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A GLOBAL APPROACH TO PHOTOVOLTAIC SOLAR ENERGY APPLICATION

10/0

Nov. 1989

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CONTENTS

INTRODUCTION

Energy and Socio-Economic Development:-

Socio-economic development calls for adequate supplies of energy in suitable forms and at reasonable cost. Tackling the energy issue cannot be done in isolation as it interacts with many other economic and social issues. Forecasts of total energy demand need to be broken down into the main categories of consumption, e.g. industry, transport, urban domestic and rural. Economic growth and social development affect energy demand in the different categories and the effect itself depends on the stage of development and the standard of living. However, all energy forecasts conclude that energy demand will continue to grow in most countries and most sectors. Satisfying this demand could be achieved in different ways. Although government policies clearly have an impact on the pattern of energy supply and demand, the availability of resources as well as socio-economic factors probably have a greater impact. Generally speaking energy policies aim at ensuring the availability of adequate supplies of the various forms of energy at socially-acceptable prices (both to the individual and to the community), in the long run, while making maximum use of nationally-available resources, and safely guarding the environment and public health.

The Energy Scene:-

Unfortunately, the energy scene is characterized by unexpected changes of far-reaching consequences, e.g. the two waves of oil price increases in the seventies, the drop in the oil prices this decade, the discovery and exploitation of new natural sources of fuels, or the fluctuations in hydro-electric supplies due to climatic changes. Although the issue of adverse environmental impacts of thermal power stations and fuel-burning transport vehicles was raised and discussed for more than a decade, it is now recognised as a serious problem at the global level - a problem that needs urgent and drastic action. Consequently, long-term energy policies need to be unusually flexible to allow for the apparently inevitable uncertainties in initial local and international assumptions and estimates of supply and demand. However, it would be wrong to conclude that the world is running out of energy, even though serious shocks and surprises will undoubtedly occur. Sound R & D policies provide a major element in formulating the best response to higher energy costs. Government policies in this area are the deciding factor in determining which technologies are developed and how fast they are developed - there is just no single or simple "technological fix" in such volatile and very diversified situations in different countries or regions, and different sectoral contexts. The flexibility of most economies and their ability to change the mix of energy demand is very limited in the short run. The demand is determined largely by the mix and design of the national stock of energy-consuming equipment. This highlights the priority of boosting energy supplies within the above mentioned constraints, particularly cost and environmental impacts. In such a situation, it is only to be expected that renewable energy resources are seriously considered for increasing energy supplies - even though at an initially high price. Higher energy prices are neither a crisis, nor the core of the energy problem. If energy prices to consumers are held artificially low, the problems associated with import dependence in poorly-endowed countries, or even inordinate increases in local consumption in the energy-exporting countries, will become even more serious than any "crisis" associated with proper pricing policies.

Renewable Sources of Energy:-

New and renewable energy resources occur in nature and in different forms of indefinite duration. Solar and wind energy, hydropower and biomass energy are the most promising renewable resources for present and future uses. The basic scientific principles of exploiting these resources have been known for some time. However, recent scientific advances, such as in the field of semiconductors, have opened up a variety of new approaches to the solution of several technological problems in harnessing of renewable energy resources for day to day use. Increasing oil prices have stimulated interest in the seventies in these new resources all over the world, including developing countries. Significant advances in harnessing solar energy were achieved. Even though interest seems to have wavered somewhat in the early eighties. Almost all countries now have active R & D programs of one sort or the other in renewable energy resources. Yet the more substantial demonstration and deployment examples have been in developed countries or the more advanced developing countries.

Solar Energy Technologies:-

Solar energy can be harnessed for practical purposes in different forms: as heat, in water heaters or water desalination stills, as mechanical energy, through a thermodynamic cycle, or directly as electricity, through photovoltaic cells. Solar water heaters are now common all over the world. Thermodynamic conversion suffers from basic theoretical constraints, particularly the low thermodynamic efficiency, as well as practical engineering problems in equipment design, manufacture and operation. By contrast photovoltaic conversion is relatively simple, does not involve complicated moving parts, and is consequently more reliable.

Although the photovoltaic effect has been known for decades, it was only in the 1950's that it was applied in the power supply for satellites. The material used then, and which is still commonly used now, is silicon in its crystalline form. Since then the technology has found many applications for several less sophisticated purposes. Meanwhile, the cost of producing crystals and their efficiency of conversion have been improving. Efficiencies now are within the range 10-12% for thin-film and around 20% for single crystal cells. Cost is expected to come down from around $100 /pW in 1970 to about $2 -3 /pW. This approach suffers from certain drawbacks. The fabrication of crystals is energy intensive and involves very high temperatures, in excess of 1,000°C. Furthermore, the process of slicing the resulting crystals into wafers involves considerable loss of material produced at appreciable cost (up to 50% or more of the original). Consequently, the energy payback period (operating time needed to recover the energy used in fabrication) is almost equal to the lifetime of the cell, although this is considerably reduced to "ribbon" cells.

Amorphous Silicon:-

Several approaches have been developed to overcome these difficulties. One of these is thin film systems, whose performance depends on the support structure and the availability and cost of material. The primary material currently in use is amorphous silicon (a-Si) based alloys. The most common technique currently used to produce amorphous silicon film is the glow discharge (GD) method, where Silane (SiH_4) gas passing between two electrodes is decomposed by the plasma created by the electric field and silicon is deposited on a substrate.

Amorphous materials - especially hydrogenated amorphous silicon - are better absorbers of sun rays than crystalline materials. The fabrication techniques are fast, not energy intensive, require much lower temperatures (around 300°C) and lend themselves to the production of large area panels on glass or stainless steel substrates. The stainless steel substrate results in light, flexible and rugged panels that are easier to handle. In contrast to the absence of a size limitation on the deposition area, crystalline silicon is usually prepared in wafers of 5 in. diameter. Consequently, a-Si:H is most suitable for large area applications where high speeds of operation are not of paramount importance. The maximum efficiency of a-Si cells occurs at temperatures of about 60°C, while that of crystalline cells occurs at a much lower temperature. This means that their efficiency at usual operating temperatures in the field is reduced to around 8.5%.

Stability is an issue in the commercialisation of solar cells. Degradation has been observed in a-Si:H cells and is a function of the operating conditions. This has been linked with the so-called "Staebler-Wronski" effect which seems to be caused by recombination of excess carriers. Some of the degradation phenomena have been linked to oxygen impurities in the device and inherent stress of the film resulting in breaking some of the weak Si-Si bonds. However, original performance can be restored by annealing for a few minutes at a temperature of about 150°C. Since operating temperatures in the field are in the range 50-80°C, this effect is self-healing to some extent. Degradation can also be engineered out of the device, through reducing film thickness and vertical stacking. This is claimed to reduce degradation over 20 years to less than 10%.

Table I gives an overall summary of the current situation in PV technologies. This highlights the advantages of amorphous silicon compared to other technologies. The main problem with the technology has been the high cost of production and the sophistication of the manufacturing process relative to the lower conversion efficiency.

THE NEED FOR A GLOBAL APPROACH TO SOLAR ENERGY APLICATIONS

International Trends in Amorphous Silicon Research, Development, Demonstration and Deployment (RDD&D):-

Intensive research effort for more than a decade has brought PV technology "down to earth" and confirmed it as the leading solar technology in power applications. Terrestrial applications now stand on a solid theoretical foundation, considerable experience with production technologies and useful feedback from the field. The most striking achievements have been in the development of cell materials resulting in steady improvements in efficiency. At the same time, there have been several new and better processes for producing cells and panels more conveniently and cheaply.

Research effort continues unabated and now concentrates on optimising cell materials, cell designs and systems. In almost all industrialised countries, government expenditure on PV research has increased over the last few years. Industry is also investing heavily in new processes and designs. Last year there was an almost incessant stream of new records in efficiency, cost and technical improvements.

As an example, the "Amorphous Silicon Research Project" (ASRP) was initiated by the US Department of Energy (DOE) in 1983, to improve the efficiency, throughput and stability of a-Si-based PV's. A five year research plan (1984-1988) was drafted and implemented by the "Solar Energy Research Institute" (SERI). This was followed by a new 3-year multi-disciplinary programme of cost-shared research for further development of the technology. The total funding for the period FY 1987-1989 was about $ 50 million. Consequently, there have been rapid improvements in cell and module efficiencies. While the efficiency of a laboratory cell was no more than 2% in 1976, it reached 12% in 1987 for a single-junction cell, and should touch 15% in the long run. Two-terminal multi-junction devices, both tandem and triple-junction, have already recorded efficiencies of 12.7%. SERI measured an efficiency of 13.3% for a triple-junction device consisting of two top cells of a-Si:H:F on top of a-SiGe:H:F alloy with a band gap of 1.45 eV. Work is proceeding on four-terminal multi-junction devices with a-Si:H as the top cell and low band-gap materials for the bottom material. Meanwhile, modules are becoming larger in size and their effective areas are as high as 95% of the total area. The efficiency of $1000cm^2$ submodules has reached more than 9% in the laboratory. Fig. (1) indicates the progress in improving efficiency of conversion since 1975.

While total shipments of a-Si:H at the beginning of the decade were almost non-existent, they were estimated as 5.4MW in 1984, rising to 11MW in 1987, or more than one third of the total PV market worldwide, although most of this was for small consumer products. However, a-Si:H modules are now finding their way in more substantial power systems used for lighting, pumping and refrigeration.

There is little doubt now that there is a significant market for PV systems. A recent publication of the US DOE [1] shows

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[1] Photovoltaic Energy Technology Division, US DOE: Investing In Success, January, 1989.

FAX to: 0043-222-230-7355

that the PV market in the US alone is approaching $200 million in sales, and 10MW of power in module shipments per year. Worldwide shipments last year are estimated at nearly 40MW. Japan has been at the forefront, although total shipments seem to have remained rather flat last year. European sales are picking up, particularly in Italy, Spain and Greece. The same trend can also be seen in countries like India, Australia and China. As the market expands, cost will be reduced and market penetration will increase, resulting eventually in the installation of the first large energy supply systems.

Apart from the applications in devices such as calculators and digital time pieces, PV systems are best suited for stand-alone and distributed, grid-connected power units in remote regions. In inaccessible locations, stand-alone PV systems are the only viable alternative. Even when diesel alternatives exist, PV systems have frequently proved to be more reliable and cost-effective over the lifetime of the system, when loads are small and operation and maintenance (O&M) are important. A study of more than 2700 remote, stand-alone systems in 45 countries showed PV systems to be well accepted by the users, reliable, requiring little maintenance , and independent of fuel supplies[1].

As the cost of PV modules drops to $2/W, they will begin to invade the utility market. Some observers[2] expect the utility market to dominate PV sales by the turn of the century. The most

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[1] D. Eskenazi, D. Kremer, L. Slominski, in <u>Proceedings of the 19th IEEE Photovoltaic Specialists Conference</u>, 1987.

[2] H.M. Hubbard, Photovoltaic Today & Tomorrow, in <u>Science</u>, Vol. 244, 21 April, 1989.

obvious candidate is the small power market where the economic advantage is clear in the tradeoff of PV system costs versus those of transformers and line extensions, or where customers have to pay for line extensions, or where they would reduce demand charges, or where the supply of extra energy is needed at the end of an existing line which could not carry it.

Inspite of their economic viability and obvious advantages, PV power systems have been slow in penetrating the market. The technology is still unfamiliar and there is an obvious need for substantial promotional effort to acquaint potential users of its benefits, as well as to dispel misconceptions, that are not in tune with recent developments, concerning overall cost and reliability. In developing countries, market penetration has depended heavily on government policies, as well as those of foreign, regional and international funding agencies.

The Economics of Solar Energy:

Comparing the cost of solar energy with other sources is complicated by many factors. Nonsolar energy involves substantial "externalities", such as environmental damage, or the vulnerability of importing fuels, that are not directly reflected in prices. Furthermore, and as mentioned earlier, (p.2), energy prices are often distorted; future prices of nonsolar energy are difficult to predict, and changing over to solar energy is resisted because of the changes it could involve in established ways of doing things.

In most cases, solar energy systems have higher initial cost and lower operating costs. The comparison now focuses on whether the savings in fuel costs offset the higher initial capital cost. This requires a "present value" estimate of the costs and benefits, corrected for inflation and discounted at "real" value. The discounting is needed to take account of other investment opportunities yielding future benefits; greater than the present costs. Unless the discounted cost savings of a solar system are at least equal to its capital cost, larger future benefits could be obtained from other approaches for investment.

However, present value calculations are made difficult by the uncertainties involved in estimating future energy costs, the durability and mode of operation of the solar system and evaluating alternative investments.

Most short-cut methods are thus misleading, if not down right wrong. Comparison of capital cost per unit peak capacity, needs to take into consideration the duration of availability of energy. Calculating annual capital charges of the solar system, including interest and depreciation, per unit energy produced over a period of time (e.g. ¢/Kwh), takes into consideration the durability of the equipment. Yet this is strictly true only if the quantity and value of energy does not vary with time. Valid economic comparisons need to take account of the type, timing and value of the energy substituted for by the solar system in order that a complete present value calculation can be carried out. Fig. (2) highlights the distortions in cost comparisons of PV systems due to pricing electricity supply at less than its true cost.

Whatever method is used for comparing the economics of solar systems with the systems they displace, capital investment looms large in the calculation, particularly as experience gained with the operation of solar systems provides increasing evidence of their reliability in the field and low maintenance costs. Table (2), compiled by the US Department of Energy in October 1988, compares the operation, maintenance and fuel costs of different power generating alternatives and highlights the superiority of PV systems.

Solar Energy and the Environment:-

Solar energy has been the instigator of many ongoing processes in the biosphere from times immemorial. By contrast, energy from the combustion of fossil fuels or nuclear fission is man-induced and very recent. Although it cannot be categorically stated that solar energy systems are absolutely benign to the environment, it is undoubtedly far less harmful than conventional energy systems. This has been dramatically highlighted by the accumulated evidence of global warming and its far-reaching environmental consequences. While curtailment of the use of chloro-fluoro-carbons (CFC's) is already in hand, there is as yet no global strategy, let alone a feasible plan, fo cutting down on the harmful emissions from conventional power plants and transport vehicles. A scientific meeting held in Toronto last year called for a 20% cut in emissions of carbon dioxide by the year 2005, and a 50% cut by 2025. In fact, carbon dioxide emissions by OECD countries have increased by 4% a year over the period 1960-1973, and by 1.5% after the oil price hikes and the proliferation of nuclear plants. Estimates are that emissions will continue to increase by just under 1% a year from now on.

Account needs to be taken also of the fact that the growth in energy consumption in the future will come mainly from the developing countries.

An alternative approach is to improve the efficiency of energy use. One estimate of the manner in which commitment to stabilising future warming by the year 2060[1], stipulates an annual improvement in the efficiency of energy use of 1.7 - 2.4%, in industrial countries, and 1 4 - 2.3% in developing countries. This could be achieved with the best technologies existing today if the prices, in real terms, of fossil fuels quadruple and those of coal triple!

It is perhaps in developing countries that solar energy will have the greatest impact on the environment. This impact would be greater in rural isolated communities if rugged photovoltaic systems could be made available for the day-to-day power needs of such communities, e.g. lighting, water pumping, refrigeration,... etc. This would contribute significantly to halting the massive desertification that has occurred in arid and semi-arid areas, restore some of the plant cover and contribute to food production.

The Need for an Integrated Global Approach:-

If a-Si solar energy systems are:

- more benign environmentally
- increasing in efficiency of conversion

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(1) by Irving Mintzer of the World Resources Institute (WRI) to be published shortly.

- becoming more rugged and trouble free
- easy to install and commission in short time intervals
- decreasing in cost of production
- easily applicable to a variety of energy needs
- unaffected by fluctuations in fuel prices,

then there is every reason to conclude that we are poised for the long-awaited breakthrough in its widespread utilisation. The need now is for a concerted approach on a global scale to address the constraints, real or imaginary, that have curtailed its use in several situations worldwide, to keep track of the rapid pace of development, to assess their potential, and to promote the widespread use of the promising ones.

This has prompted UNIDO - which has maintained an active interest in solar energy ever since it was established - to go a step further and promote a worldwide "Committee for Solar Energy Research & Applications" (COSERA), as a global umbrella under which the global approach could take shape.

Breaking Out of Two Vicious Circles: A Global Production Facility:

On the assumption that solar energy is presently at a crossroads, the question arises as to how best to break out of the first vicious circle in which the absence of a large scale market is not conducive to more intensive R & D effort, while low levels of R & D, in their turn, postpone the expansion of the market.

The second vicious circle has been the controversy as to the relative priorities of increasing conversion efficiencies, or decreasing overall costs (mainly capital) Experience over the past few years has confirmed the wisdom of pursuing both routes and striving to improve efficiencies and decrease cost at the same time.

As discussed earlier (p.10), any method of costing will conclude that capital cost is the major item in the overall cost of a solar system of any worthwhile capacity. The main thesis of this report is that substantial cost reductions could be achieved if a global market for the amorphous route is created. The prima facie reason for this view is the recent developments in the fabrication of large panels in continuous processes. This will lead to substantial cost reductions if such processes are developed for really large scale production to meet the needs of a global market that is held together by a framework of mutual financial and social benefits, and on the understanding that the production facility will be so designed as to benefit from future developments in materials and process technologies.

A GLOBAL PRODUCTION FACILITY FOR A GLOBAL MARKET

The Case for a Large-Scale PV Material Production Facility:-

The case for a large-scale production facility is based on the fact that capital cost is the deciding factor in the overall cost of a solar system. The bulk of this capital cost is in the production of the solar energy converting material, whether this is crystalline or amorphous. The encapsulation into modules costs a good deal less than the production of the photovoltaic elements to be encapsulated.

Whatever type of photovoltaic material is used, large-scale production offers an obvious advantage. The problem now hinges on two other considerations. First, the cost, reliability and convenience of the process itself. This depends on the type of photovoltaic material chosen. Second, the cost and practicability of supply to worldwide markets.

To take the first criterion, we note:

1. Crystalline silicon cells, as indicated in Table 1, use a lot of expensive material, involve considerable waste in producing wafers, and are costly to manufacture. Furthermore, the round wafers are awkward to fit efficiently in power modules.
2. While ribbon silicon overcomes some of the abovementioned problems, its production involves a complex process that is still at the pilot and small-scale plant, without worthwhile experience in large volume production.
3. Against these disadvantages, amorphous silicon is very low in material use. Modern techniques of production are mainly based on continuous, highly automated processes, capable of

scaling up and upgrading. The substrate passes through a series of hermetically-sealed chambers where the different layers are deposited. The finished panels emerge from the plant ready for encapsulation in modules, either manually, or by semi-automated processes. Recent developments have proved that upgrading through multi-junctioning can easily be incorporated in the manufacturing process. The multi-layer, multi-cell device is produced in a single pass.

As for supplying a worldwide market, the main considerations are:

1. Whether to ship finished modules of different sizes and capacities, or the photovoltaic elements for encapsulation into modules on site, and according to local market conditions.
2. It is obvious that shipping the photovoltaic elements would be more practical and economical. However, for amorphous silicon cells, this depends on the properties of the substrate used. Glass panels are fragile, awkward and expensive to transport safely over long distances, involving loading and unloading at several locations on their routes to destinations. With the advent of triple tandem multi-band gap deposition on a roll-to-roll flexible and rugged ultra thin stainless steel substrates, the problem of transporting such high efficiency panels (see fig. 1) over any distance is solved.
3. It has been estimated that to produce 2MW of coated web over 5 years would require an investment of around $10 million ($5 million per MW). The production cost of the coated web alone

would be around $2.5 per watt. However, a central facility for the production of say 300 MW of coated web over the same period would cost about $200 million. The cost per MW would drop to $660,000 and that per watt to about $0.6.

The Case for Downstream Processing in Different Locations:-

The convenience of transporting thin stainless steel-based coated cheaply-produced web, makes it desirable to further process this intermediate product into panels and complete systems in different locations in accordance to the nature of the local demand for power. As mentioned earlier, this can vary considerably from location to location, whether in power output, final application, or extra equipment needed to package a solar system suitable for a specific purpose. In rural areas, these may be low power systems for modest lighting and refrigeration loads, electronic equipment such as radios, TV's and telecommunication, or for water pumping. Besides producing the panels, the extra equipment, be it energy-saving lighting systems, efficient storing batteries, D.C. refrigerators and electronic equipment, or rugged pumps would be provided to the end, user as an integrated and reliable system at reasonable cost. For more ambitious applications to shave off peak loads in power stations, or to provide stand-alone systems of higher capacity, the need will be to integrate the panels with the necessary converters and/or storage batteries, as well as the control and standby equipment.

The process of further processing of the coated web into panels can be essentially labour-intensive, for small scale systems in less developed countries, or could be semi-automatic for relatively large scale production. This flexibility in down-stream processing contributes further to bringing down the overall capital cost of the complete systems.

The Imperative of a Global Market:-

The above mentioned advantages of using a flexible efficient coated web, mass-produced, to be further processed in different locations, would only work if there is a truly global market that would justify the large scale production of the intermediate web material in one expensive central facility.

For this to be achieved, the enterprise should be truly international and in more than one sense. While it is obvious the capital funding needs to come from as many countries as possible - particularly the industrialised and other rich countries, it must also be noted that the enterprise has a very significant developmental slant when we consider its impact on the developing and less-developed countries. In this latter case, the provision of environment-friendly, rugged and reliable sources of energy, unaffected by the fluctuations in the cost of other conventional sources and very cheap to operate, would have a dramatic impact on almost all socio-economic development projects. Donor countries, funding agencies and institutions would find this the optimum approach in tackling the energy problems in many situations.

In order that such a global market be created, there is need for a massive promotional effort on a global scale, combined with very careful consideration of the financial and business strategies adopted. This latter issue could make or break the project, depending on every partner, whether in the industrialised or developing countries, feeling that it is a fair deal to which he would be committed over a long time horizon.

AN ILLUSTRATIVE PROJECT PROPOSAL

On the basis of the above mentioned approach, Messrs. Suryovonics Ltd. of India - a company in which Energy Conversion Devices (E.C.D.) Inc. of the USA has a 40% share holding - has formulated a project proposal which is summarised here as an example for the practical realisation of the benefits of large scale central production of amorphous silicon coated web on large thin stainless steel substrates for downstream processing in a number of locations worldwide. This is summarised here in order to provide the basis for discussion of the feasibility of the idea and the conditions and actions for its realisation.

The Main Features of the Proposal:-

The main features of the proposal are as follows:-

1. The product specification is coated web, 1.16' wide, 4' long, 0.008" thick. This yields a standard module of 1'x4', or fractions of this size. The output of the standard module will be stabilised 30 watts, and the weight of one coated web slab will be 650 gms.
2. The assembly materials required in downstream processing of the 1'x4' webs into PV modules consist mainly of encapsulant materials, bus bar tapes, diodes, silver ink, polyester tapes, copper foil, copper tabs, etc. The cost for one module is estimated at $15, or $0.5/watt.
3. The present efficiency of 7.5w/ft^2 is expected to increase, as a result of ongoing R&D to reach 11 w/ft^2 in five years. The net effect of such improvements is expected to reduce the cost of the coated web to around $0.30/w.

4. The impact of large scale production is illustrated in Table 3. This shows that the cost of a slab drops from $56.50 for a 2MW coated web plant, to $30.64 for a 25MW plant, to $16.93 for a 150MW plant. The table also highlights the fact that raw material cost is relatively low and decreases for the largest unit.

The proposal recommends the installation of a 200MW plant in India, for which the cost /w of modules would be $1.48/w ($10/ft^2) and suggests India as the location of the central coated web production facility. This is based on the fact that the current sale price of photovoltaics in India is $1.8/Wp, while the domestic market is thought to absorb 50MW with minimal introduction and sales effort.

Furthermore, India is considered as possessing the infrastructure and qualified personnel needed at low cost, as well as providing considerable incentives for e port-oriented industries, particularly in duty-free importation of equipment and raw material, and a 5-year corporate tax holiday.

The Business Plan:-

The main issue here is raising the capital of $150 million, for the central coated web production facility. The proposal bases its business plan on "co-operation and understanding on a global basis". This is articulated as follows:-

1. Each country would encourage a small group of entrepreneurs to study the proposal and acquaint themselves with its details, by arranging visits and discussions with E.C.D. in the USA and Suryovonics in India, to answer all their queries

and doubts to their complete satisfaction and ensure their commitment to participation in the project.

2. A detailed market survey has to be undertaken in each country. This would define the most appropriate applications for PV modules and products, based on the assumption that modules will be manufactured in the country and marketed at a price of $1.5-2.0/Wp for the coming years. ECD/Suryovonics, as well as international specialized agencies, such as UNIDO, and development funds, would support the effort needed in such market surveys.

3. This should yield a conservative yearly demand of coated webs for five years to come. The partners in the different countries would thus be in a position to make a firm commitment covered by a cash deposit guaranteeing importation of at least 50% of the conservative yearly demand estimate for five years to come[1].

4. The proposal estimates that the guaranteed demand for coated web would start with a little over 60 MW in the first year, exceeding 110 MW in the third year and reaching 165 MW in the fifth year.

5. On this basis, it plans to install two production lines, each of 100 MW capacity. The first line, as well as all the common plant facilities for the final capacity would cost $90 million to be invested in year 1. The second 100 MW line, costing $60 millions would be installed in year 3. Further 100 MW lires would be added as the need arises.

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[1] The proposal estimates for 50% of the conservative market demand for different countries, are given in Table 4.

6. It is expected that each of 19 partners (Table 4) would be encouraged to invest $1000/KW of coated web they will buy over the five year period. This means that the total equity made available would add up to $56.02 million, i.e. 40% of the equity of abut $140 million. Should some partners decline to participate, their share of equity would be taken by ECD Inc. and Suryovonics Ltd.

7. An additional deposit of 25% of the equity will be raised as security deposit from all countries buying coated web. This will be returned at the rate of $10 for every 4 ft^2 slab of coated web. Furthermore, up to $75 million in loans, will be solicited from financing institutions such as Exim Bank and OPIC.

8. ECD/Suryovonics would also consider equity participation in downstream processing plants should this prove possible and necessary. They also undertake to make available to the international joint venture of the central plant all the benefits of any future improvements in technology. The 40% equity participation guarantees that such improvements will be incorporated in the plant, since they can only increase its profitability and accelerate amortisation of the investment.

Implementation Phases:-

The proposal envisages that original shipments will be from a module fabrication facility in India, for which the machinery is already in place. The coated web used in making modules will come from E.C.D. in the States. This will offer an opportunity for the developing countries to train their personnel in the Indian plant on module making, using imported coated web supplied eventually (in 2-3 years time) from an Indian 3MW plant producing triple tandem coated web. The main skills needed in module production are cutting, silver screen printing, soldering, encapsulation and final mounting. All these are labour intensive skills that are relatively easy to acquire. Thus the availability of coated web from India would be synchronized with the setting up of module making plants in the different countries importing coated web. In five years, the large scale coated web production facility would be on stream, with one line in production.

At the early stages, and to help in the market surveys, the Indian module making facility would provide complete PV systems to different countries at competitive prices, in order to feel the market and assess future potential.

A Preliminary Assessment:-

<u>On the credit side,</u> this proposal has obvious merits:-

1. It is one of the very few - if not the only - proposal that holds the promise of a solution for the thorny problem of capital cost of PV systems. The solution is based on the following:-
   - centralized production of the photovoltaic material on a global scale
   - encapsulation and system integration in a diversified manner to suit the conditions in each locality.
   - the low material cost of amorphous silicon material

- the development of continuous manufacturing processes at much greater speeds
- the ease and economy of transporting rugged, flexible and light web with thin stainless steel as the substrate.

2. It involves many countries, national and international organizations, business enterprises, and funding agencies in a truly international effort.
3. It could assimilate future developments in this technology, as well as expand as demand increases.

<u>On the debit side</u>, one could cite:

1. So far, it is more of a vision than a business plan on the basis of which investment decisions and commitments could be made. In order that this worthwhile vision is turned into a feasible plan, at least the following issues have to be thoroughly investigated and favourable conclusions reached.
2. Two crucial issues come immediately to mind. The first, which is clearly emphasized in the proposal, is to conduct a careful market survey on a truly global scale. This is far from being an easy task and is bound to be very costly. It is not enough for investment decisions to state that some countries will be provided with the necessary support in conducting market surveys in those countries.
3. Furthermore, it is doubtful if many developing countries are in a position to participate in the equity for the central coated web plant, nor is investment of the holding company in downstream processing facilities on the spot always a straightforward business. Perhaps regionalisation could offer a solution to this problem.

4. Consequently, a substantial and costly promotional effort worldwide is needed if the results of the market survey are encouraging. It is not clear who would foot the bill before a corporate structure takes shape.

5. The scaling up of production from 2-3MW/year to 75 MW could run into problems, take more time than expected, or prove so expensive as to upset all the cost estimates given in the proposal.

6. Testing the market using panels and/or systems produced in India, may turn out to be counterproductive. Such items are bound to be expensive, as they do not benefit from the economy of scale which is the core of the proposal.

7. According to the proposal, it would be 7-8 years before the central facility is on stream. Judging by the current rate of technological development and the constant stream of announcements of new and promising developments, the technology might not be the best at the time the main facility goes on stream. This calls for a thorough investigation and assessment of the potential of ongoing and planned RDD&D.

However, no doubt some at least of these uncertainties and ambiguities could be overcome and clarified. The forthcoming COSERA meeting would be a good opportunity for conducting a preliminary evaluation of the proposal and recommending appropriate venues for pursuing these ideas until their feasibility, or otherwise, is established with reasonable certainty.

What is needed at present is the development of markets on a global scales, diversification of economical applications, as well as sensitization to the benefits of the technology now to be made available at much lower capital cost and greater reliability, and in a truly international cooperative effort.

FUTURE ACTION

1. The first thing that needs to be done is to check reactions to the idea of centralized production for a global market – both politically and financially. The idea needs to be discussed initially with a carefully chosen group of funding agencies, development and aid organizations, government officials and private financiers and entrepreneurs.

   It is reasonable to expect UNIDO, perhaps in cooperation with one or more international or national development agencies to undertake this task.

2. Should the outcome prove encouraging, the next step would be a reasonably thorough and convincing market survey and market testing of total PV systems in a variety of situations. This need not achieve complete coverage; but like most market surveys, its success would hinge on choosing the minimum number of appropriate localities that would be a good representative sample of the larger market.

   This is more difficult to fund. However, the promoters of the proposal in cooperation with UNIDO, may consider benefiting from certain aid programmes that could use PV systems to get a feel for the market.

3. In short, there is a real need for market development in as many countries and many ways as possible. This will be even more difficult and costly.

   Here again the aid and technical assistance projects could play an important role in sensitizing potential beneficiaries, and potential investors, to the advantages of PV systems tailored to local specific needs and made available at a reasonable cost.

4. Since the project depends on decentralized downstream processing of the coated web into systems, there is a need to build and/or strengthen local capabilities in this activity and to encourage investigating novel applications and development at the local level of the other bits and pieces of equipment that go into an integrated system.
This is obviously the domain where technical assistance and technical cooperation can play a decisive role in turning this proposal into a feasible project.

5. To initiate the process of downstream processing into suitable systems tailored to local needs, the governments, particularly in developing countries, have to provide effective incentives - both to manufacturers and users - to help create the market size that would ensure widespread benefits from solar PV systems. Tax holidays, participation in equity, price subsidies, demonstration and extension services, popularization and promotional campaigns by the state-owned mass media, are examples of government actions that would promote the use of PV systems where they best serve national development effort.

6. Finally, there remains the need for investigating and defining the most viable and appropriate business structure for implementation. Some innovative formula is needed since there are not many, if any, precedents on whose experience the new structure could be planned.

Table I

Cell Type	Efficiency Lab. Record	Efficiency Prod. Record	Advantages	Disadvantages
Single Cell Crystal	19.1%	10-13%	- well established & tested technology - stable - relatively efficient	- uses a lot of expensive material - lots of waste in slicing wafers - costly to manufacture - round cells cannot be spaced in modules efficiently
Polycrystal Silicon	18%	10-12%	- well established & tested technology - stable - relatively efficient - less expensive than single crystal Si - square cells for more efficient spacing	- uses a lot of expensive material - lots of waste in slicing wafers - fairly costly to manufacture - slightly less efficient than single crystal
Ribbon Silicon	15%	10-12.5%	- does not require slicing - less material waste than single crystal & polycrystal - potential for high speed manufacturing - relatively efficient	- has not scaled up to large volume production - complex manufacturing process
Amorphous Silicon	11.5%	4-8%	- very low material use - potential for highly automated & very rapid production - potential for very low cost	- Staebler-Wronski effect

Source: Photovoltaic News, February 1986, Vol. 5, No. 2

Table 2

Power Generating Technology	Operation/Maintenance/Fuel Costs Cents/Kwh
PV	0.60
Wind	1.00
Combustion Turbines	6.45
Slow Diesels	6.17
Combined Cycles	4.20
Pulverised Coal	3.20
Atmospheric Fluidised Bed Combustion (AFBC)	3.00
Conventional Coal	2.90
Nuclear	2.13

Table 3

Coated Web Production Cost Estimates [1]

Capacity	2MW	25MW	150MW
No. of slabs/year (1'x4'. 30W)	70,000	875,000	5,250,000
No. of slabs in 5 years	350,000	4,375,000	26,250,000
Capital cost ($)	10 million	40 million	90 million
Raw material cost/slab ($)	14.00	14.00	11.50
Total manufacturing cost/slab ($)	14.00	7.50	2.00
Depreciation/slab ($)	28.50	9.14	3.43
Total cost/slab ($)	56.50	30.64	16.93
Cost of slab for producing 1 watt ($)	1.88	1.02	0.56
Cost of module/w ($)	3.88	2.52	1.50

[1] According to Suryovonics Ltd. of India.

Table 4

Estimates of 50% of Demand Over Five Years (KW)[1]

Country of Origin	Years 1	2	3	4	5	Total for 5 years
Sweden	250	300	350	400	500	1,800
Holland	250	300	350	400	500	1,800
West Germany	400	500	600	700	800	3,000
France	500	600	700	800	900	3,500
Spain	600	700	800	900	1,000	4,000
Italy	600	700	800	900	1,000	4,000
Hungary	250	300	350	400	500	1,800
Yugoslavia	500	600	700	800	900	3,500
Poland	250	300	350	400	500	1,800
Middle East	1,000	2,000	3,000	4,000	5,000	15,000
Pakistan	2,000	4,000	6,000	8,000	10,000	30,000
India	25,000	30,000	35,000	40,000	50,000	180,000
Bangladesh	1,000	2,000	3,000	4,000	5,000	15,000
Far East	2,000	4,000	6,000	8,000	10,000	30,000
Australia & N.Z.	2,000	4,000	6,000	8,000	10,000	30,000
Pacific Countries	5,000	7,000	9,000	11,000	13,000	45,000
China	5,000	7,000	9,000	11,000	13,000	45,000
USSR	10,000	15,000	20,000	25,000	30,000	100,000
Others	5,000	7,000	9,000	11,000	13,000	45,000
Total	61,600	86,300	111,000	135,700	165,600	560,200

[1] According to Messrs. Suryovonics of India.

CONTENTS

PROGRESS OF AMORPHOUS SILICON

Efficiencies for 3 Different Multijunction Cells

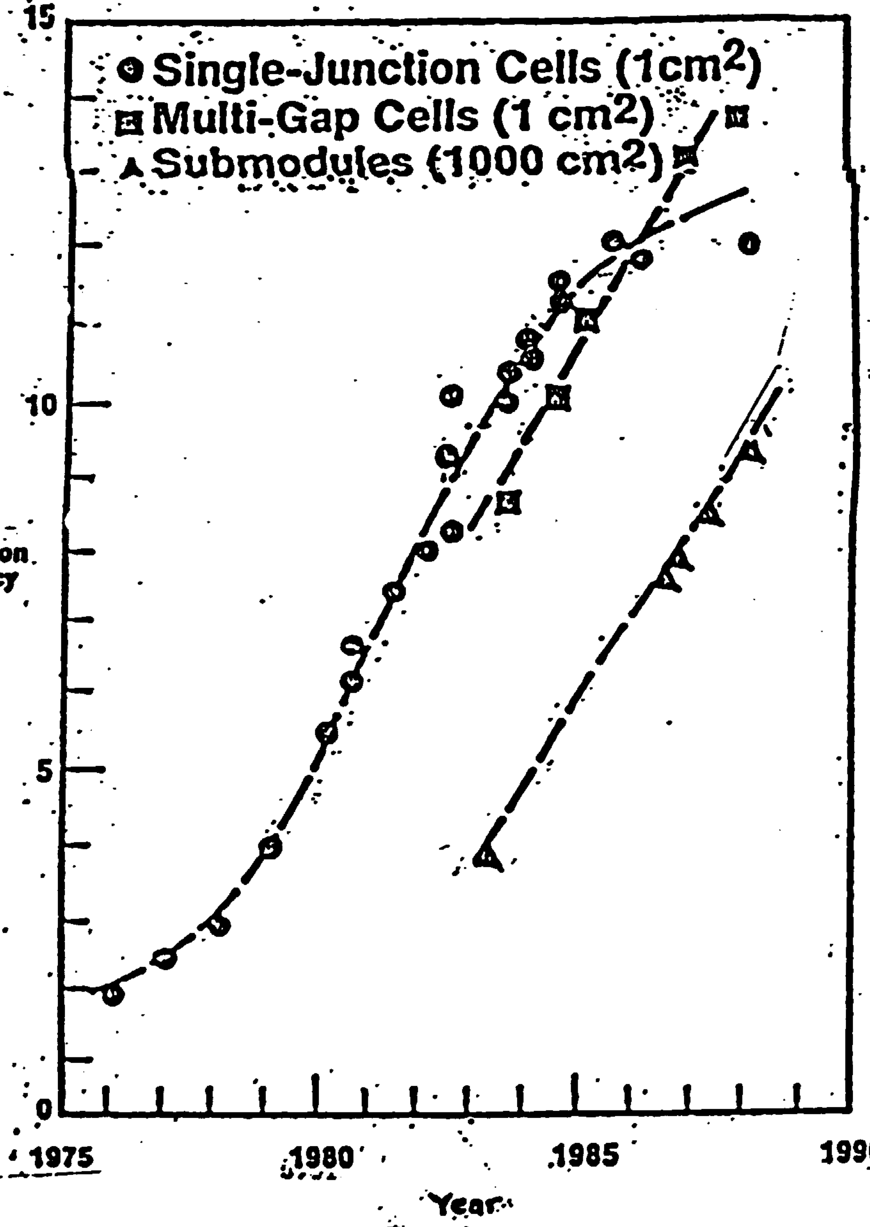

Fig 1

PRICING ELECTRICITY AT ITS TRUE COST ENABLES PV TO MEET 2% OF THE UNPLANNED POWER NEEDS OF 60 GWe BY YEAR 2000

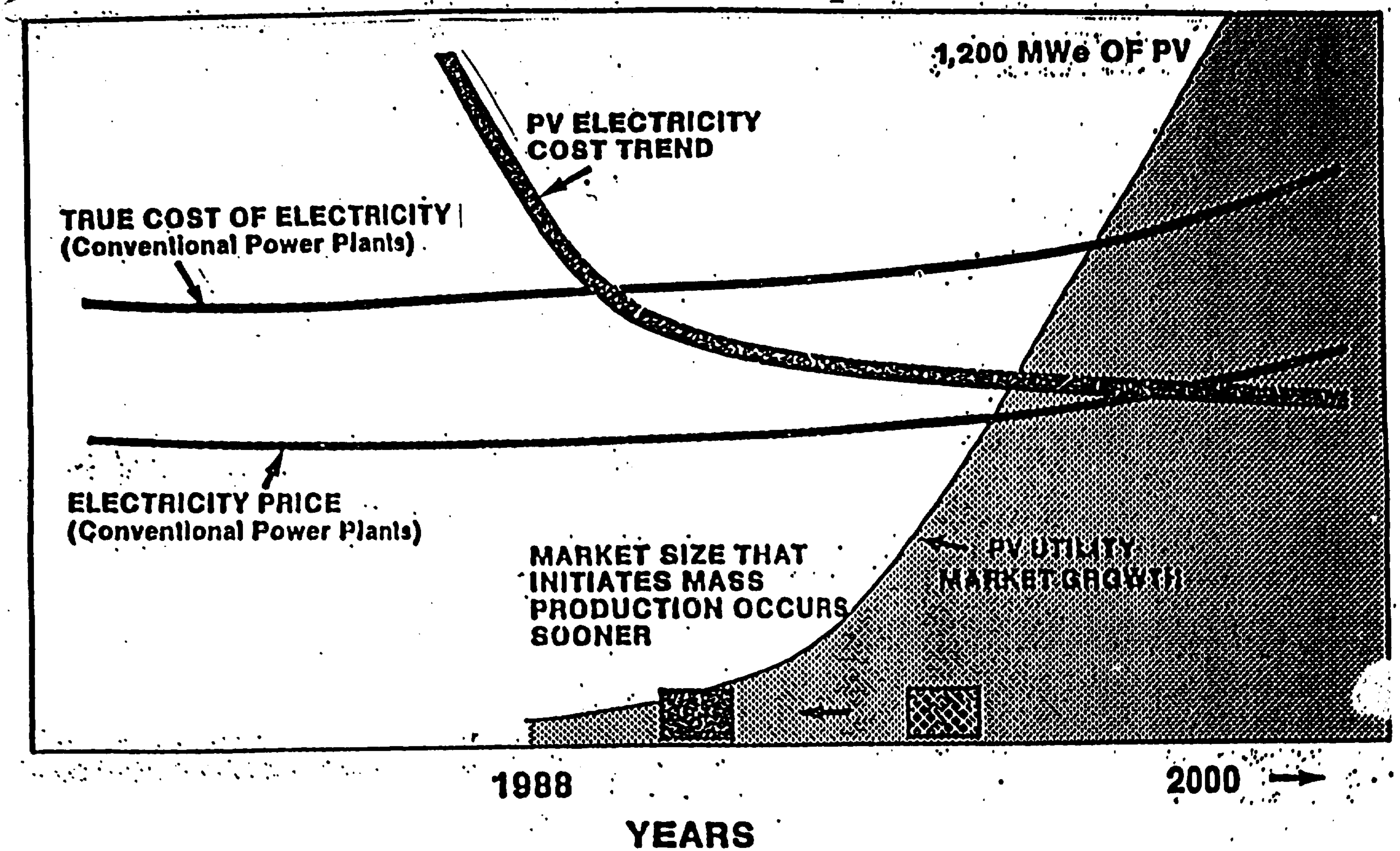

Fig. 2

A GLOBAL APPROACH TO PHOTOVOLTAIC
SOLAR ENERGY APPLICATION

O.A. El-Kholy CLT 89/369
(Backst. off. A. Bromley, IPCT/TD/INF)

Corrections

Page 17, paragraph 3, lines 1 and 2, should read:

"It has been estimated that to produce 2 MW of coated web per year would require an investment of $10 million ($5 million per MW).

Page 22, line 11, should read:

"the current sales price of photovoltaics in India is $8/Wp".

Page 27, paragraph 7, lines 1 and 2, should read:

"According to the proposal, it would be 2-3 years from date of final decision before the central facility is on stream".