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ADVANCED SOLAR ENERGY AND EDUCATIONAL TECHNOLOGY

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Abstract
Photovoltaic (PV) forecast, prospects and barriers (worldwide, Russia and Indonesia) are discussed. A short review of new technologies and projects in VIESH are presented. A new technology of PV modules with life time up to 40-50 years without traditional plastic materials like EVA, Tedlar, Mylar etc. is described. New resonant electric power transmission systems for different power consumers are considered including stationary single-wire waveguide line and single-trolley and contactless high frequency electric transport. Tendencies of integrating solar energy technologies leads to higher output parameters and better service to consumers. Solar PV and PV/T (thermal) concentrator approaches based on tracking and stationary systems with bifacial solar cells are demonstrated. PVT concentrator system with vertical p-n junctions' solar cells is discussed. Advantages and technology of vertical p-n junctions' solar cells are presented. Non expensive solar energy (PV, thermal and PVT, concentrators, heliodon etc.) lab equipment and portable satellite receiver getting space images of Earth and analyzing meteorological information for educational and research purposes are described.

Keywords: solar energy, concentrator, photovoltaic, PVT technology, resonant transmission line, solar education.

1. Introduction

According to PennWell Corporation by 2020, about 50,000 MW (50 GW) worth of photovoltaic (PV) systems will be installed annually, up by a factor of nearly 20X from more than 2,5 megawatts in 2007. By 2010, as many as 400 production lines in the world that can produce at least 1MW of PV cells per year will be in place, representing a fourfold increase from about 90 to 100 production lines in 2007.
We are in a crucial time. Energy crisis starts to affect our daily life. If the world economy expands to meet the aspirations of countries around the globe, energy demand is likely to increase the efficiency of energy use. Given adequate support, renewable energy technologies can meet much of the growing demand at prices lower than those usually forecast for conventional energy. By the middle of the 21st century, renewable sources of energy could account for three-fifths of the world's electricity market and two-fifths of the market for fuels used directly.
The European Union wants renewable energy to account for 20 percent of its output by 2020.
"Yet Russia is the sleeping giant of renewable energy potential," said Ramsay, Deputy of Executive Director of IEA. "Renewables can contribute to its energy needs in a cost-effective way and yield important economic and social benefits."
With some 10 million people not connected to the electricity grid, Russia also has huge potential markets for off-grid electricity systems based on renewable energy. In many isolated settlements, renewables can be the most economic, and perhaps even the only way to provide electricity and heat to consumers.
According to signed in Jan 2009 government guidelines on renewable energy (REN) generation Russia plans to increase the share of electricity it generates from renewable sources to 4.5% by 2020 from less than 1% now as the nation seeks to lessen its reliance on natural gas and coal.
Comparing REN situation in Russia and in Indonesia in spite of big differences such as: geographical location, number of inhabitants - in Indonesia 115, in Russia 8 (per square km) one can see many similarities (Table 1).
Indonesia and Russia are endowed with substantial resources of renewable energy, but until now it has not been widely used.
Barriers to widespread use of solar PV and PVT reflect technical (scientific and engineering), market, financial, law, educational and institutional problems, lack of governmental policy supporting, etc. One of important issues concerns reducing the cost of manufacturing PV systems and components, and also its durability.

2. Review of new VIESH technologies

All-Russian Research Institute for Electrification of Agriculture (VIESH) was founded in March 1930. The main activity of the Institute is the solution of power engineering problems, with the tasks of national agriculture electrification, automation, and with the development renewable energy (REN).
The Institute has the research laboratories on PV, solar concentrators, wind, hydro and biomass technologies, rural electrification and thermal power engineering.

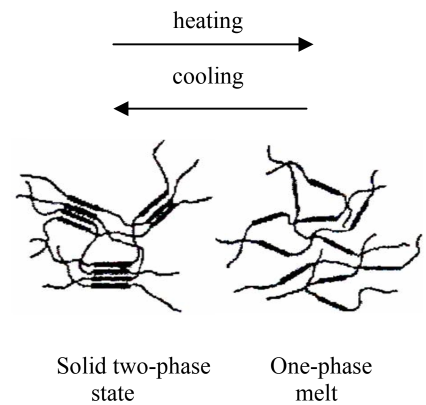
Table 1. Comparing Indonesia and Russia

	Indonesia	Russia	Positive/ negative factors
Big and wide spread territories	+	+	P
Oil and gas reserves	+	+	N
Solar/REN resources	+	+	P
REN laws/tariffs	-	-	N
Rise of population	+	-	P/N
Total population	228,864,000	143,221,000	P
Energy needs for remote areas	+	+	P
Human Development Index	0.726	0.806	

The main objective of the REN program and rural electrification is the elaboration and application of new technologies of rural electrification in order to ensure the sustainable development of un-electrified rural areas of the Russia. REN systems are increasingly being viewed as a favorable option for providing power to isolated villages or homes, collective or private farms, etc. Small-scale systems, including solar PV and wind turbines, are reliable and cost-competitive options for household electrification in remote and isolated communities. REN based grids can be also an increasingly attractive alternative for rural electrification plans because many of local grids are not reliable. Technology options include small-hydroelectric plants, biomass-powered generators, small geothermal, PV, solar thermal, wind turbines, and hybrid systems which may be connected to the electric grid.
A short review of new technologies and projects of VIESH under leadership of director Prof. Srtebkov D.S. related solar energy is presented below.

PV modules without plastics

A new technology of PV modules with life time up to 40-50 years without traditional plastic materials like EVA, tedlar, mylar etc. is described in this section.
The analysis of long experience of manufacture and operation of the PV modules made by a method thermal-vacuum lamination with application gluing films on the basis of copolymers EVA (ethylene-vinyl acetate: as peroxide, as well as radiating lacing), shows that real durability of their effective use does not exceed 25 years in a temperate climate, 20 - in conditions of a dry tropical climate and is essentially reduced in conditions of damp tropics. Substantially these restrictions are caused by degradation processes in gluing films layers, accompanying with formation chromoform groupings that results in decrease of spectral optical transmission factor in the spectral sensitivity field of PV modules. The second group of the processes, resulting in reduction of electric parameters of modules, is processes of contact system elements corrosion and formation of leakage currents due to presence and activation ionogenic groups in damp environment. Thus, quality of encapsulant materials is a determinative factor of long service ability of PV modules.
The problem of achievement of solar energy competitiveness in comparison with traditional energy technologies can be solved by reduction cost of modules, increase of efficiency of conversion of solar energy, and also, appreciably, by increase of service life of operation at least twice.
In this connection there is essential interest on development of materials with increased optical transmission and thermal stability for their use in modern designs of PV modules, including in systems with the concentrated sunlight.
Modern achievements in the field of organic-silicon compounds synthesis allow producing the materials combining high operational properties of polysiloxanes with an opportunity of their usual processing methods for thermoplastic materials, in particular, by extrusion.
Such materials, belonging to thermoplastic silicon elastomers (TSE) group, are obtained by block copolymerization an alpha, omega-aminosiloxane (the flexible block) with bi- or multifunctional isocyanates (the rigid block).
At temperatures higher than temperature of melting copolymer shows properties of thermoplasts. At temperatures lower than temperature of melting material behaves as spatially structured polymer (Fig.



1).

Fig. 1: Scheme of reversible process cross-linking TSE

Technological approbation of TSE films carried out on two-chamber and single-chamber laminators, has confirmed, that transition from the use of TSE films instead of EVA does not demand essential changes of technological modes of operation and can be carried easily out without updating the existing process equipment.
Influence TSE on stability of output electric parameters of modules was investigated during the natural - weather and accelerated laboratory researches.
Preliminary laboratory tests were carried out on separate constructive elements of modules with amorphous and monocrystal silicon of different manufacturers in the conditions appropriate to requirements of domestic and international standards, PV modules concerning qualifying tests: GOST 16962.1-89, GOST 15150-69, IEC 1646, ASTM E 238, E 1171-93, IEEE 1262-1995, IEC 61215.
The results of laboratory experiments have shown that the filler on basis TSE does not concede, and on a number of parameters (for example, stability of adhesive characteristics) surpasses materials on basis EVA. The received results were checked and confirmed in the expanded laboratory and natural - climatic tests.
Thus, the analysis of results of the carried out complex of researches allows to acclaim that TSE films essentially surpasses now films on basis EVA in optical and adhesive characteristics, and also has the lower corrosion activity.

Fillers on the basis thermoplastic silicon elastomers are perspective from the point of view of increase of durability of PV modules, including intended for use in systems with the concentrating of a solar radiation [1].
Also research on behavior of materials and elements for the design flexible PV modules on the basis of amorphous silicon in damp tropical climate conditions was done [2]. Experiments and tests made in Vietnam conditions showed the ways of improving durability PV modules in entirely tropical in climate like Indonesia.

Resonant electric power transmission systems

A new resonant electric power transmission systems (REPTS) for different power consumers were developed including stationary single-wire waveguide lines, single-trolleys and contactless high frequency electric transport [3].
The operation principle of REPTS is based on the use of two resonance circuits with a frequency of 0.5 - 50 kilohertz and a single-wire line between the circuits with a line voltage of 1 - 1000 kV during the resonance operation mode. Electric power transmission is carried out with the help of alternating electrostatic field that is why Joule losses in the line are minimal.
Actually it was rediscovered the method of the single wire energy transmission based on the Tesla discoveries 100 years ago.
Experimental 20 kW, 10 kV, 1.7 km long electric power transmission line was tested. Also there was demonstrated appearance of specific current density 600 A/mm^2 and specific electric power density 4 MW/mm^2 without overheating of copper single-wire line of 80 μ diameter.
The book [4] describes this new technology of electric power transmission lines and their applications, including in solar PV illumination systems. An example of project implemented by L.Yu.Yuferev, O.A. Roschin, A.A. Yufereva using REPTS with stationary solar concentrator with bifacial solar modules is shown at Fig. 2, 3.

Fig. 2: Concentrator system is accumulating solar energy in camp for youth during daytime

Solar stationary PVT concentrator systems

Tendencies of integrating of different solar energy technologies in one system lead to higher output parameters and better service to consumers.
More and more publications devoted to combined PV/thermal (PVT) systems are appearing now. There is a tendency of using PV combined in integrated systems (Fig. 4). These systems are very suitable for integrating into buildings because of importance to use simultaneously photo and thermal non-photo active of solar radiation. The better results can be achieved in concentrating PVT systems.

Fig. 3: Accumulated solar energy is used for illuminating camp for youth during nighttime

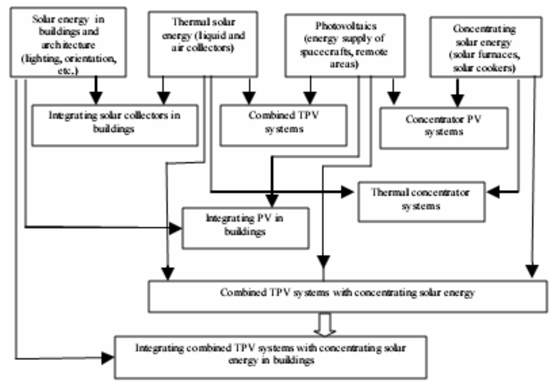


Fig. 4: Main trends of integrating solar energy technologies

In Russia cogeneration approach was actively initiated at VIESH from 1990th (some ideas and results were published even earlier). Our papers described how it is possible to decrease the production cost of PV/thermal concentrator module to the level of 1 – 2 $/Wp cost in case of mass production [5 - 11].
Among concentrator PVT systems there two types of approaching; with tracking concentrator and stationary concentrator.
Our approach with stationary concentrator includes:
• Bifacial solar cells (BSC). It allows to increase aperture accepting angle using back side of BSC;
• Using principles of non-imaging optics allows to avoid tracking system;
• A new plastic-free PV module technology with estimated operating time of 50 years;
• Extracting additional heat allows to cool BSC improving their output characteristics and generating useful heat. Stationary PVT systems are simpler in manufacturing and in exploitation, easier for integrating into buildings (Fig.5). Vertical design from metallic frame and Alanod reflective aluminum sheet is shown at Fig. 6.
Horizontal design was realized by author during Fulbright project in University of Oregon (UO) form aluminum/wood frame. Very simple easy reproduced model was made at student workshop at UO with NREL reflection film (Fig.7, 8) [7].
• The awning design was chosen for demonstration concentrator installation because in addition to combined energy supply (photo-electricity and heat) the system can play a role of awning (sun-visor, canopy). Such choice is explained by a number of factors.

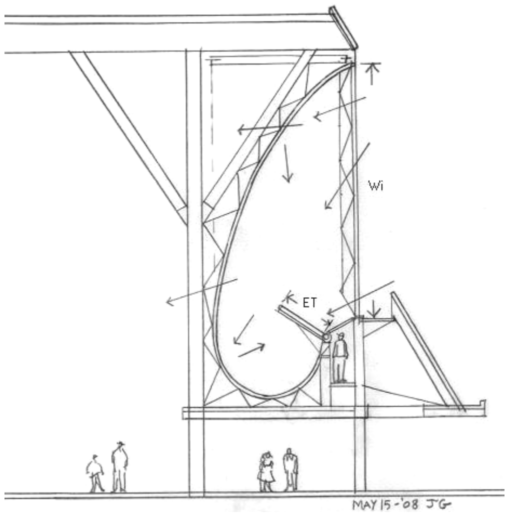


Fig. 5: Vision of integrating by research architect – thanks to Joel H. Goodman

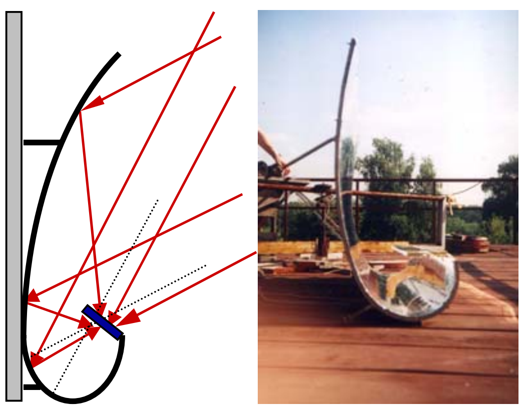


Fig. 6: Ray tracing and photo of concentrator with bifacial receiver (on the roof of the VIESH)

• In USA many buildings in the form of low (1-2 floors) long parallelepipeds are constructed and such design of installations allows to build them in existing buildings, creating thus new architectural decisions. Awning above the windows creates additional shading, providing comfortable zones in a hot season. The modular principle (in this case connection of new systems along a building) economically allows to solve problems of connecting installations in a uniform system. In Fig. 8 the photo of the concentrator with bifacial receiver is depicted.
Such design can be used for long awning applications. Disadvantage of described systems is low concentration ration – usually about 3- 6 x.

PV/T concentrator system with vertical p-n junctions' solar cells

In spite of complications of creating reliable tracking systems they can give higher output temperatures and save more expensive semiconductor materials of SC because of opportunities of using higher concentration ratio.
A research project devoted to combined PVT system based on tracking concentrator with vertical p-n junctions' solar cells. The project is carrying out at the All-Russian Research Institute of Electrical Engineering (VEI) jointly with VIESH and Moscow Institute of Steel and Alloys [12].

In the framework of research project concentrator PVT system was built on 2D rotational frame. Concentrator providing 30 x concentration ratio was made from flat mirror facets and PVT receiver

Fig. 7: Photo of concentrator from Al/plywood frame

Fig. 8: The photo of the concentrator with bifacial receiver in horizontal working position

The solar cells with vertical p-n-junctions are known as a good alternative of bifacial planar concentrator solar cells [13, 14].
They have a number of advantages: high temperature tolerance, low series resistance, bifacial sensitive accepting surfaces suitable for bifacial illumination, low equilibrium temperature, quite simple technology of manufacturing etc. Low series resistance gives them to work under high concentration ration.
A method of manufacturing solar cells with vertical p-n-junctions using thermal compression bonding with silumin was developed in VEI and defended by Russian patents [12]. The main goal of this technology is to provide a structure for a photovoltaic cell which gives as a result improved characteristics: improving quality of interconnecting soldering, eliminating of compensative influence of aluminum to n-layers, high temperature tolerance and mechanical firmness. The main stages of technology for producing solar cells with vertical p-n-junctions (without some steps, for example, such as antireflection coating) are showed at Fig. 9.
According to our approach, the silumin (alloy of Si and Al) layers prevent a penetration of compensative impurities (Al) into n - region. The produced solar cell structures result in the high quality mechanical and electrical contacts, high fill factor for I-V-characteristic (more than 0.8), and increased tolerance to high temperature under high intensity and

higher tolerance to penetrating particle radiation (for space applications).

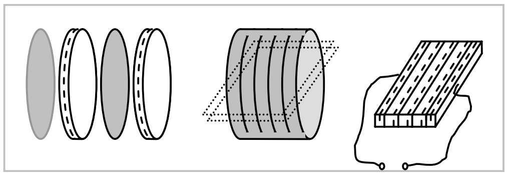


Fig 9: The main steps of fabricating solar cells with vertical p-n-junctions (assembling of wafers with p-n- junctions and aluminum or/and silumin inter-layers foils in stack – on the left, soldered stack with showed cut planes – in the center, vertical p-n-junctions solar cells with external contacts – on the right).

For optimization of technology processes the modern high resolution scanning microscopy methods of investigating vertical p-n-structures are used besides spectral-probe method elaborated earlier [14].

Also some new technological improvements are developed in addition to base patented technology (please see references at [12]). The improvements are at the stage of patenting.

Realization of VEI systems started from VEI PV/T concentrator. Photo of the experimental concentrator built and assembled on the VEI roof for testing is shown at Fig. 9.

The concentrator provides bifacial illumination and regulating number of illuminated mirrors with help of movable shields located at the tops of concentrator wins and hence to investigate output parameters and characteristics depending on concentration ratio. PVT receiver includes row (array) of solar cells with vertical p-n-junctions in a case with quartz windows and special cooling liquid inside.

PVT receiver is designed for two side illumination because of ideal symmetrical design of solar cells with vertical p-n-junctions (Fig. 10).

Facets of mirror concentrator direct sunlight into window of PVT receiver (box with solar cells and filled with a thermal transfer liquid) (Fig. 11)[13].

Fig. 10: Experimental concentrator for VEI PVT system

Educational activity

This section is about PV lab equipment and satellite GIS (geographic information systems) developed by initiative of UNESCO Chair on Renewable Energy in VIESH in cooperation with some other institutions to help teaching the basic principles of conversion solar energy and PV systems [15].

Fig. 11: Experimental PVT receiver in concentrator

Both properly designed PV lab experiments and satellite receivers are used to teach sciences, so this equipment can be used not only for renewable energy speciality but also for adjacent specializations. The usefulness of PV lab equipment and satellite receivers in teaching renewable energy to school and university students is quite evident.

Non expensive solar energy (PV, thermal and PVT, concentrators, heliodon etc.) lab equipment and portable satellite receiver getting space images of Earth and analyzing meteorological information for educational and research purposes are described.

A number of lab kits were developed at the UNESCO Chair: for studying: parameters and characteristics of solar cells (Fig. 12), ray tracing in models of different concentrators (Fig. 13), characteristics solar cells with reversible fuel cell (Fig. 14), characteristics of solar air thermal collector with different absorbing elements and glazing (Fig. 15), which includes PVT receiver (Fig. 16), simulating of Sun's path on the sky and shading of solar systems on solar houses models (Fig.17).

The created lab are used by students of the Moscow Power Engineering Institute (Technical University), Moscow State University of Engineering Ecology, Moscow State Agro-Engineering University etc. during practical training at VIESH.

New Laboratory on Renewable Energy in Mari El State University (MARGU) was developed with cooperation UNESCO Chair (VIESH) during 2005 - 2008 as essential part of course "Non-traditional and renewable sources of energy" (specialisation 100900) prepared for two groups of electrical engineering speciality (Fig.18).

Fig. 12: Lab equipment for measuring characteristics of solar cells

Fig. 13: Lab equipment for measuring characteristics of concentrators

Fig. 14: Lab equipment for study of solar-hydrogen system with reversible fuel cell

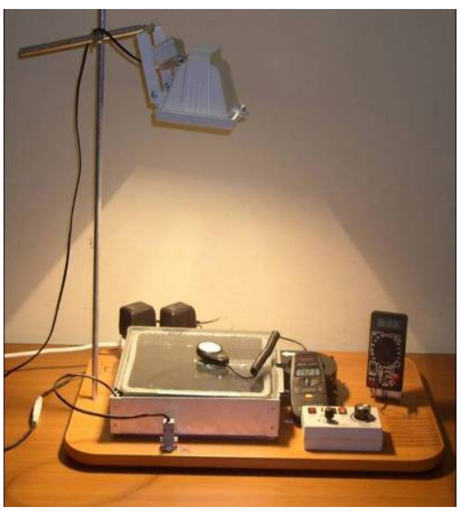


Fig. 15: Lab set for study of solar thermal collector

Fig. 16: PV/T receiving element of hybrid collector module

Fig. 17: Simulator of Sun's path on the sky for shadow analysis of solar buildings with small models (heliodon)

Teaching with using new lab equipment has started in spring term of 2007 (Fig.18). Nine lab kits were created and are implemented for in educational process.

For the purpose of teaching student modern technologies the portable, relatively inexpensive receivers installed at a number of Moscow schools designed to get and process space images of the Earth sent by satellites in real time. Images can be received on a free basis, which makes it possible to minimize the expenses connected with the teaching process. Since satellites, moving on polar orbits, pass with intervals of about 3 to 4 hours and their signals can be received reliably within 5 to 10 minute period, receiving sessions during the classes are scheduled accordingly.

Fig. 18: Students of Mary El State University are studying model of solar illuminating system

Fig. 19: Solar PV module developed for schools with test equipment

Hardware-software complex «Kosmos–M2» is designed by Prof. M. Schakhramanyan for receiving of the Earth images transmitted from NOAA series polar orbiting satellite (NOAA-12, NOAA-14, NOAA-15, NOAA-17), Meteor, in APT format (Automatic Picture Transmission) in the range 137 MHz (Fig. 20, 21).

During one session with NOAA satellites Advanced Very High Resolution Radiometer (AVHRR) transmits images only via two from the five channels: 1) visible VIS (during daytime) or middle infra-red (NOAA-14) and 2) far infra-red (IR) with reduced spatial (up to 3 km) resolution and radiometric (up to 8 bites) resolution in the swath about 3000 km. From satellites Meteor, single-channel images in the visible range were transmitted with spatial resolution of 2 km.

The complex can be used in hydro meteorological centers, aviation, railway, sea, car industry, air photography, fishing and yachting, educational institutions (schools and universities), research institutions, ecological services etc. (Fig.22) [15, 16].

It can be also used in educational institutions training process for learning of receiving and processing techniques of the Earth images transmitted from space in real time mode ("space geography"). This allows students to receive in real time mode objective information on environment over quite large territory (around 7 000 square meters) and its changes, analyze and hypothesize, make forecasts.

The basic purpose is synoptic forecasts, training of Earth remote sensing techniques, scientific work.

Fig. 20: Satellite antenna at the VIESH roof

Fig. 21: Portable receiver of satellite space images of the Earth

3. Conclusions

Concentrator PV/T technologies are prospective alternative of traditional solar thermal collectors and PV modules.

The tendencies in developing solar systems show, particularly, evolution of solar energy technologies to integrating photovoltaic and thermal conversion with using of concentrators

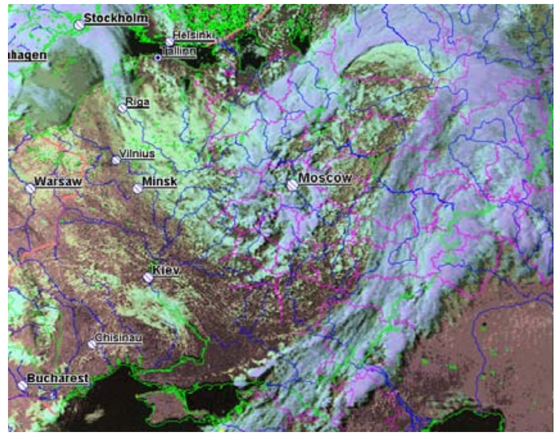


Fig. 22: Sample of satellite space image of the central Russia

Described research project started from designing, building and testing of concentrator PV/T system based on solar cells with vertical p-n-junctions.

Solar cells with vertical p-n-junctions shows good prospects for using in concentrator systems.

The practical steps in realization of the concept concentrator PV/T system with vertical p-n junction's solar cells were demonstrated.

The next step of this work is testing of created experimental concentrator and PV/T receiver with solar cells with vertical p-n-junctions and cooling liquid inside.

The bright future of solar power is impossible without key technologies, high qualified professionals and well educated population at all levels from politicians to consumers.

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