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Draft Report on An Approach to Establishing the Capacity for the Testing and Application of Advanced Materials and the Development of New and Renewable Energy Technologies in the Republic of Sudan

by

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Consultant's Report Commissioned by UNIDO, Vienna

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by

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I Introduction

The materials used in a modern economy can be classified into five broad groups according to their major characteristics and use-forms: 1. Structural, 2. Functional, 3. Civil Engineering, 4. Renewable and 5. Biomedical. While conventional forms of these five groupings are in use in both industrialised and developing countries, the new forms, now generally termed the "New Materials", that have been developed over the last two decades, are still almost exclusively confined to the industrialised countries and a few of the relatively more-developed developing countries.

Metals and alloys, ceramics, polymers and composites comprise the four major categories of structural materials. Not only have a host of new materials been innovated among these four categories of structural materials, but also their production has been made much more technologically and economically efficient through advances in instrumentation, process equipment and data manipulation. In the area of functional materials, there have been breakthroughs in photovoltaics, photonics, sensors and electro-mechanical, magnetic and superconducting materials. Cement, concrete and plaster required in civil engineering are today technologically superior to, and less energy-intensive than, yesterday's products. The sophistication and variety in the use of wood and waste paper , which are the prime renewable materials, are continually on the increase. As for biomedical materials such as protheses and transplants, they are in the main made of structural and functional materials and thus enjoy the advantages accruing from the advances made in those two fields.

The State of the Art in Photovoltaics

Over the last three decades, the material most in use for making photovoltaic cells (commonly called "solar cells") has been crystalline silicon. But in the last few years other materials like amorphous silicon, gallium arsenide, indium phospide and copper-indium diselenide have been researched into, because of their higher technical efficiencies. However, when it comes to large-scale production and use, amorphous silicon alloys have emerged as more cost-effective than others. Today, the thickness of a solar cell using amorphous silicon alloys can be reduced by factors of 100 to 300 compared to earlier designs. This has led to significant reductions in both material and processing costs, as well as to faster rates of production. Small experimental solar cells made of flourinated amorphous silicon and amorphous silicon-germanium alloys have shown nearly 14 per cent efficiency in multi-junction devices, the highest achieved so far.

A widely used commercial product consists of a thin sheet of stainless steel coated consecutively with metallic back reflector, six layers of amorphous silicon alloy and a transparent conducting oxide. Large-scale tandem solar modules made from this automated continuous deposition process can achieve nearly 10 per cent efficiency in actual field use. The use of multijunction tandem cells and narrow band gap materials combines higher efficiencies with good stability. These stainless steel substrate modules have the advantage of being rugged, light weight and flexible. They can rolled into a spool and shipped to any destination in the world. The firm in the United States that holds patents for the production of these modules is allowing India and the USSR to produce them under license. The present planned capacity of the Indian plant is 200,000 square metres per year and of the two USSR plants is 300,000 and 1,500,000 square metres per year. Under United States production conditions, the 200,000 square metre plant would produce solar cells at the cost of 200 dollars per square metre, while the larger 1.5 million square metre plant brings the cost down to 50 dollar per square metre.

In the arid climate of northern Sudan, for instance, a state-of-the-art photovoltaic array covering an area of 9 square kilometeres can produce 3000 megawatts.

Assuming the currently achievable module cost of US$ 1.25 per watt and a module efficiency of 10 per cent, the cost of electrcity becomes about 9 cents US per kwh. At these efficiencies and costs photovoltaics is quite competitive with fossil fuel generated electricity.

II The experience of the Sudan in the use of photovoltaics

Sudan imports photovoltaic modules and devices. Often these come as part of the "aid package" from donors. The Sudanese engineers and scientists at the Sudanese Energy Research Council (ERC) assemble the modules into devices and train the local technicians in the installation and servicing of the devices.

Solar Refrigerators

There are about 120 photovoltaic-operated refrigerators in the country, imported with the funds provided by UNICEF, WHO, USAID and other agencies. They have been assembled, and are being tested, by ERC engineers and scientists. They are in use at a number of rural health centres. ERC has trained about twenty technicians in the installation and general maintenance of these solar refrigerators, with the help of the manuals provided by the manufacturers and the WHO.

Solar Transmitters in Civil Aviation

ERC participated in a feasibility study to set up photovoltaic-driven VHF radio transmitters and beacons at 11 airports. It provided the technical specification that went into the international tendering, which was won by ARCO-Solar of California. The transmitters have been installed, and are being maintained, by the technicians trained by the ERC. They are powered by mono-crystalline solar cells, with the current being stored in locally made lead-acid batteries. The operating cost is USD 4.5 per peak watt (Wp).

Solar Lighting in Rural Areas

This project was started in 1984 and continued till 1986. The intention was to evoke the interest of the Sudanese private sector to go into the business of providing photovoltaic lighting devices for use in the rural areas. The ERC identified the Sudanese private sector counterparts who would take part in this experimental venture. It selected the devices, bought them with the foreign-exchange at its disposal, and determined the price in Sudanese currency at which to sell them to the private sector. The private sector firms were expected to provide the batteries for storing the current, and the spare parts and servicing; but as they were unable to do this, the project came to an end in 1986.

Television Receivers for the Rural Areas

Twelve villages were selected in the Gezira area for testing the use of photovoltaic-powered TV receiver sets in connection with the promotion of educational and agricultural extension programmes. The premise behind this scheme was that the villagers would pay a modest fee towards the cost of acquiring and running the sets. With the foreign exchange at its disposal the ERC imported the PV-units for powering the TV sets. But as the local Sudanese firms were unable to continue their earlier activity of assembling and marketing TV sets, this scheme had to be abandoned.

Solar Water Pumps

Eight borehole pumps and five floating pumps have been installed in rural locations in the vicinity of Khartoum for field testing and monitoring purposes. They are used on a community-basis to service all the households in the villages where they have been installed. Insolation, heads and pumping parameters are being measured.

Solar Systems for Health Centres

Solar Systems for Health Centres

A photovoltaic system has been set up at a health centre in Khartoum for testing, monitoring and demonstration purposes. It has a capacity of 1KWp and is coupled to lead-acid storage batteries. It powers refrigerators, lights, lamps for microscopes, fans and air-coolers.

III Solar Thermal (Non-Photovoltaic) Devices in the Sudan

Solar Water Heaters

The use of solar water heaters to meet the requirements of households, institutions and industries has been studied by M.Sc. candidates leading to three M.Sc. theses at Khartoum and Gezira universities. All the technical work was done locally. The water containers are made of imported steel. But the heat insulators are made from local material. The technical efficiency and the economic viability of the heaters have been studied. Anti-corrosion measures, heat-absorbing paints and pre-heating for industrial use are among some of the things being investigated. Water heaters for individual household use are being developed at the New Halfa Agricultural Scheme along the border with Egypt, where the farmers can afford to buy them.

Solar Dryers

The ERC is collaborating with the Sudanese Food Research Centre in developing techniques for the solar drying of crops, vegetables and fish. The method most preferred uses natural convection. In fixing the values for the parameters for the drying process, particular attention is being paid to the maintaining of the quality of tne products being dried. For instance, improper drying produces aflotoxin in peanuts, which is a major export crop. The design parameters are determined by the specific requirements of different enduses. Financial and technical support from West Germany was made available in the initial stages of developing the dryers. Present work is funded solely by Sudanese sources.

Solar Stills, Solar Cookers and Passive Cooling

Research work is going on at the ERC and elsewhere in the Sudan into these processes and devices.

IV Other (non-solar) renewable energy activities in the Sudan

Briquetting of Cotton Stalks

Sudan is one of the world's major producers of cotton. After the cotton is harvested, the stalks are burnt *in situ*. Cotton stalks have a big potential as a heating fuel for household and institutional use. With the assistance of **UNIDO**, a briquetting project has been initiated. The cotton stalks are harvested using tractor-driven implements. They are then chopped by a machine into small pieces, which are then converted into charcoal. The charcoal is powdered and then briquetted by a machine. The briquetting technology has been obtained from Holland through the collaboration of Twente University. Three Sudanese engineers and three Sudanese technicians are being trained by the Dutch to handle this technology. They will be involved in further adapting and improving the technology as experience is gathered during the production process. This includes quality control work involving analysis of the chemical composition, heat values, density and hardness.

UNIDO has also financed a study for the marketing of these briquettes. A company has been set up to produce and market the briquettes, which is a joint-venture between the Sudanese public and private setors, with the public sector Agricultural Corporation owning 51 % of the shares and the rest 49 % taken up by the private sector.

Improved Charcoal Stoves

With financial and technical assistance from the United States and West Germany, the ERC has developed and disseminated two types of improved charcoal stoves, which save about thirty per cent of the charcoal in comparison with the traditional stoves. Marketing surveys have been conducted. The market for charcoal stoves is almost entirely urban for the time being. Many Sudanese personnel have been trained in the development, testing, demonstration, dissemination and commercialization of these improved stoves.

Windmills for Water Pumping in the Rural Areas

The ERC is experimenting with several types of windmills at various locations. Among other things, wind regimes are being studied with the help of computer-programmed wind loggers.

V Present Scientific and Technological Capacity in the Sudan Related to Materials Science and Renewable Energy Technology

1. The Renewable Energy Research Institute (RERI)

RERI is the research arm of the Energy Research Council. Its activities are organized under four departments: Solar energy, wind energy, biomass and dissemination. Tables 1 and 2 below show the distribution of RERI scientists and engineers by area of activity, scientific discipline and qualification:

Table 1

Activity	Number	Ph.D.	M.Sc.	B.Sc.	*Reading for *Ph.D	M.Sc.
		(or their eqivalent)				
Solar/PV Tech	7	2	1	4	1	3
Wind Energy	3	2	1			
Biomass/Biogas	5	3	2			
Carbonization and Briquetting	2			2		1
Ceramic Stoves	1			1		
Dissemination and Marketing	4		2	2		1
Total	22	7	6	9		

Table 2

N.B. The figures in this table refer to the same persons as in Table 1 above, but now distributed according to their scientific discipline.

Discipline	Number	Ph.D.	M.Sc.	B.Sc.	*Reading for *Ph.D.	M.Sc.
		(or their equivalent)				
Physics	3	2		1		
Chemistry	1	1				
Chemical Engnr.	3	2	1			
Mechanical Engnr.	11	1	3	7	1	4
Electrical Engnr.	3	1	1	1		1
Economics	1		1			
Total	22	7	6	9		

*(Footnote to lables 1 and 2) These are not in addition to the total of 22 persons, but refer to those among the 22 who are reading for higher degrees while in the employ of the ERC.

In its work, the RERI also involves Sudanese specialists with Ph.D. degrees and post-doctoral research experience working in the universities of Khartoum and Gezira, the National Energy Administration and the National Electricity Corporation; these collaborating experts, who at present number about fourteen, span the following fields: solid state physics(5),semi-conductor physics(1), applied nuclear physics(2), mechanical engineering(3), electrical engineering(2), and chemical engineering(1).

2. Post-Graduate Training in Renewable Energy Technology

Training at the M.Sc. level is being given in renewable energy technology at the Khartoum and Gezira universities since 1987. It lasts two years, the first year consisting of course-work and the second year of project-work. This M.Sc. training was developed with the help of the University of New Mexico, U.S.A. So far eight candidates have taken their M.Sc.s, while six more are now undegoing training, some of whom are employeees of RERI. After their graduation, some are re-absorbed by RERI, while the others may either also enter RERI, or join the National

Energy Administration, the National Electricity Corportaion, etc.

The seven Ph.D.s who are employed by the Renewable Energy Research Institute (RERI) obtained their research degrees in Europe and North America-- two in photovoltaic and solar energy technology, two in wind energy technology and three in bioenergy.

3. Materials Science Related Research Capacity at the University of Khartoum

3.A Solid State Physics

Research in experimental solid state physics_is being carried out in the Department of Physics of the University of Khartoum by a small team of seven physicists. The leader of the team has post-doctoral experience, while the rest of the team consists of one Ph.D. candidate and five M.Sc. candidates. Work has been initiated in three inter-related areas: Structural analysis of materials, electron spray resonance and high temperature superconductivity. The techniques used cover sintering and doping, Mossbauer spectroscopy, X-ray diffraction and flourescence, susceptibility and resistivity, thermo-gravimetry and nuclear magnetic resonance.

3.B Experimental Nuclear Science

In the Department of Physics at Khartoum Uni ersity a small team of six Ph.D. candidates, led by a senior researcher with considerable post-doctoral experience, is applying the techniques of neutron scattering, atomic absorption spectroscopy and X-ray diffraction and flourescence to determine levels of concentration of elements in , and the degree of purity of, a variety of materials. This team has some basic, as well as sophisticated equipment, including a neutron generator at its disposal, acquired through support by the International Atomic Energy Authority in Vienna.

3.C Mechanical Engineering

The Department of Mechanical Enginering has a mix of some quite old and some fairly new equipment. Am g the old ones are machines for testing tensile strength and hardness of materials. The new equipment includes rigs, instruments and gauges for measuring static and dynamic stress, and load-related properties, including Computer Aided Design (CAD) as applied to stress analysis. But on the whole the facilities for doing research on materials are extremely limited in this department. This situation is reflected in the fact that very little research is going on in mechanical engineering as such.

Within the Engineering Faculty there is a Physical Metallurgical Laboratory with facilities for conducting heat and surface treatment investigations.

3.D Building and Road Research Institute (BRRI)

Research is going on at the BRRI into soil mechanics, soil stabilization, concrete structures, chemistry and minerology of soils, etc. It has a core of scientists and engineers who have acquired considerable experience in tackling R & D problems. These skill assets, together with its well-equiped workshops and laboratories, point to the BRRI as a suitable place to concentrate research on building and ceramic materials. As the competition to find positions in the BRRI is intense, those who are accepted at the junior professional level tend to be among the best graduates in the country; they are good potential recruits for R & D work in the materials field and can be tested for that endeavour by first letting them undertake M.Sc and Ph.D. work.

4. The Industrial Research and Consultancy Centre (IRCC)

The IRCC was established in the early 1980s by the Sudanese Government. It has spacious laboroatories and workshops well-equiped to undertake research in the technologies of textiles, polymers, and other materials, as well as in food processing, microbiology and organic chemistry. Despite this good infrastructure and a core staff with doctoral and post-doctoral qualifications and experience, little seems to have come out of the IRCC in terms of usable R & D. One explanation advanced for this lack-lustre performance was that the scientific and technological personnel of the institute have devoted, and are devoting, most of their time to consultancy jobs.

5. Other Facilities

In addition to the main capacities mentioned above, the following departments and the scientific and technical personnel attached to them at the University of Khartoum, can provide some infrastructural and service support to materials R & D: Chemistry; Geology; Civil, Electrical and Chemical Engineering.

Similar support can be canvassed from the Gezira University's Faculty of Science and Technology, in particular its Departments of Chemistry and Electronics.

One can also draw upon the resources of the locally-famous Central Workshop of the Sudan Railways, and the big central foundry in Khartoum.

VI Recommendations about Approach and Strategy

The Sudan is typical of the majority of Sub-Saharan African countries in that it is highly dependent on imports of structural and functional materials, as well as on imports of process and product technologies that make use of these materials. The question then arises as to what sort of approach to adopt in order to reduce the severity of this import-dependence and to create indigenous capacity in the area of advanced materials and new and renewable energy technologies.

As one can gather from Sections IV and V above, the Sudan has today a small number of highly qualified people with some research experience in certain areas of physics, chemistry, metallurgy and engineering that constitute part of the essential ingredients in the creation of R & D capacity in advanced materials and new and renewable energy technologies. These few specialists, and the very limited instrumentation and equipment at their disposal, are located in the following institutions: The Faculties of Science and Engineering of the Universities of Khartoum and Gezira, The Renewable Energy Research Institute (RERI), The Industrial Research and Consultancy Centre (IRRC), and The Building and Road Research Institute (BRRI).

In order to make rational use of the existing potential and to build on the existing base in an optimal way, the central approach we recommend is one of linking-up the above-mentioned institutions and the specialist knowledge available in them to tackle well-defined tasks. This approach confers several advantages: It utilizes the synergies inherent in the country's S & T personnel and infrastructure , it motivates the institutions to exert themselves in the mobilization of existing and future resources by giving each of them a visible and important role, it counteracts the tendency of depleting some institutions of their S & T personnel in order to staff new ones, and it can avoid the ills of bureaucratisation and stagnation that sooner or later afflict official institutions created solely for R & D purposes.

Within the framework of such an approach of linking-up, expanding and strengthening existing institutions, a scientific task force should be created under the aegis of the Sudanese National Research Council to articulate the specifics and the details of the strategy for creating indigenous R & D capacity in advanced materials and new and renewable technologies. While, to be effective, a task force of this nature has to be necessarily small, it should nevertheless be representative of those scientific and enginering disciplines which are crucial to the objective at hand.

Its mandate should include the co-opting of essential foreign expertise for short periods of time to help it in its strategy formulation work.

In order to service the institutional link-up and the task force, a small **planning and coordinating unit** will be required. It too is best placed under the National Research Council. The unit's professional and administrative staff should be kept to a minimum that is commensurate with its limited mandate of planning and coordination.

We recommend that the scientific task force evolves a strategy with three dovetailing prespectives: the short-term, the medium-term and the long-term. We visualise the strategy as having five broad fronts, with a number of steps and initiatives on each front, to be made operational by the scientists and engineers in the relevant disciplines in the link-up of the above-mentioned institutions.

In our opinion, such a strategy should begin by expanding and strengthening the front that looks the most promising in the present context of the Sudan, viz. **photovoltaic systems**. Simultaneously, one can proceed along Front 2. But the others would require medium to long term sequencing.

Front 1. Photovoltaic Systems

1.1 As pointed out in Section I above, the most efficient and cost-effective solar cells today are made of amorphous silicon alloys. They are being mass produced in the U.S.A. and a few other technically-advanced countries in the form of coatings on thin stainless steel sheets. They are lightweight, rugged , flexible and easily transportable. They are being exported at very competitive prices. All the indications are that the price of amorphous-silicon-alloy solar cell is destined to fall further and its efficiency to rise higher as a result of the ongoing R & D by the present producers. In this context, it is advisable for the Sudan, as for most developing countries, to import the solar cells, and not attempt to manufacture them locally.

1.2 Acquiring and learning the science behind, and the technology used in,

(a) the testing instrumentation,

(b) the actual testing of solar cells for their performance parameters under both laboratory and field conditions, and

(c) the manufacture and testing of photovoltaic modules, devices and systems on the basis of the imported solar cells.

1.3 Establishing technical standards and quality control criteria for the local manufacture of modules, devices and systems, and

1.4 Creating and strengthening training and research facilities.

Front 2. Training in **technology assessment** for those involved in the formulation and implementation of policies in technology transfer and technology adaptation

Front 3. Expanding and strengthening post-graduate training and research in the Universities of Khartoum and Gezira in the following fields:

Solid-state physics, surface physics, fracture mechanics, electronics, and applied mathematics;

Analytical, physical and polymer chemistry ;

Metallurgy and ceramics;

Structural, mechanical, chemical, electrical and electronic engineering;

Computer modelling and computer aided design (CAD).

Front 4. Wind Energy and Bio-Energy

The work with photovoltaics will provide valuable lessons as to which of the steps and mechanisms sketched under Front 1 need revision and indicate the directions for innovations in institutional links and operational procedures. They can be incorporated into the same kinds of steps as in Front 1 in order to develop indigenous capacity in the testing and application of materials and technologies required for the exploitation of wind energy and bio energy.

Front 5 Metals, Ceramics and Polymers

5.1 Acqusition and learning of the science and technology of testing the structural and functional properties and parameters

5.2 Acqusition of the technology , as well as the technical standards and quality control procedures, for the manufacture of products using imported materials, and adapting them to local conditions

5.3 Initiation of the industrial processing and refining of minerals and clays

5.4 Training and research

VII The Next Phase of the Project

It is recommended that feasibility studies be commissioned to work out in detail as to how to operationalize the following components of the approach, which are amenable to implementation already in the short-term: 1. Linking of institutions, 2. Setting up the scientific task force, 3. Establishing the planning and coordinating unit, 4. R & D work in photovoltaic systems and 5. Capability building in technology assessment.

The proposed feasibility studies should specify in detail the resources that will be required in terms of foreign exchange; local currency; imported instruments, equipment and material; short-term contracting of essential expertise from abroad, including installation technicians; etc. They should also analyze in detail the various constraints facing the project and propose measures to overcome them.

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