DEVELOPMENT OF THE FRENCH PHOTOVOLTAIC PROGRAM

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INTRODUCTION :

IMPORTANCE OF SOLAR ENERGY IN THE WORLD - THE POTENTIAL OF PHOTOVOLTAIC ENERGY

The energy given by the sun is enormous :

- 10 minutes of Photosynthesis on Earth could give the energy needed by humanity for 24 H if one could recover it with 100 % efficiency. The Sahara desert receives more than 2000 KWH/m^2 per year (ATAR in Mauritania 2300 KWH/m^2).

- and relatively well distributed : North of France receives 1000 KWH/m^2/ year in average, that is equivalent to 100 barils of oil on a roof of 100 m^2 in NICE).

But Solar Energy is whimsical, diluted and often available when we do not need it and not often available when we do need it.

The different forms of Solar Energy are :

- Biomass.
- Thermic Energy.
- Photovoltaïc Energy.

and derivative forms are winds and hydraulic energy.

Solar Energy covers 12 % of the total needs of humanity in energy (6 % Biomass - 6 % Hydraulic) and this energy is important for the developping countries.

In fact, Biomass (Wood, manure...) supplies :

- 20 % of energy in South America.
- 60 % in Africa.
- more than 90 % in India.

Though the available areas for Biomass were initially unlimited at human scale, Bionass is an energy converter with low efficiencies : 0,2 - 0,5 % though the nature has found several ways :

- a main way, that of superior plants, which are able to perform water photolysis through the use of several photons.

- several secondary ways, the interest of which may presently appear in the frame of the "solar fuels" goal : for instance, the green or blue-green algae which synthetize hydrogen or ammonia, or the photosynthetic bacteriae which use only one photon, cannot hydrolyse water but are able to transform some organic matters into hydrogen.

If the efficiency range is now (0,2 to 0,5 %) the processus of the nature allows stockage of the energy.

By a one-photon transformation, solar cells can produce electricity directly, a "noble" energy vector, with a much larger efficiency than that of photosynthesis. (12 - 15 %).

However, its use is handicapped by inadaptability to storage, and mainly by its high investment.

The high cost can be progressively reduced by research, technological development and mass production.

TABLE 1 - ADVANTAGES AND DRAWBACKS OF SOLAR ENERGY QUANTUM CONVERTERS

	Vegetation	Solar Cells
CONVERSION EFFICIENCY (% of solar enerflux)	0,2 - 0,5 %	9 - 13 %
INVESTMENT COST ($/oil equivalent ton/year)		
Typical land cost	500 - 800	
PV generator cost		7500 - 25000
OPERATING COST (order of magnitude)		
in $/hectare-year	2500	10 000
in $/oil equivalent ton	500	125
USING CONVENIENCE		
- Energy transportation	rather easy	rather easy
- Energy storage	easy	difficult
Oil equivalent tons/tons of biomas	0,6	
Oil equivalent ton/tons of batteries		0,002

(Professor RODOT - Photovoltaic Solar Energy Conference CANNES 1980)

CONCLUSION : ENERGY WOULD BE CHEAPER THAN BIOMASS IN OPERATING COST BUT MUCH MORE EXPENSIVE IN INVESTMENT COST.

3 FRENCH POLICY FOR PHOTOVOLTAIC ENERGY

3-1 First period 1973 - 78

In 1973, the chairman of the DGRST (Délégation Générale à la Recherche Scientifique et Technique) decided to create a program in order to increase french photovoltaic know-how :

- of Research : by strenthening teams working in this field, by creating new teams inside CNRS (Centre National de la Recherche Scientifique), by organizing the coordination between these laboratories.
- of Development : of Technology in industrial laboratories and by organizing several pools of research laboratories and companies working for the same goals.

During five years, 1974 up to 1978, the French Government contribution was $ 5 M which, added to the CCE contribution gives an amount of $ 8 M.

This French photovoltaic policy stimulated during this period the Research and Development of companies and a rough estimation of the overall French effort during this period was estimated at $ 25 M.

It was decided to create an agency for renewable energies and its responsible, Mr. Jean-Claude COLLI succeeded to justify these actions at the level of government and the French population.

We emphasize that a French Company, R.T.C., La Radiotechnique Compelec, produced its first generation of photovoltaic modules for terrestrial applications in 1960 and the first system of 144 modules was set up in ANTOFOGASTA UNIVERSITY in CHILI in 1961.

RTC carried out this activity continously and designed one generation of modules every five years up to now in order to supply other companies involved in systems and so has got a lot of experience in reliability and applications od photovoltaic modules.

3-2 Period.- From 1978

The French government decided the creation of COMES (Commissariat à l'Energie Solaire - Solar Energy Agency) in 1978 in order to develop the different forms of Solar energy in France.

The President of the COMES has been Professor Henry DURAND from the beginning.

As far as photovoltaic energy is concerned, in 1980, COMES coordinates a total governmental effort of $ 25 M.

- including its own effort of $ 8 M, that is 23 % of its total budget
- including PRIDES (Programme Interdisciplinaire de Recherche et Développement en Energie Solaire) and other administration agencies (help to SAHEL countries...).

2 RECALLS ON PHOTOVOLTAIC CONVERSION

The direct conversion of solar light into electric power is achieved by means of SOLAR CELLS by the photovoltaic effect. This behaviour is accounted for by the fact that the photons coming from sun transfer their energy directly to electron-hole pairs that which explains the high invasion efficiency compared to other forms of Solar Energy.

Silicon is the semi-conductor material for photovoltaic conversion because its physical properties are fit for the spectrum of sunlight and it is the base material for the transistors and integrated circuit industry.

The diagram N° 2 presents the main steps of the realization of solar cell and photovoltaic solar module.

The first steps lead from the sand to a high purity polycristalline silicon (99, 99999999 %).

The manufacture of solar cells begin by the pulling of single crystal of Silicon.

Silicon wafers are obtained by cutting wafers from single crystal Silicon ingot.

These wafers receive a diffusion of phosphorous impurity on a very thin depth (0,15 μm) in order to create a n-p junction.

Ohmic contacts are made on both faces of the wafer and Solar cells are ready to run.

But a protection against atmospheric agents is necessary,so an hermetic encapsulation transparent to the solar light is a determining factor in reaching the reliability raquired.

Figure N°3 shows typical photovoltaic module for territorial use.

The modules have a power peak between 2 - 35 WP, but this power is increasing up to 60-100 WP.

These modules are gathered into flat-plate arrays, they are the generator of photovoltaic system which also includes an energy storage (batteries), a charge regulator, a converter, a management system of energy, securitie ...

We predict that single crystal or semi-crystal Silicon will remain the primary practical commercial photovoltaic material for use in a variety of flat-plate arrays and concentrating collectors at least for about five years.

4 FRENCH PHOTOVOLTAIC ENERGY RESEARCH PROGRAM

4-1 In the early 70's, DGRST and CNRS decided to cover a broad spectrum of research subjects, specially in semi-conductor materials : monacrystallerie Si, polycrystalline Si, amorphous Si, III-V and II-VI compounds.

Most of the research was lead in close cooperation with development activities. So 50 % of the budget was used for Research Development and Technical Development on materials.

On the other hand the technology development uses 44 % of the total budget, whereas long-term research uses 56 % of this one. (See tables 5 et 6).

4-2 Today, research efforts are split into three parts these are :

1) "Programme Interdisciplinaire de Recherches pour le Développement de l'Energie Solaire" (PIRDES), an horizontal organization, gathering laboratories of "Centre National de la Recherche Scientifique " (CNRS) and some Universities working in Solar Energy Research. Professor RODOT is the Director of PIRDES.

75 scientific research workers and 50 assitants are involved in this effort.
There are 13 large research laboratories and a dozen other teams.

The overall expenses rise up to \$ 10 - 15 M this year.

2) Research Laboratories of :

- Companies involved in electronics, such as LEP (Laboratoire d'Etudes Physiques) in connection with RTC ; Centre de Recherche de Marcoussis in connection with CGE.

- Companies involved in chemistry for research and development on solar-grade silicon material :

  RP (Rhône Poulenc)

  PUK (Pechiney Usines Kuhlman)

3) Research sponsered by COMES budget, in these laboratories and other ones (CEA : Commissariat à l'Energie Atomique,....).

The overall research expenses can be roughly estimated at \$ 20 M.

Thus the overall 1980 budget ($ 25 M) is equal to the amount of the overall 1973 to 1978 budgets.

So in 1980, this budget may be the second largest in the world after the US ($ 118 M in Fiscal Year 1979).

In 1980, the French Government has established a six year program. The program objective is to bring photovoltaic modules and systems to achieving major cost reductions in order to widen applications.

The overall goal is the development of a strong industry in France, from the development of industrial process to produce Solar Grade Silicon to the supplying of photovoltaic modules or systems all over the world.

So, an half-dozen companies have been asked to present their plans to the Ministry of Industry.

Their answers were instructive and, in spite of some differences, answers were basically the same, for exemple :

Price of the PV module	:	$ 2,85 in 86
Price of the PV system	:	$ 12 in 86
The capacity of one production line	:	about 10 MWP
Turn over	:	$ 120 M
World Market	:	150 MWP

Target of each company :about 6 % of world market (Informations given by Professor H. DURAND, President of COMES, during the International Photovoltaic Solar. Energy Conference of CANNES 27-31 October 1980).

These objectives are compatible with those of COMES that is a share of about 20 % of the World Market for France, with two or three companies.

The key of this program is not the residential applications like in US, but to answer a large spectrum of applications where photovoltaic energy can be competitive with other sources of energy (chemical batteries, diesel motors, gas turbines).

So developping countries can have a large number of possibilities to solve some of the energy problems they meet.

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4-3 Scientific Program :

4-3-1 Near Term :

The short term objective has been the technical feasibility of a system using Si solar cell with a concentration of about 45 times.

A 1 KWP prototype has been realised : SOPHOCLE (Solaire Photovoltaïque à Concentration Limitée d'Energie).

The reliability of 140 W units of SOPHOCLE is under study by several teams in different climates: FRANCE - ALGERIA - BRAZIL - GABON - GREECE - INDIA - MEXICO - SENEGAL - THAILAND.

The SOPHOCLE program is a part of a longer CNRS-PIRDES interest in the development of concentrating systems and of high efficiency solar-cells (AsGa, tandem mounting, multispectral cells) to be mounted in these systems.

SOPHOCLE is being industrialized by three French companies, the leader being AEROSPATIALE.

4-3-2 Mid Term :

The medium term scientific program has been orientated towards the silicon, today the only way to lead to the national goal of $ 12/Wp in 1986 with a conversion efficiency of 12 % at a level of production of several 10 M WP/year is :

- Prospective study of two new chemical purification ways of metallurgical grade silicon :
  - by electrolyse.
  - by zone melting process with plasma.
- Development of HEM method (Heat Exchange Method) in order to produce semimonocristal (polycristal with large grains) with the collaboration of RTC.
- Silicon in ribbon is one original method of growth of feasibility. This method needs no support (Madam RODOT's Method).
- Characterization of different kinds of silicon made by industrials (Seven teams).
- Advanced development of p-n junctions by pulse annealing (laser and electron-beam) in connection with industry.

4-3-3 Far Term :

The first part of the long term scientific program includes high concentration solar cells Ga Al As/GaAs and multispectral high efficiency cell ("Arc-en-Ciel project") up to 48 % theoritically. (fig. 7).
A new lab is being built for this last research in SOPHIA-ANTIPOLIS.

The second way consists to bid on the potentiability of very low cost of polycrystalline films.

So CNRS has settled, several years ago, a pilot line of CU_2S - CdS photopiles made by a spray technic - efficiency of 6 % has been reached. CdTe and InSe and other exotic materials are under study.

The objective of another group including 8 teams is the so-called amorphous Si (Si-H).

Good scientific studies contributed to a better knowledge of this new photovoltaic material and to reach a 5 % efficiency.

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- Elaboration of "HEM" semicrystal ("Heat transfert Method").

  One CNRS laboratory and RTC established a close cooperation on this now well-known technic.

- Elaboration of "SEMIX" semicrystal planned in 1981 by FRANCE-PHOTON in collaboration with SOLNEX.

- Silicon ingots processes could be the key for the mid-term objectives of reduction of silicon substract cost, if the losses of materials can be dramatically reduced by a new slicing process.

  So RTC's goal is to cut in 1982 a complete ingot (80 cms length Ø 100 diameter or square shape) at a rate of 500 slices/run and 25 slices/cm.

  Results obtained this year are promissing with a MCWT process (Multi-cutting Wire Technology) allowing the possibility of cutting 180 slices 100 mm diameter.

  The weight of a silicon 100 mm diameter wafer can be reduced from 14 g to 9 g. So 1 MWP needs about 16 tons of Si ingots instead of about 25 tons.

- Elaboration of Si ribbon with a new process created by LEP .

  This new pulling process called RAD (Ribbon Against Drop) is quite competitive to other well known ribbon pulling process that is "EFG" (Mobil- Tyco), "WEB" (WESTINGHOUSE) "RTR" (MOTOROLA), "SOC" (HONEYWELL).

  This pulling process is under development in LEP in close cooperation with RTC.

  The rate of growth is higher than 200 cm^2/min with a thickness of ribbon of 100 μm and a width of 5 cm.

  This method can reduce the quantity of silicon per MW necessary today by about 10 :

  2-3 T/MW instead of 25 MW by CZOCHRALSKI.

  The inversion efficiency reaches 10-11 % for ribbon solar cells.

- The other processes studied in the World (SEMIX - SILSO, TYCO ribbon) are investigated to check their real possibilities versus the last ones.

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6 FRENCH INDUSTRIAL POLICY AND POTENTIAL FOR PHOTOVOLTAIC ENERGY

6-1 French Industrial Policy

French government decided in 1980 to push forward the technological and industrial development of photovoltaic modules and systems (as it is described in the Chapter 3).

The plan includes 4 parts :

1) Sponsorship to some Research Development Studies : 38 % of the photovoltaic budget of COMES and the major part of PIRDES budget.

2) Loans bearing no interest for development work and industrial investment

3) Bunched orders by COMES :

   55 KW were ordered in 1978-79 and 60 KW in 1980 from three French module producers (RTC, FRANCE PHANTON and PHOTOWATT).

   An important user of these bunched orders has been TDF (TELEDIFFUSION DE FRANCE) for its program for educational TV sets in black africa : several hundred educational sets have been set up in IVORY COAST, NIGER, UPPER VOLTA...).

   "Le Ministère de la Coopération" with its program "Help to Sahel Countries" has also been a major user of modules for :

   - Instalment of photovoltaic pumping wells in the countries devastated by drought.
   - Setting up photovoltaic electricity in African villages

4) Grants for most demonstrative applications all over the world especially in black Africa.

In order to guarantee the reliability of these bunched orders of modules, COMES set up in "The Laboratoire Central des Industries Electroniques" equipment needed for life tests and specifications. This laboratory works in close cooperation with industrials and CCE ISPRA Laboratory.

Moreover, CCE has prepared a proposal to install 50 KW (or more) systems in the European community countries and some French module or/and system producers organized joint-ventures with other European producers to answer to CCE demands.

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5 FRENCH PHOTOVOLTAIC ENERGY TECHNOLOGICAL DEVELOPMENT PROGRAM

The objective of the French Photovoltaic Technical Division Energy Program is to reduce the module and system cost to a competitive level to other energy sources (chemical batteries, diesel, gas turbines ...) and to develop their applications.

In order to achieve this overall objective, two actions have been defined :

- Technological Development action.
- Industrial Development action.

As far as Technological Development actions are concerned, several programs for flat modules have been defined by COMES.

The first program involves silicon preparation : Silicon wafer represents always about 40 % of the overall production cost of a module from 1965.

So great efforts are made on :

5-1 Development of a Solar Grade Silicon Process

The goal is to reduce by about 5-8 the cost. RHONE-POULENC is the leading company in this action..

5-2 Development of Several "Crystals of Silicon" Processes

In order to compare under industrial consideration their pro's and con's the technics studied are listed :

- Advanced CZOCHRALSKY single-crystal silicon :

  In RTC, this company having a more than 20 years experience of monosilicon growth gets about the same technical results than other big companies involved in Si pulling.

- Elaboration of semicrystalline silicon ingots in CGE :

  This process of unidirectional crystallization is using a fast variant of the BRIDGMAN's method.

  The cost analysis indicates that the add-on cost of silicon wafers has to be reduced from the present 80 $ 300-400/m^2 to less than 80 $ 25/m^2.

  Some basaltic structured semicrystalline silicon blocks are obtained giving 10 % efficiency cells.

  The potentiality is quite competitive to HEM or SEMIX methods.

5-3 Improvement of Wafer Processing and Encapsulation of Modules

This item can be split into 3 parts :

- Diffusion process, key for high efficiency.
- Metallization of contacts, key for performance and reliability.
- Encapsulation of modules, key for reliability.

The three French producers work on new different technologies in cooperation for some items with research laboratories such as :

In diffusion processes :

. Out of thin solid discs.

. In implantation and damage removal by thermal annealing.

. Laser induced diffusion.

. All over screen printing diffusion process.

In metallization of contacts :

. Screen printing with Ag postes.

. New Cu or Ni postes cheaper than Ag ones.

. Plating of electroless Ni.

The three French companies are sponsored for :

. Automatisation of diffusion process.

. Setting up in production screen printing for contacts.

. Cheaper or better encapsulation.

Other objectives are studied by other system producers such :

. Management of photovoltaic energy in function of Applications.

. New converters, from direct to alternative current, fit for photovoltaic modules.

Some of these programs are also sponsored by CCE in close cooperation with COMES.

It is anticipated that achievement of these goals will make photovoltaic systems economically competitive with alternative energy sources for dispersed on-site applications from 10 W to 100 KW.

7 - APPLICATION OF PHOTOVOLTAIC ENERGY -

PROJECTION OF MODULE AND SYSTEM COST

The inherent modularity of photovoltaic arrays permits power systems to be developped for power levels, ranging for a few Watts to 100 KW, today and much more in several years.

Table N° 9 shows typical application for a range from a few Watts to 10 KW.

Table N° 10 indicates non-exhaustive list of applications led by irrigation pumps and electrification of remote villages or habitations.

These two applications will cover about 90 % of module production.

The weight of module cost in an overall cost of a photovoltaic system is about 50 %, but it can vary from 10 % to 90 % depending on applications.

Information is already given on water pumping or electrification of hospitals (SAN in MALI, for example) or villages.

Other applications will be now briefly discussed :

7-1 Solar generators for educational television

Designed and built under the direction of TDF (TELEDIFFUSION FRANCAISE) since 1972, hundreds of them are now being installed in black Africa, on the request of national authorities of NIGER, IVORY COAST, etc.... The consumption profile for black and white TV is about 35 Watts, 40 hrs a week; this corresponds to an array of 50 peak-Watts (0,5 m^2). Such a system is considered to be cheaper than the use of batteries in remote areas.

The cost of modules was 37 % of the total cost : $ 38.00 in 1977, $ 22.00 in 1979 and less today with a new TV with 18 Watts (12V x 1,5 A) and one 33 W module.

7-2 Solar powered telecommunication systems

Since 1971, the "Centre National d'Etude des Télécommunications" (CNET) has been involved in the development of solar powered communication systems. A first 12 Watts system (16 panels of 8 peak-Watts each, associated with a 900 A.h. battery) was built in LA TURBIE, near NICE, and is still operating. At the same site of Southern FRANCE was completed in 1976 a power station for a standard 1800 channel PTT relay station.

A continuous power of 200 W under 48 V has been specified. The system comprises an array of 104 panels, each delivering 10,7 peak Watts ; the array charges a battery of 720 A.h. The system is complemented by an aeolian generator delivering 300 W at a wind speed of 7 m. s^{-1} (diameter of the blades : 3,20 m) ; a 800 A-h Zn-air battery is also provided for back-up power.

The cost of module was about 10 % of the overall price.

7-3 Radio Beacons

The Air Navigation Technical Service (S.T.N.A.) which is responsible for the continuing improvement of radio navigation systems, has been interested in the production of electrical energy by photovoltaic cells since 1967. Since 1968, a 100 km range radio beacon marking the PARIS-BORDEAUX air route, located at St-GIRONS, has been operating with solar panels.

The installed power is 300 Wp.

The system was made in 1965 with the second generation of RTC modules and it has been running for 15 years and other stations have been installed.

7-4 Light Beacons in MEDINA Airport

MEDINA Airport in SAUDI-ARABIA is located on a plateau in a mountainous area. Aircraft approach is difficult due to the proximity of rocky peaks, which need to be marked at night with beacons.

Supplying power to the beacons by electric cable would be expensive due to the difficulty of the terrain and the distance from the airport.

In 1973 the seven peaks were equipped with beacons fed by solar generators.

The peak power is 48 W. Figure 7 gives some views of application.

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- PROJECTION OF MODULE COST

With the remarks previously made, some evaluations have been given by a French industrial (Mr. GOMIS - President of PHOTOWATT INTERNATIONAL) during the Photovoltaic Solar Energy Conference in CANNES (October 27 - 31 1980) :

in $ 1980	1 9 8 0	1 9 8 5	85 - 86 DOE
Modules	10-12	3 - 4	0,7
Frame-wiring	2 - 3	1,2 - 1,5	
Charge regulation	2 - 3	1 - 1,5	
Batteries	3 - 4	0,8 - 1,2	1 to 2
Energy management, securities ..	2 - 4	1 - 1,8	
Commercial and Financial cost (ROI..)	5 - 7	2 - 3	
Subtotal (without modules)	14-21	6 - 9	1 - 2
Overall system cost	24-33	9 - 13	1,7 - 2,7

- PROJECTION OF SYSTEM COST

The balance of system (that is the system except modules) would represent in 1985, 2/3rd to 3/4th of the price if cost reductions in a factor two for these components are expected.

Efforts will be important to reach these goals.

The DOE cost estimations were established for a special application : home electricity supply in US territory ; that is : without battery, frame management of energy, sophisticated converters, etc... and moreover there will be no financial burden expected and local electrical companies will buy the energy excess !

So the DOE cost estimations are not valid for broad spectrum of applications, especially in the Third World where the sites are very often remote from energy supply.

In the same way, hypothesis retained for evaluation of cost of modules in the mid-term future are not the same in FRANCE, EUROPE and the US.

In the same lecture, Mr. GOMIS give these following :

	1979-1980	1985-1986 probable	1986 DOE objectives
Solar grade Si	1 to 1,1	0,25 to 0,60	0,07
Si wafers, ribbons	1,8 to 2,1	0,25 to 0,40	0,16
Si cells	2 to 2,4	0,50 to 0,65	0,22
Mounting encapsulation	1,7 to 4,5	0,50 to 0,95	0,25
Financial, commercial cost (ROI...)	3,5 to 4,7	0,75 to 1,40	?
TOTAL	10 to 15	2,25 to 4,0	0,70

Notice that the other French producers could give basically the same figure, in spite of some differences :

Implicit in the projections for cost reductions by 1985-86 are the requirements :

- to get solar grade Si at a cost about 6-7 times lower than today.

- to perfect a cheap chemical physical process in order to realize high efficiency by solar cells with low cost.

- to invest in automated production facilities and processes in order to increase all output from the present (about 0,5 MWP/year) to at least 5 MWP within 5-6 years ; that is a scaling-up by about ten !

There are a lot of conditions to fulfil and all the technology option forecast in these projections may not all be available in mid-term.

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8 FRENCH INDUSTRIAL POTENTIAL FOR PHOTOVOLTAIC ENERGY - CAPTURE POTENTIAL OF PHOTOVOLTAIC SYSTEM

French Industrial Potential for Photovoltaic Energy is already important and second in the world after the US :

- Several industrial organizations are active in the photovoltaic market all over the world.

- Three module producers are in the Market :

- RTC which is the pioneer in this activity and was alone in the world for about 10 years to supply modules for terrestrial applications.

  RTC started a module pilot line in 1961 and many systems using its modules have been running well for 10 to 15 years or more.

  The adaptation of double-glazed panels in 1974 for its fourth generation of solar modules is recognized today by experts as the ideal solution to problems to get a long term reliability in various climates espcially under tropics :

  For example, the hospital of SAN (MALI) with a 10 KW station and several hundred scholar TV equipment run well.

  According to Mr. Arthur D. LITTLE's document and ITT Research Institute, RTC is one of the four leading companies in the world with three well-known US companies : ARCOSOLAR - SOLAREX - SOLARPOWER. (See table 8).

- FRANCE PHOTON created by Moteurs LEROY SOMER, Pompes GUINARD and SOLAREX, has launched a module production line this year, but its French sponsors have a lot of experience of systems especially water pumping in black Africa.

- PHOTOWATT INTERNATIONAL S.A. created by CGE after the take over of SENSOR TECHNOLOGY Co., has set up a module production line this year and has got the experience of CIPEL which installed several hundred systems all over the world, from small units (10 W) to large ones (5KW).

  Besides, as far as concentrate silicon arrays are concerned, AEROSPATIAL planned to launch the production of SOPHOCLE 2000 (2KW) described page 7 and makes some adjustments on an airborne /heliborne prototype for remote sites difficult to reach.

  Moreover, a dozen of French companies have an experience of systems besides these four module / system producers:

- SERI-RENAULT which recently installed a 5 KWp station in a stand-alone refuge in high mountain.

- OMERA known by its high efficiency converter and by a photovoltaic remote house (1.6 KWp) near NICE.

- BRIAU one of the pioneer in water pumping in Africa fed by photovoltaic arrays.

- ELF an oil company which installed photovoltaic power stations in drilling sites for example : VHF radio-telephone links in GABON.

- SUFREAVIA, TH-CSF more specialized in solar generator in radiocommunication field (microwave links, TV relay transmittor,...)

9 CONCLUSION : CAPTURE POTENTIAL OF PHOTOVOLTAIC SYSTEM

The main problem these companies could meet is the emergence of PV from pilot lines in laboratories, this has been the significant French goverment involvement from the recognition that solar energy could be a possible alternative to the non-renewable energy resources.

But the French energy policy gives priority to nuclear energy, thanks to great industrial experience in this field and the potential nuclear energy low cost.

Thus, the possibilities of Photovoltaic Energy utilization in FRANCE (and in EUROPE, except MEDITERRANEAN countries) are weak compared to US and developing country markets which are full of potentiabilities.

So, young French photovoltaic industry has to seek markets all over the world. It's a risky job when the home market is weak compared to US producers' situation having an enormous market.

Thus, the experience acquired by French companies is in developing countries and it is said that this experience is up to now the best in the world (maybe more than 500 photovoltaic systems installed).

With their experience in numerous sites and under many climates, French industrials agreed that the cost of modules, systems and KWH depend on application or goal.

The "magic figures" given by the D.O.E. (Department of Energy - US Federal Government) are considered a fantastic challenge for the future, but they don't correspond to an industrial reality at medium range (1985/86).

The "D.O.E. magic figures" for 1985 are given for home applications and the model is a system made with "shingle modules" on the roof of the house, a rustic converter connected to local grid and it is planned that local companies of electricity have to buy excess photovoltaic home electricity.

This US system model is completely different from complex systems installed in tropics by FRANCE or European countries. They use high efficiency converters, alternative current generators, management of energy and storage of this energy.

Morever, there are differences between production cost and price.

US balance of system cost sometime includes some indirect costs and return of industrial investments, but in addition commercial price must include :

- Recovery of Research and Development costs.
- Cost of engineering.
- Cost of quality and process control.
- Return of total investment (R.O.I.).
- General expenses.
- Capital renumeration.
- Financial cost (storage...).
- Commercial cost, etc...

So it is more reasonable to use coefficient of 1,5 to 2 apllied to production cost to get commercial price.

These remarks should'nt be taken as pessimistic.

On the contrary, realism has to try to identify better the real and economical application of Photovoltaic Energy.

At each price level, Photovoltaic Energy is a possible alternative to a new renewable energy source, depending on the distance of the site from energy supply and of the energy capacity (in KWp) needed.

For example, water pumping in rural desertic sites, electrification of remote villages are the best examples in which Photovoltaic Energy would be the right alternative.

Don't forget that there are :

- A lot of applications all over the world, in Radiocommunication for example.
- More than 50 % of black African villages which need water.
- More than 1 million villages in INDIA without electricity.
- More than 1,5 billion inhabitants in the Third World whose unique source of energy is a limited Biomass energy (wood, manure...).

Sot it's an urgent human problem to help at once as much as possible these populations, without waiting for the arrival of very low cost magic Photovoltaic modules in setting Photovoltaic systems.

In conclusion , I would like for you to think about possible solutions to this problem and maybe the sight of these curve numbers showing the decreasing (historic and future) price of modules in relation with the price of a fuel baril could help you to find a solution. (Figures 12 - 13).

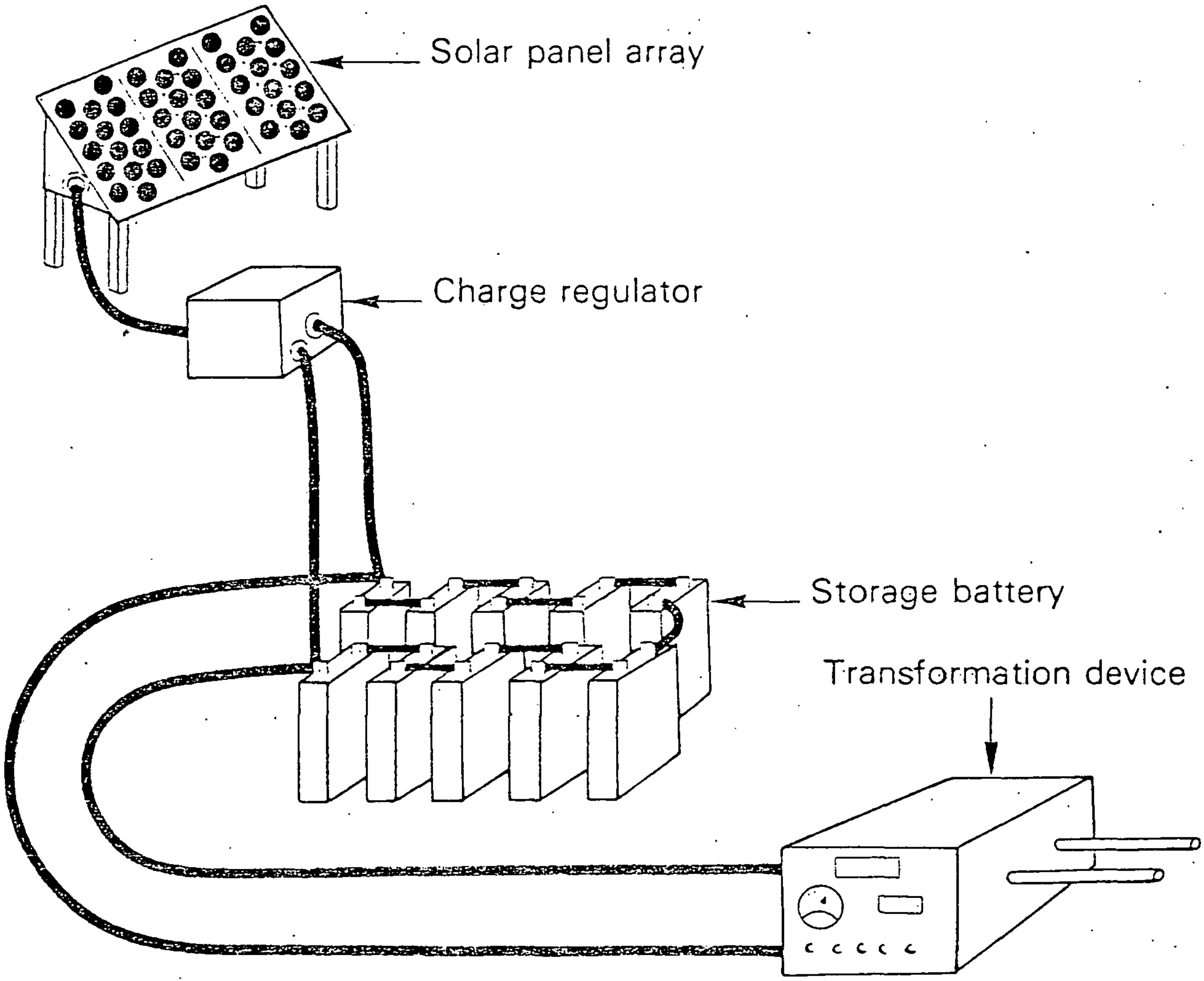
x

x x

PHOTOWATT
INTERNATIONAL S A

Solar energy

Photovoltaic generators



Advantages

Reliability	No moving parts
Nearly maintenance free	1 annual inspection by non specialist personnel
Modularity	Easily modified if power requirement change
High flexibility	Provide electricity anywhere (no utility extension)

Disadvantages

New technology

Fig 2

PHOTOWATT
INTERNATIONAL S.A

Solar energy

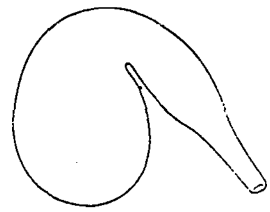
Process flow diagram

Sand

Chemical processing
Distillation

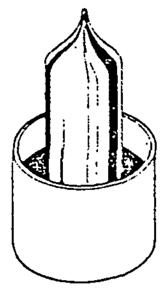
Gas (SiH_4)

Thermal decomposition
Si deposit



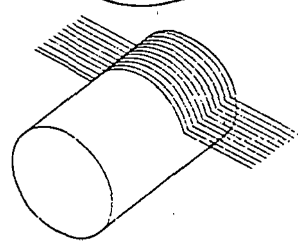
High purity silicon polycristral

Silicon ingot growth



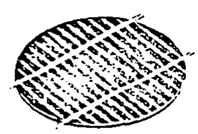
Silicon single cristal

Sawing - Polishing



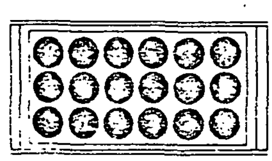
Wafer (200μ)

Doping - Contacts deposit
Antireflection coating



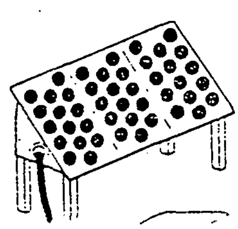
Cell

Assembly and encapsulation



Module

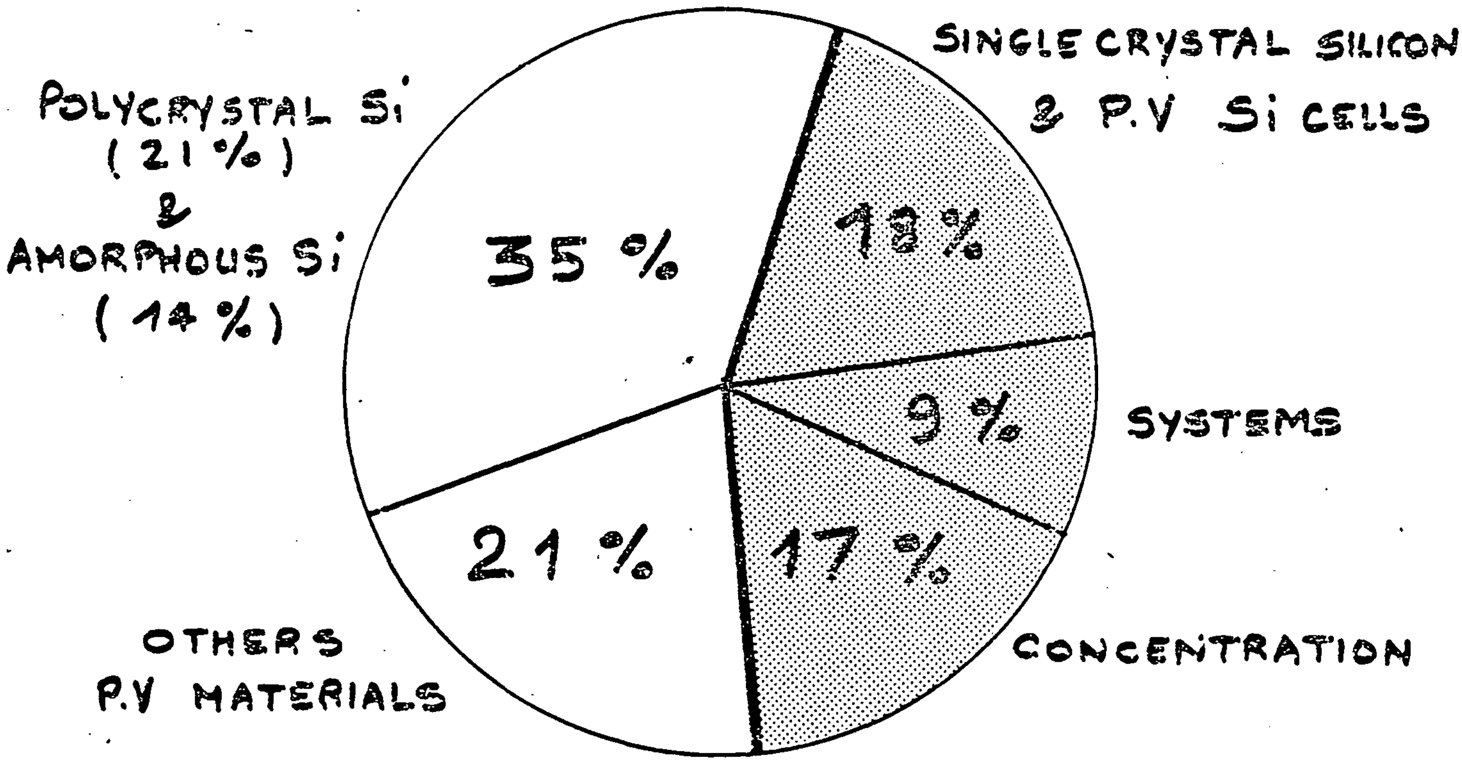
System sizing
Mechanical and electrical assembly



Generator

FRENCH R&D 1976 - 1977 BUDGET

(10 millions $)

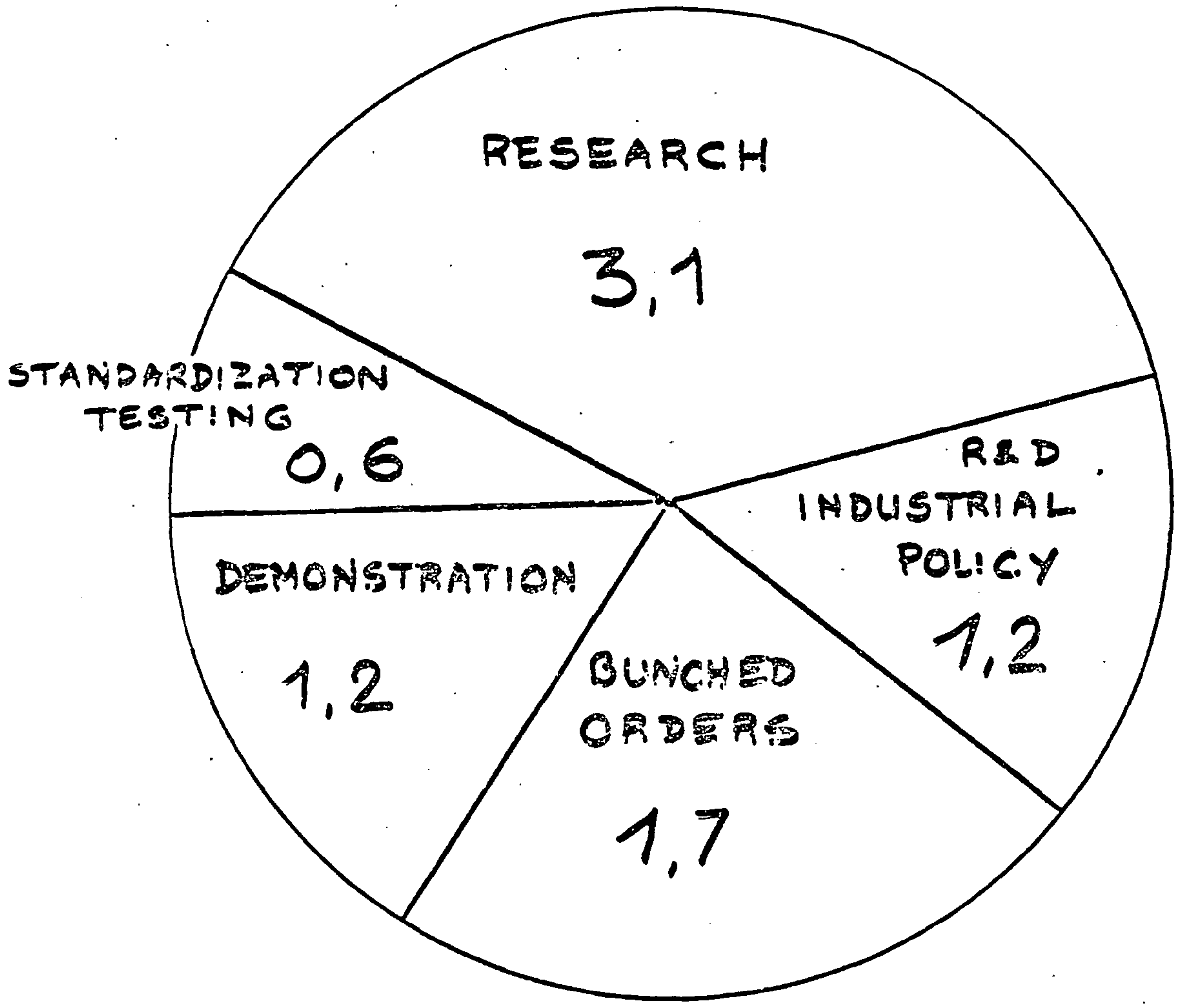


MID TERM
FAR TERM } 56 %

NEAR TERM 44 %

COMES PHOTOVOLTAÏC BUDGET
(Million $)

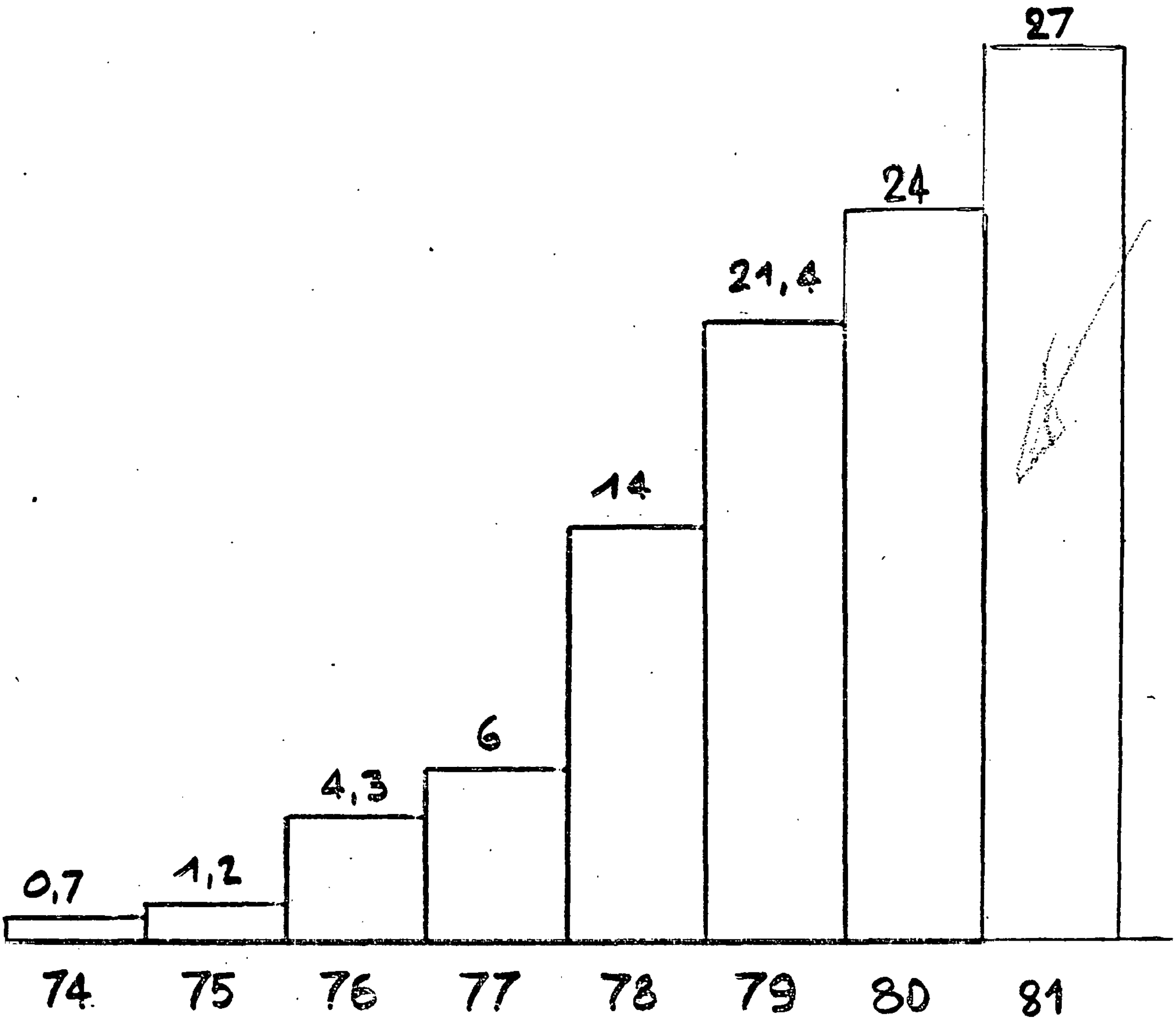
1980



COMES INVESTMENT FOR PHOTOVOLTAÏC RESEARCH -1980- (Thousand $)

FIELD OF RESEARCH	COMES SUBSIDY (P.V. COMMITTEE)	
	1979	1980
SOLAR GRADE POLY Si	19	825
MONOCRYSTAL Si	218	715
RIBBON Si	203	383
CELLS		
CELLS WITH SEMICRYSTALS	24	98
CONTACTS		112
N-P JUNCTION	465	440
ENCAPSULATION	325	340
CONCENTRATION		
OPTIC	251	62
FLUORESCENCE		73
P.V SYSTEMS	286	119
RESEARCH	476	369

ANNUAL INDICES OF FRENCH PHOTOVOLTAÏC ACTIVITY
(Estimation of total budget - million $)



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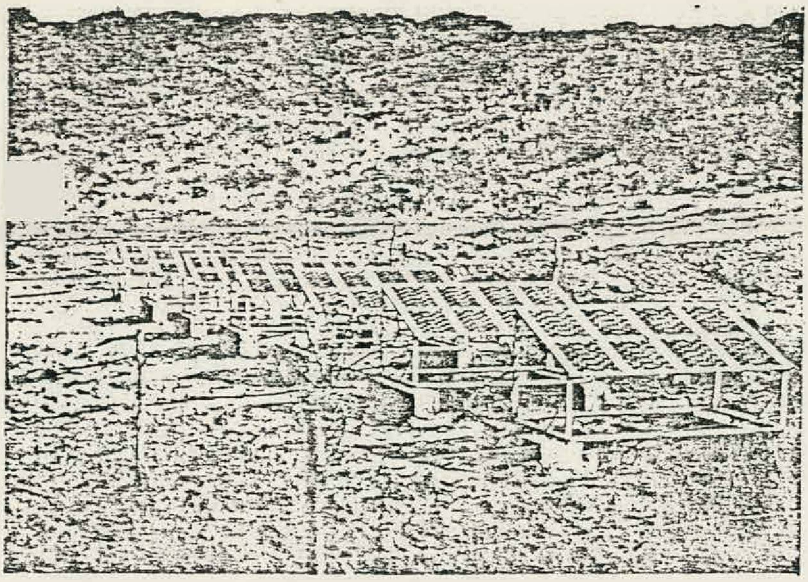


Agricultural water pumping
peak power range 500 W - 5 KW
no storage battery

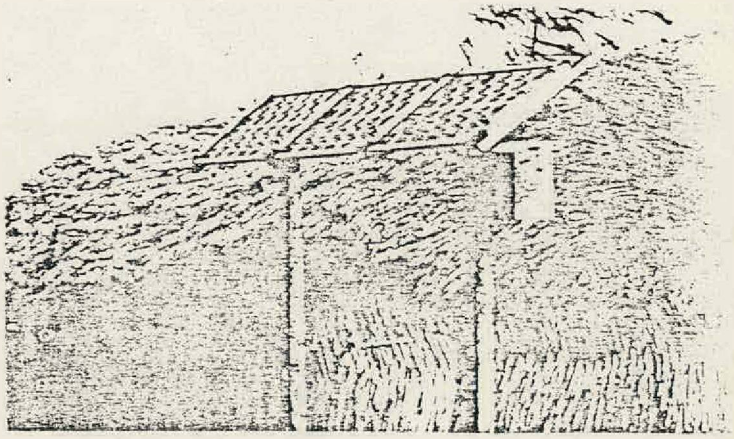
First station 1974 - CORSICA

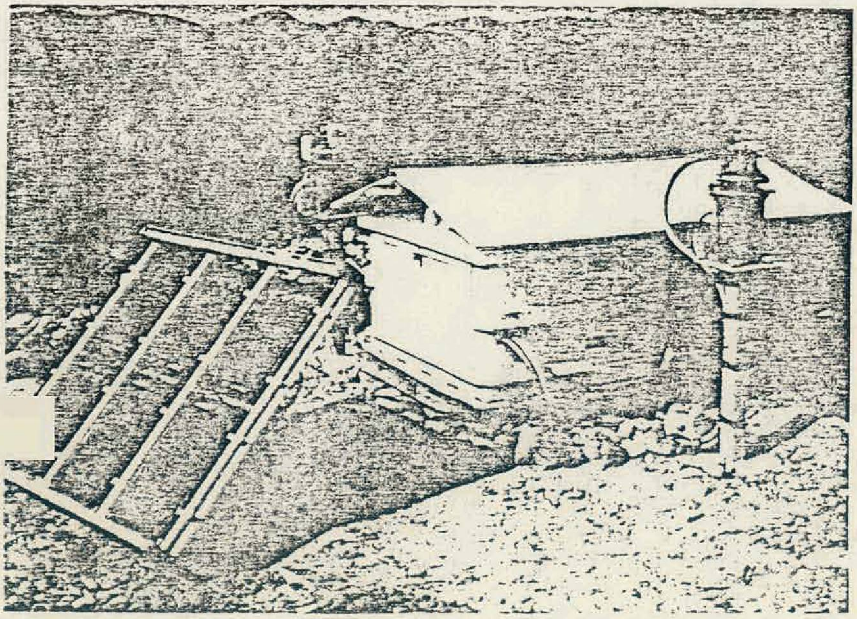
Station in CORSICA (Mediterranéan site)

Pear power 616 W - water flow 16m3/day

Educational television in NIGER
(Black Africa)
peak power 33 W programmed operation 25 h/week
Storage battery 200 Ah

First station in 1968





Light beacons in Medina Airport
in SAUDI ARABIA
Peak power 48 W
Average power 6 W

Seven stations in 1973

. Project "Arc_en_ciel".

FIG 7

Nb.	CONVERSION EFFICIENCY η	(AM1)	- Gaps -	(C≃1000)				
1	32 %	1.4						
2	44 %	1.0	1.8					
3	50 %	1.0	1.6	2.2				
4	54 %	0.8	1.4	1.8	2.2			
5	57 %	0.6	1.0	1.4	1.8	2.2		
6	58.5%	0.6	1.0	1.4	1.8	2.0	2.2	
7	60 %	0.6	1.0	1.4	1.8	2.0	2.2	2.6

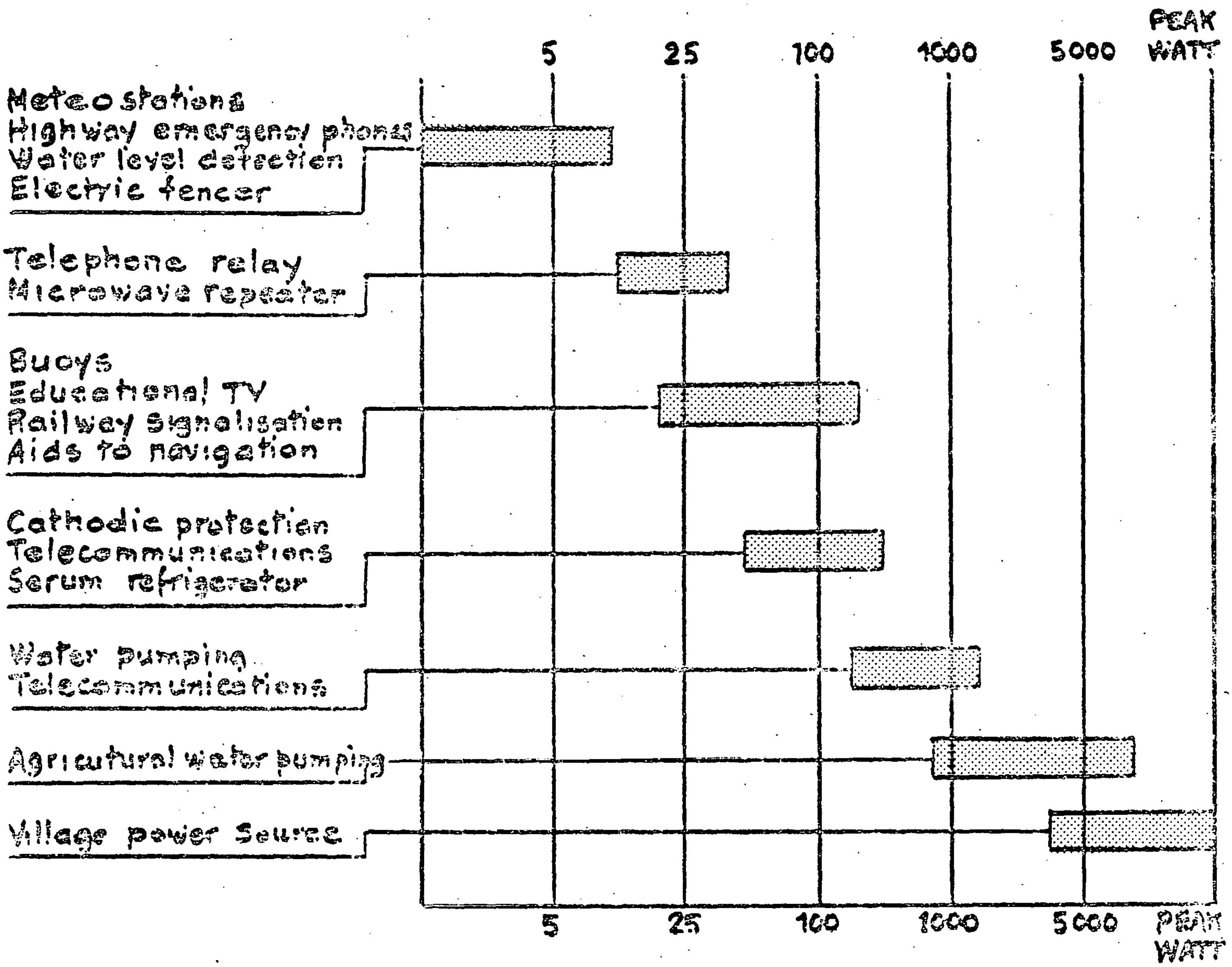
- $\eta^{eff.} \simeq \eta^{ideal} \times (0.75 \text{ to } 0.80)$

- Photopiles based on GaAs
  - Bicolore_Ge : 39.5 %
  - Bicolore_GaInP : 41.4 %
  - Tricolore Ge_GaAs_GaInP : 48.5 %
  - Tricolore Ge_GaAs_GaAlAs (1.8 eV) : 47,5 %
  - Ideal : Quadricolore.

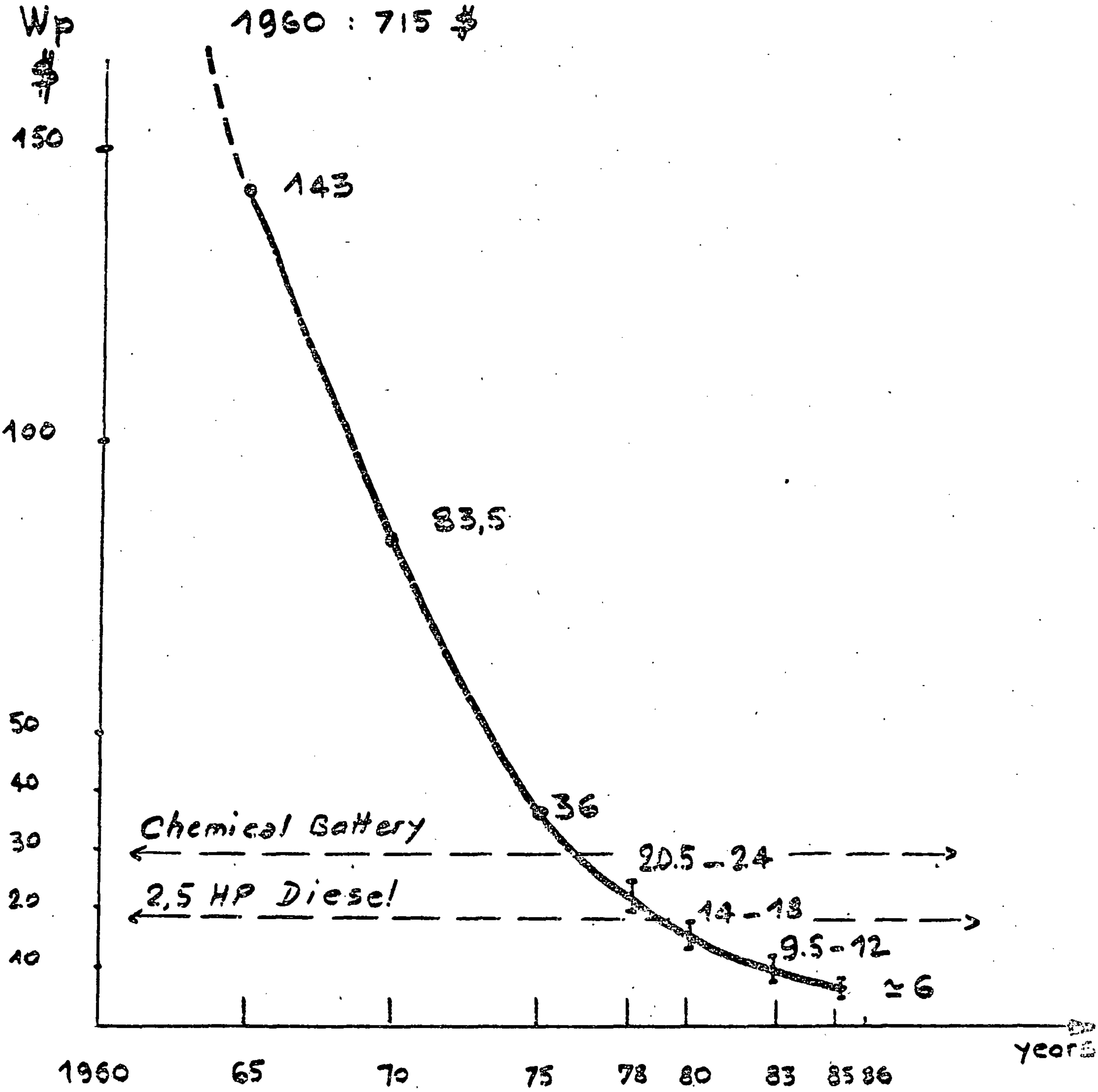
ESTIMATED 1985 APPLICATION CAPTURE POTENTIAL OF PHOTOVOLTAÏC SYSTEMS (%)

AGRICULTURE	IRRIGATION PUMPS	72 %
VILLAGE ELECTRIFICATION	REFRIGERATION OF FOOD FOOD PRESERVATION (Drying) VENTILATING FANS PUMPING POTABLE WATER RURAL TELEVISION RURAL LIGHTING WATER TREATMENT AIR CONDITIONING	18 %
RADIO-COMMUNICATIONS	RAILROAD SIGNALS CONTROLS TELEVISION BLACK-UP TO UTILITY MILITARY REMOTE REPEATERS	6 %
OTHERS	BOATS - SAILBOATS PORTABLE WATER PACKS CORROSION CONTROL OUTSIDE LIGHTING ELECTRIC VEHICLES WITH SOLAR THERMAL CONSTRUCTION TRAILERS WARNING/FLASHING LIGHTS POOL PUMPS PORTABLE MEDICAL MACHINES	4 %
TOTAL		100 %

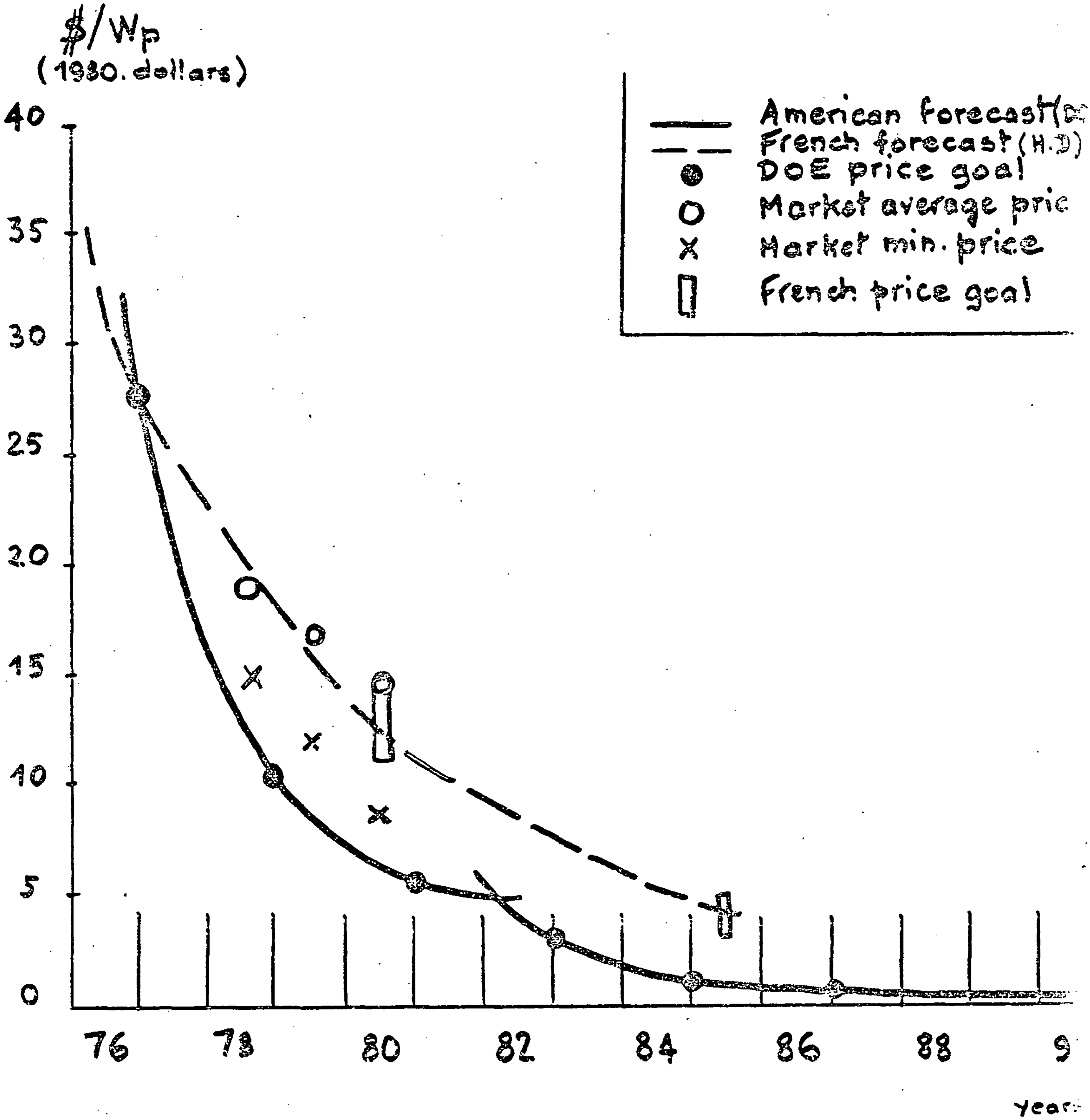
PHOTOVOLTAÏC SYSTEM APPLICATIONS



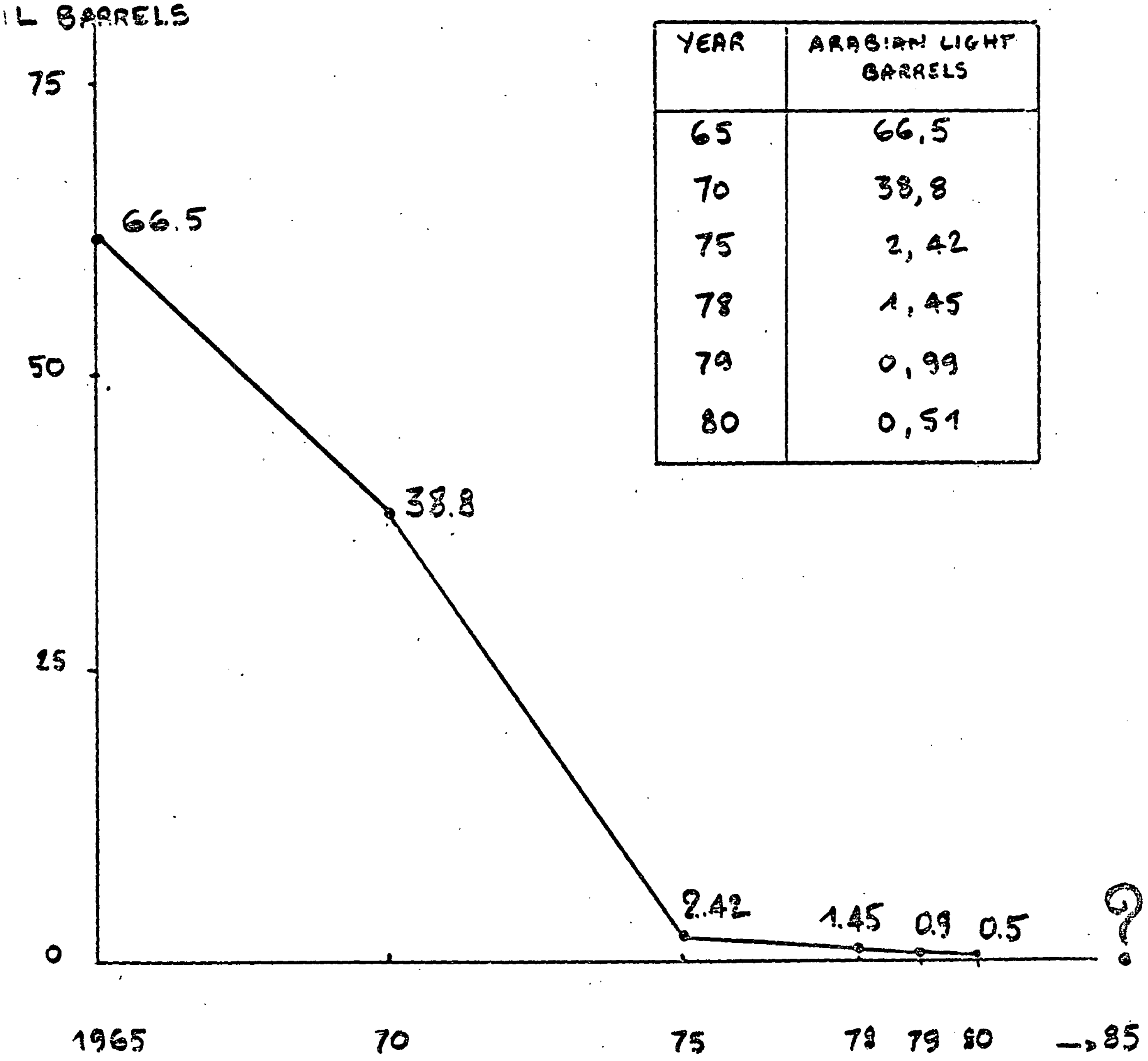
EVOLUTION OF MODULE Wp PRICE



MODULE PRICE



1 Wp COAST f(OIL BARREL)



YEAR	ARABIAN LIGHT BARRELS
65	66,5
70	38,8
75	2,42
78	1,45
79	0,99
80	0,51

ESTIMATION OF CAPACITY / PRODUCTION OF PHOTO-CELLS FOR TERRESTRIAL APPLICATIONS

	74	75	76	77	78	79	80
	Peak kW				Peak MW		
FRANCE	10	15	40	80	0,15	0,40	0,80
U.S.A.	10	30	150	600	0,9	2	4
TOTAL WORLD	20	50	200	700	1,2		

Source : DGRST / COMES PV ACTIVITY REPORT

ESTIMATED WORLD SALES OF LEADING PHOTOVOLTAÏC MODULE PRODUCERS - 1979 -
(Factory-level sales for terrestrial use only)

COMPANY	SALES RANGE MMS	APPROXIMATE MARKET SHARE (%)
ARCO	7 - 10	25
SOLAREX	7 - 10	25
SOLAR POWER (EXXON)	5 . 7	17,5
R.T.C. France	5 - 7	17,5
MOTOROLA	2 . 3	7
ALL OTHERS	3 - 5	8
TOTAL	29 - 42	100

Source : . ITT Research Institute
. Arthur D. Little (May 27. 1980)