without taking into account random occasions)".

Difficulties are in everything: starting from finding cotton and alcohol to several grams of molybdenum or gold and also computers.

"In order to control the flow intensity of the doping vapor in the vacuum scattering chamber we need simple sensors. In Western countries one can easily buy it from a specialized shop. We are compelled to make them ourselves", says Dr. Arsen Darbassian.

"Our problems are similar to others' ", concludes Dr. Haroutyunian, "in order to continue the work we need in investments".

"An installation similar to one that we had developed had Siemens Co., that is why we are whiling to cooperate with them".

5. Nica Co.

This firm was organized in 1992 and was planing to construct a plant of solar photovoltaic panels. They managed to interest several western banks and semiconductor firms (OLIVETTI GROUP, PEAT MARVICK HIGH TECH, ENCOTECH, J+T INDUSTRIES LTD. (Germany), BARCLAY's BANK (London), BERLINER BANK, FIRST NATIONAL CITY BANK (NY)), but the venture didn't materialize todate and they are still working at it.

Today's activity of "NICA" is actually restricted by merchandising and financing.

6. Energan Co.

In brief, they want to construct a 2 MW solar-thermal power station with a seasonal accumulator. Solar radiation must be collected by parabolic troughs.

Natural ground rock in a special location is selected as the media for heat accumulation. Now they are completing the research work concerning the seasonal accumulator. In the case of success they are planning to construct a station that will provide electricity for the whole country.

One must take into account the necessary volume for heat storage in conditions when traditional (fossil) fuel sources are absent. Let's calculate that volume.

The experience of the last winter showed that in order to heat houses and provide electricity for other needs it is necessary to have at least 1kW/person of electric power at home 24 hours in 100 days of the winter period. That means that the whole thermal energy Q that is necessary to store must at least equal to:

$Q = 1\text{kW} \times 24 \text{ hours} \times 100 \text{ days} \times 4{,}000{,}000 \text{ people} = 9{,}600{,}000{,}000 \text{ kWh}$ (9.6×10^{9}kWh)

As 1 kWh = 1,000 × 3,600(joules/seconds) × seconds = 3,600,000 joules ≈ 860,000 calories, for Q we will have:

$$Q = 8.256\times10^{15}\text{calories}.$$

On the other hand the amount of heat Q that can be stored in mass m with heat capacity c_h if the temperature is increased by ΔT, hence:

$$Q = c_h \cdot m \cdot \Delta T.$$

Now let's assume that we are choosing water as the media since its heat capacitance is the largest. Also we assume that we are able to have $\Delta T = 60°C$, e.g. in summer we are able to heat water up to 90ºC and use the thermal energy of cooling water to 30ºC, which is obviously an overestimate. It is known that any other option will be or less effective (physically), or too expensive and not considerably effective. Therefore we will get for m (c_h= 1 calorie/ccm·gram):

$$m = Q/(c_h \cdot \Delta T) = 1.376\times10^{14}\text{grams} = 1.376\times10^{8}\text{tons}$$

One can calculate the side L of a cube of the volume containing this mass of water:

$$L \approx 510 \text{ meters}.$$

It is interesting to do similar calculations for rock and concrete media.

It is known that almost all natural or artificial rock materials' heat capacity lays within c_h=0.18÷0.22 calorie/(°C gram); the heaviest rock material's mass density (ρ) is 3.3 g/ccm and the heaviest concrete has density of 2.5 g/ccm [6]. Therefore for the necessary volume we will get:

$$V = L^3 = \frac{m}{\rho} = \frac{Q}{\rho \cdot c_h \cdot \Delta T}$$

The obvious merit of rock materials is that they allow to be heated up to much higher temperatures compared with water. The usual upper limit of the temperature range, which is known to be relatively easy and cheap to utilize is 300°C; the lower limit usually equals to the water boiling temperature (100°C).

This allows to get the heat from the rock accumulator by the help of water vapor. Hence in this case ΔT=200°C.

$Q = 8.256\times10^{15}$calories.

This gives for the hard rocks:

$$V_{hardrock} = L^3_{hardrock} = \frac{Q}{\rho \cdot c_h \cdot \Delta T} = \frac{8.256\times10^{15}\text{calories}}{(3.3\text{grams/ccm})\cdot(0.2\text{calory/[°C}\cdot\text{gram]})\cdot(200°\text{C})}$$

$$=62.5\text{x}10^6\text{ m}^3,$$

$$L_{hardrock} = 3.97\text{x}10^2 = 397\text{ m}.$$

For concrete we get:

$$V_{concrete} = L^3_{concrete} = \frac{Q}{\rho \cdot c_h \cdot \Delta T} = \frac{8.256\times10^{15}\text{calories}}{(2.5\text{grams/ccm})\cdot(0.2\text{calory/[°C}\cdot\text{gram]})\cdot(200°\text{C})}$$

$$=82.56\text{x}10^6;$$

$$L_{concrete} = 0.435\text{x}10^2 = 435\text{ m}.$$

Taking into account that efficiency of the system scarcely would be more than 50%, we will get finally approximate 640 meters for water medium, 500m for hard rock medium, and 548 meters for concrete medium. Is it feasible or not? Answer can be given only after constructing some small stations similar to one that "Energan" has in it's project.

Unfortunately, "Energan" failed in trying to increase it's financial potential by banking and merchandising. Taking more and more money from the new customers he used that money to pay interest (15% monthly!) to older customers. In the result of this not licensed practice president of the company, Symon Hayrapetian appeared in the jail, and all works are actually stopped.

7. Transistor Co.

This firm was founded in 1961 as an experimental project for powerful transistors (100 amperes, 800 volts) production. It has new facilities for semiconductor production in Armenia.

In 1991 Ministry of Energy and Fuel sponsored a test production of monocrystalline silicon solar cells utilizing the same technology used for making transistors' emitter p-n-junction. The cells were tested at the Solar Institute and performed with ≈ 8% efficiency. At a price of ≈ \$0.50 which was considerably lower than the world market price (≈ \$2). Without any doubt they can increase efficiency up to ≈ 14% easily (which is normal efficiency for that type of PV cells), One of the vice presidents of the company, Gagik Makarian, says: "Theoretically we can produce cheaper options of PV cells, but we must do an R&D on that, and it requires more funds".

The new plant in Ashtarak is completed with new British equipment, but in order to start to operate it's necessary to have more money (estimated $10 millions). In that case they would be able to produce the major part of powerful transistors' existing demand in CIS and approximately 15% of world demand. So this plant is also able to produce a large amount of solar photovoltaic production.

"We now cooperate with an American firm. We plan to start the production of transistors right a year from now", says the president of the firm, Dr. Aram Vardanian, "we also cooperate with firms which are producing PV converters, with SENI (France) and Amonix (USA). Solar energy has never been out of our consideration. New facilities that are installed in our Ashtarak plant theoretically allow to produce PV converters on amorphous silicon, which is one of the cheap and promising options".

In order to continue works upon alternative energy sources (PV) a new business plan was written, costing less then $14,000, having an aim to demonstrate the possibility to manufacture PV converting wafers based on monocrystalline silicon and assembly them into panels. The business plan is attached to this report.

Another project that is carried out in "Transistor" and is also related to the alternative energy is the project of so called Air-aluminum batteries, a new know-how, allowing to get electricity from a small (35×20×15 cm) battery, which, being environmentally benign can provide 1 ampere of current 8 hours daily, in a three month period of time. In such a period of time aluminum plates are wearing out, and also consumer must change the electrolyte (salt solution) every day. The Business Plan for this project is also attached.

8. Bagramian Solar Station

This is a solar station of photovoltaic panels. It was arranged in 1991 in a private farm. Panels are produced in Krasnodar (Russia). Total power is 8 kW. It is now operating, but is not connected with the electric grid. In 1991 the price of the panel was ≈$1/watt. The metallic frame for the panels was made by Machine Constructions' Hrazdan Plant at $10,000 (with installation). Hence total costs were ≈$18,000. It is necessary to mention that the frame is

lifted over the ground (five meters high). This is done with the purpose to show that the ground under the solar panels can be used as any other piece of land.

In order to complete the work (to install inverters, batteries, and the connections) it's necessary to invest more $5,000. The system was designed also for installation of solar thermal (water heating) panels which are not installed. The latter job requires more $3,000 to be completed.

The total demand of this farm in electric power is 100 kW, of which 60 kW are necessary for pumping the water. If direct mechanical wind power is used to pump the water, the total demand could be reduced to 40 kW. Probably there are some other possibilities to reduce farm's demand in electricity by optimizing overall energy consumption.

The main purpose of this project is to gain operation experience, and to apply it locally in solar energy supplied farm as model in Armenian conditions.

9. Radiophysical Measurement Institute

This institution is internationally recognized as the developer of a famous and unique astrophysical instrument, the 54 meter in diameter radio telescope which has exceptional resolution in the shortest (mm) range of radio wavelengths and other extraordinary characteristics. The telescope, has the following features[2]:

Instead of having a large rotating dish which will require a very expensive and complex construction, the 54 meter in diameter spheroid dish is mounted on the ground permanently, only the small parabolic collecting mirror is mobile and this enables the fixed telescope to scan actually the whole sky, simplifies the whole construction (only spheroid shaped identical dish elements are required), makes it exceptionally stabile and insensitive to thermal and electromagnetic noises.

Described design made this telescope for about 20 times cheaper compared with others with the same diameter but not having the mentioned high characteristics.

Paris Herouni[3], president of the "Radiophysical Measurement Institute" association, responded to the energy scarce situation by a proposal to design and construct a solar thermal station, where solar radiation will be collected by a stable, ground mounted dish, and here the same principle is used to follow the sun. As the seasonal deviance of the sun's altitude above the horizon is approximately equal to $\pm 23°$ and also it is possible to eliminate first and last less radiant hours of the daily sunny period and get for the effective solar sky path angle a value equal to 150°, the dish requirements decrease making possible to design and construct it much cheaper compared with similar ones.

The next idea which intends to decrease the project expenses as well as the price of one kilowatt-hour concerns the heat→electricity conversion. The efficiency of conversion must be improved using a new, even non patented[4] type of turbine, so called "***air turbine***". This is an idea though not yet supported by elaborate theoretical calculations nor experiments, if successful, promises to increase the conversion efficiency from 15% of the vapor turbine widely used today in solar thermal tower stations up to 35-40% of the gas turbine .

---

[2] Among others are exceptional sensitivity (signal/noise ratio and amplification factor).

[3] Professor, Doctor of Technical Science, Member of International Union of Radio Science, Member of Armenia Academy of Science, Head of Chair in Yerevan Polytech. Inst., Laureate of International CAP-90 Antenna Prize, Laureate of Armenia and USSR State Prizes.

[4] The patent is to be received.

A British firm, (prefers to remain anonymous) is interested in this project, and wants to finance it. It is expected to start in 1994. At the end of the first year an operating 100 kW small station will be ready; and a half year period is needed to carry out testing experiments and evaluation.

If successful, it will be the start for the next step, i.e. design and construction of a large solar station, which is supposed to produce electricity at a price approximately equal to 3 cents per one kilowatt hour. This price is only the half of the average price of electricity produced in Europe by conventional methods (fossil fuel, nuclear energy).

10. Hydrogen as Solar energy backup and accumulating means:

One of the Armenian International Energy Conference participants, Dr. Barkev Bakamjian, professor of the University of Tulsa suggests to use the water hydrolysis process in order to convert solar energy into gaseous hydrogen form. As it was mentioned above all solar energy options require certain means of energy accumulation, which will make possible to utilize solar energy not only when sun shines but also in cloudy weather, at night and in winter time. Having a storage of gaseous hydrogen one can either use it directly by burning (similar to the natural gas, for heating, and cooking purposes), or to use it for conversion back to electricity through so called fuel cells.

Fuel cells are relatively expensive for urban utilization in Armenia, but all other similar to natural gas applications are possible and may be economically efficient to use.

In order to demonstrate feasibility and usefulness of electrolyzer for urban utilization in Armenian conditions, an agreement was arranged between Dr. Bakamjian and Engineering Research Center of American University of Armenia. The aim is to cooperate in construction of a small hydrolyser and organize its presentation. In the presentation scheme there must be the electrolyzer and a solar panel, which will produce electricity necessary for the electrolysis process.

Actually there are a lot of problems that are necessary to solve in order to be able to use this option widely. Some of them are:

- feasibility: how much will cost such an electrolyser?
- marketing: how many people will be able to by it?
- perhaps it makes sense to use it with PV or wind generator installations?
- are there appropriate specialists to design and perform the production?

To the last question answers Dr. Tigran Vardapetian from Solar Institute who had worked for a long time on different hydrogen related research programs in terms of ex-Soviet Union military and space programs:

"There is no doubt that hydrogen is the fuel of the future. Those who will start to work upon hydrogen related projects right from now, will benefit soon.

Concerning to Armenia we have to mention that this may be one the best possibilities to solve the energy problem. There are specialists on this topic and the real problem is the government's attitude and lack of money".

11. Results and Discussion

There are three groups of researchers interested in solar energy in Armenia:

In the Solar Institute (solar thermal, photovoltaic);

In the State University (photolysis, thin - film photovoltaic receivers);

In the Polytechnic Institute (photolysis, photovoltaic, solar thermal, wind, monitoring).

There are capabilities for production of PV cells, PV panels, thermal collectors (flat and parabolic).

PV semiconductor converters can be produced in "Transistor" (after carrying out the works upon completion of the Ashtarak plant).

Now let's consider such a question:

What can several photovoltaic panels do? Is it possible to satisfy one home's minimum needs in electricity by the help of solar panels and/or a small windmill and how much will it cost?

Let's consider four member family minimum daily needs as following.

CONSUMED CURRENT	**SUPPLY TIME**	**CHARGE NEEDED**
1) 3 fluorescent 12 W bulbs, 1 each 3 A	3 hours	9 A·hr[5]
2) A radio receiver, 6 W 0.5 A	10 hours	5 A·hr
3) A TV set, 60 W, 5 A	3 hours	15 A·hr
Maximum current, 8.5 A	-	Total 29 A·hr
Where A-amperes; W-watts; A·hr- ampere-hours		

Thus daily consumption is around 30 A·hr.

Assuming there are 6 sunny (or windy) hours per day, the solar panels and the windmill must provide current equal to the total charge needed, devided by the number of hours. Taking into account that the charge managing system (battery, charge controller, invertor) has an efficiency approximately equal to 75%, for the total charge needed Q_{Total} we will get 38.1 A, and one can write:

---

[5] battery voltage is considered equal to 12V.

$$_{Charging} = \frac{Q_{Total}}{t} \approx \frac{40A \cdot hr}{6hr} = 6.7A.$$

This implies:

A. Battery capacity must be:

--- For an acid battery charging current must be equal to the 10% of the battery capacity, therefore

$$Q_{Battery} = I_{Charging} / 0.1 = 67A \cdot hr;$$

--- For a sodium battery charging current must be equal to the 20 - 40% of the battery capacity, therefore

$$Q_{Battery} = I_{Charging} / \{0.2 \div 0.4\} \approx \{17 \div 34\} A \cdot hr$$

and we chose $Q_{battery}$ = 40 A·hr, as this is the needed minimum charge.

B. Solar panel (and/or windmill) must provide power equal to charging current multiplied by the battery voltage:

$$= I_{Charging} \cdot U_{battery} = 6.7A \cdot 12V = 80.4W \approx 80W.$$

Acid and sodium batteries cost approximately \$1 & \$2.5 per ampere hour of their capacity, and the solar panel cost \$6 per each watt at its peak power, then the overall price for each system (cost of wires, TV set and radio are not included) will be as following:

ITEM	RELATIVE COST	QUANTITY	COST
PV panel	\$6 per W	80 W	\$480 (\$960)[6]
Acid battery	\$1 per A·hr	67 A·hr	\$67
Sodium battery	\$2.5 per A·hr	40 A·hr	\$100
Inverter	\$1 per W	100 W	\$100
Total	-	-	\$747 (\$1227)

Similar calculation show that one square meter of solar water heating panel may satisfy home's needs in hot water in the summer period. To have such an option family must pay about \$150 for one square meter of the solar water heater and about \$50 for the tank, pipes and a small pump.

---

[6] In parenthesis are shown numbers for the case of having 100% backup PV solar panel (and/or windmill) power.

12. Conclusions

Solar energy can be considered as one of the means of solving the energy problem in Armenia, especially for small and midsize situations.

General difficulties are concerning the blockade and total bad condition of Armenia's economy. To solve large scale problems large investments are required. Proper organization of governmental support, tax policy, laws, as well as some financial aid, can initiate fast development of the field in Armenia. (both in the areas of research and production).

Another general notation is that to organize a production in today's conditions all, having the pursue of solar energy, feel that new companies in the area of solar energy perhaps must be joint ventures.

It is also important to emphasize that there is room of reasonable expectation of success for joint ventures undertaking in Armenia.

Concerning to the period of time that author monitored solar energy related activities in Armenia, necessary to notice that the fact is that overall activity is increasing slowly, but steadily, researchers are getting more familiar with new conditions, more links are being established with foreign companies. Anyway the governmental tax policy and support problem, as well as the problem of investments are still remaining unsolved.

References

1. Carl J. Weinberg and Robert H. Williams. "Energy From the Sun". SCIENTIFIC AMERICAN, 1990, September, special issue: "Energy for Planet Earth".

2. J. R. Panossian. Some Optical and Photoelectric Properties of Rutile. IZVESTIA AN ARM. SSR, PHYSICS, v.15, issue 4, 1980.

3. J. R. Panossian. A New Model of Surface Excitons. SOLID STATE COMMUNICATIONS.

4. J. R. Panossian. Utilization of Solar Energy in Armenia. AESA SYMPOSIUM PROCEEDINGS. Los Angeles, 1991 (1page).

5. V. M. Aroutiounian. Solar-Hydrogen Conversion Studies and Systems in Armenia. SECOND WORLD CONFERENCE OF ARMENIAN SCIENTISTS, Paris, 1993.

6. Vorobyov. Stroitelnie Materiali. Moscow, 1967, p.12 ("Construction Materials", in Russian).