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SPACE ORBITING LIGHT AUGMENTATION REFLECTOR ENERGY SYSTEM

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Presentation to the NASA COUNCIL
April 22, 1977
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(NASA-TM-74960) SPACE ORBITING LIGHT AUGMENTATION REFLECTOR ENERGY SYSTEM (SOLARES) (NASA) 59 p

N78-71490

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SPACE ORBITING LIGHT AUGMENTATION REFLECTOR ENERGY SYSTEM (SOLARES)

OVERVIEW

- REASONS FOR STUDY
- HISTORY OF SPACE MIRRORS
- SYNOPTIC EXAMINATION OF THE SPACE-TERRESTRIAL SYSTEM
- TECHNOLOGY CHALLENGES AND POSSIBLE PAYOFFS
  - MIRRORS
  - ORBITS
  - GROUND STATIONS
  - REPRESENTATIVE ECONOMICS
  - INCREMENTAL IMPLEMENTATION
  - MULTIPLE/SIMULTANEOUS USE
  - ENVIRONMENTAL IMPACT
- AREAS OF FUTURE STUDY
- ACTION OPTIONS

SOLARES
- CONCLUSIONS -

- A COST EFFECTIVE ALTERNATIVE TO SPS AND CONVENTIONAL POWER SOURCES
- COULD ABATE WORLD'S FOSSIL FUEL USAGE BY SUPPLYING ALL ELECTRIC POWER
- REQUIRES LARGE INPUT CAPITAL BUT INCREMENTAL DEVELOPMENT POSSIBLE
- MAJOR COST ASSOCIATED WITH GROUND FACILITY - NOT SPACE
- SIGNIFICANT, SIMULTANEOUS NON-POWER APPLICATIONS EXIST
- CRITICAL ISSUES ARE: CONTROL, MIRROR FIGURE , MICRO WEATHER CHANGES
- NUMEROUS OPTIONS AND DEVELOPMENT PATHS NECESSITATE IN-DEPTH STUDY

SPACE MIRRORS - HISTORY

I. HERMANN OBERTH

1929 - 'WEGE ZUR RAUMSCHIFFAHRT', 1957 - 'MAN INTO SPACE'

DISCUSSES:

GENERAL SPACE MIRROR CONCEPT

SPACE FABRICATION - SPACE POWER STATION, MINING MOON AND ASTEROIDS

APPLICATIONS: ILLUMINATION, WEATHER AND FOOD GROWTH MODIFICATION, MILITARY

II. KRAFT A. EHRICKE

1975 - 'SPACE PRODUCTIVITY, NEW OPTIONS FOR THE FUTURE'

DISCUSSES:

LUNETTA - ILLUMINATION, $I \simeq I_0/4 \times 10^4$

PSPE SOLLETA - PHOTOSYNTHESIS AND ILLUMINATION, $I \simeq I_0/5$

} LOW ORBITS, INTERMITTENT

SOLLETA - POWER GENERATION, GEO, $I \simeq (0.5\text{-}0.75) I_0$, CONTINUOUS

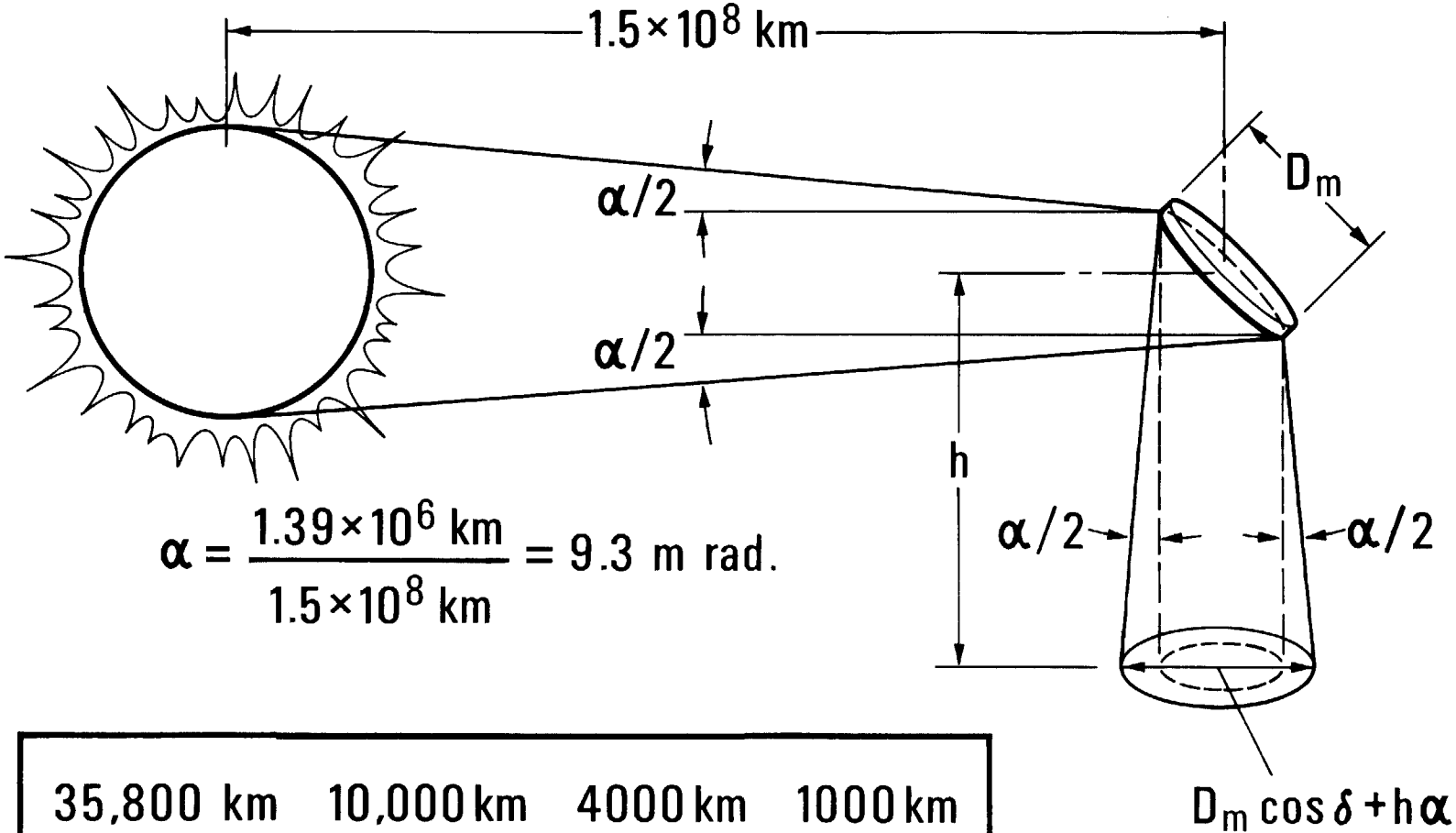
SOLARES
NEW CONCEPTS STRESSED IN THIS STUDY

- THE KEY IMPACT THAT A SPACE SYSTEM WHICH PROVIDES CONCENTRATED AND CONTINUOUS INSOLATION CAN MAKE ON THE ECONOMIC VIABILITY OF SOLAR ENERGY CONVERSION
- THE INCORPORATION OF RECENT ADVANCES MADE IN LOW AREAL DENSITY, LARGE SPACE STRUCTURES
- THE EXTENSIVE USE OF RADIATION PRESSURE FOR TRANSPORTATION AND POSSIBLE USE FOR MIRROR CONTROL AND NEW ORBITS

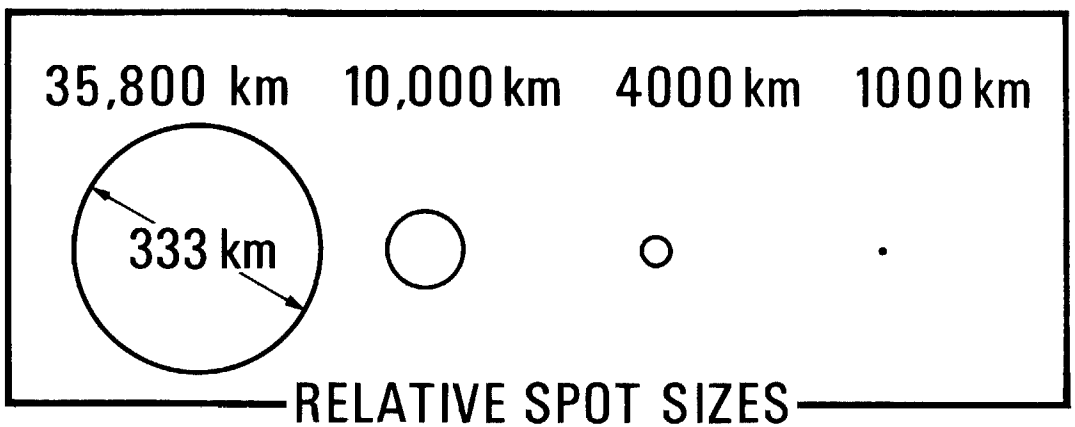
MINIMUM GROUND SPOT RELATION

The basic mirror (lens) equation fixes the object and image size ratio; the image must subtend at least the same angle at its mirror-distance as the object does. Thus, the ground spot size of the sun reflected by a mirror in geostationary orbit is immense, about the size of the state of Maine. Proportional spot diameter reductions occur with lessened mirror altitudes, enhancing the lower altitude orbits as far as engineering requirements for mirrors and ground stations. To provide an added solar constant (1.4 kW/m^2) to the ground spot, the mirror size must be the same size as the spot.

SOLARES
MINIMUM GROUND SPOT RELATION



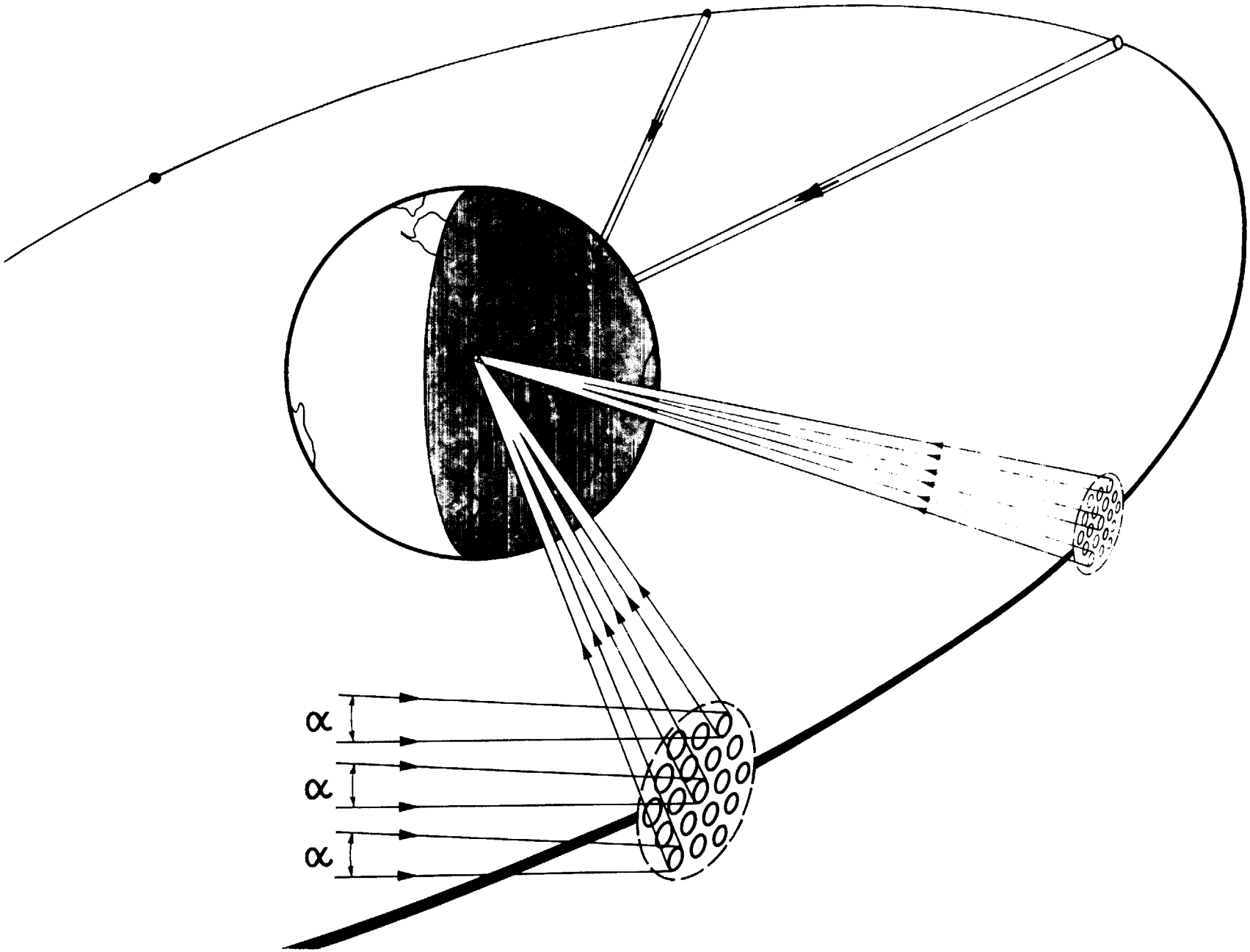
$$\alpha = \frac{1.39\times10^{6}\ \text{km}}{1.5\times10^{8}\ \text{km}} = 9.3\ \text{m rad.}$$



SATELLITE MIRROR CONCEPT

SOLARES would employ an orbit belt of mirrors, sufficient in number to ensure at least one satellite mirror always reflecting sunlight to the ground station. A given mirror after passing from view of a station would then reflect sunlight to another station.

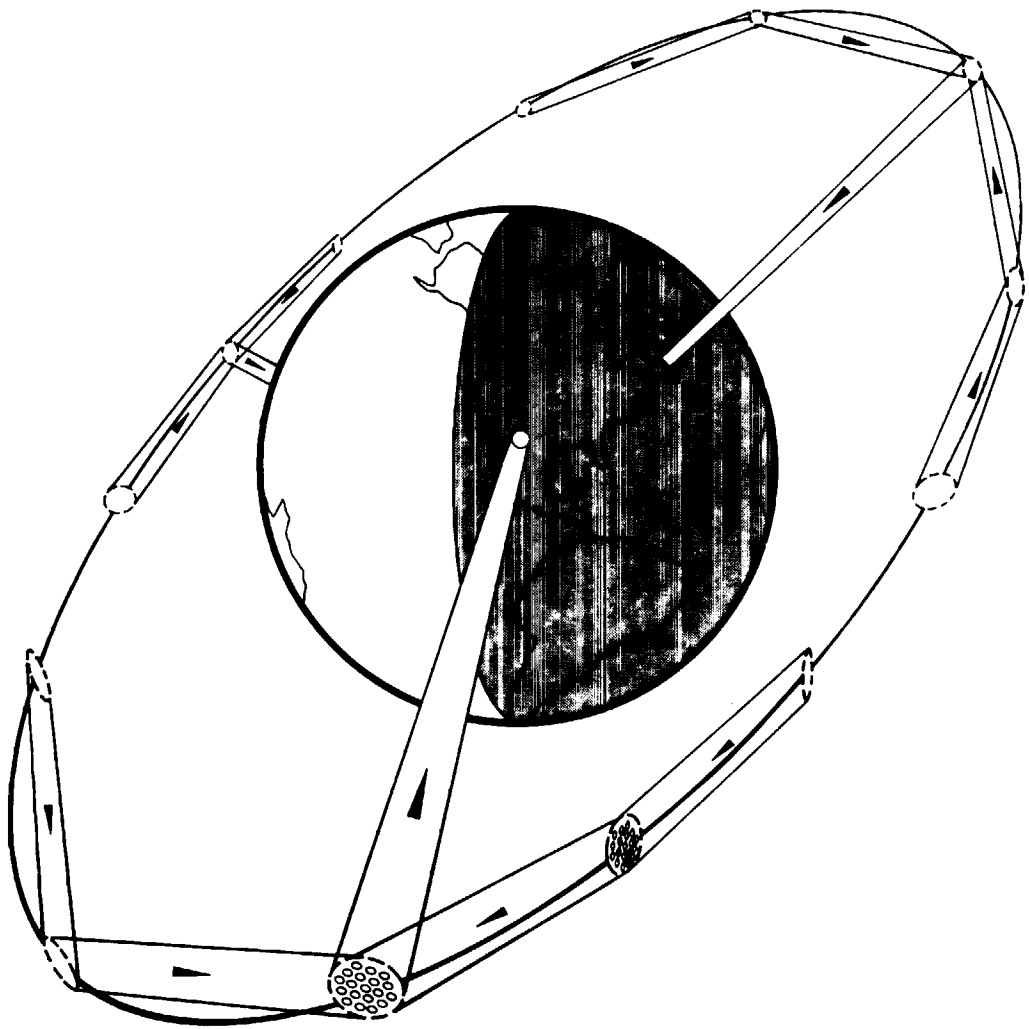
SOLARES
SATELLITE MIRROR CONCEPT



RELAY MIRROR CONCEPT

The relay concept by, perhaps, employing additional mirrors at each satellite mirror cluster or by active optics, would reflect sunlight from out-of-view mirrors to a master mirror passing over the station. Thus, for a fixed mirror size the radiation at the receiving station would be enhanced. By this concept more effective use could be made of all the mirrors in a belt, but the number of ground stations in simultaneous use would be reduced.

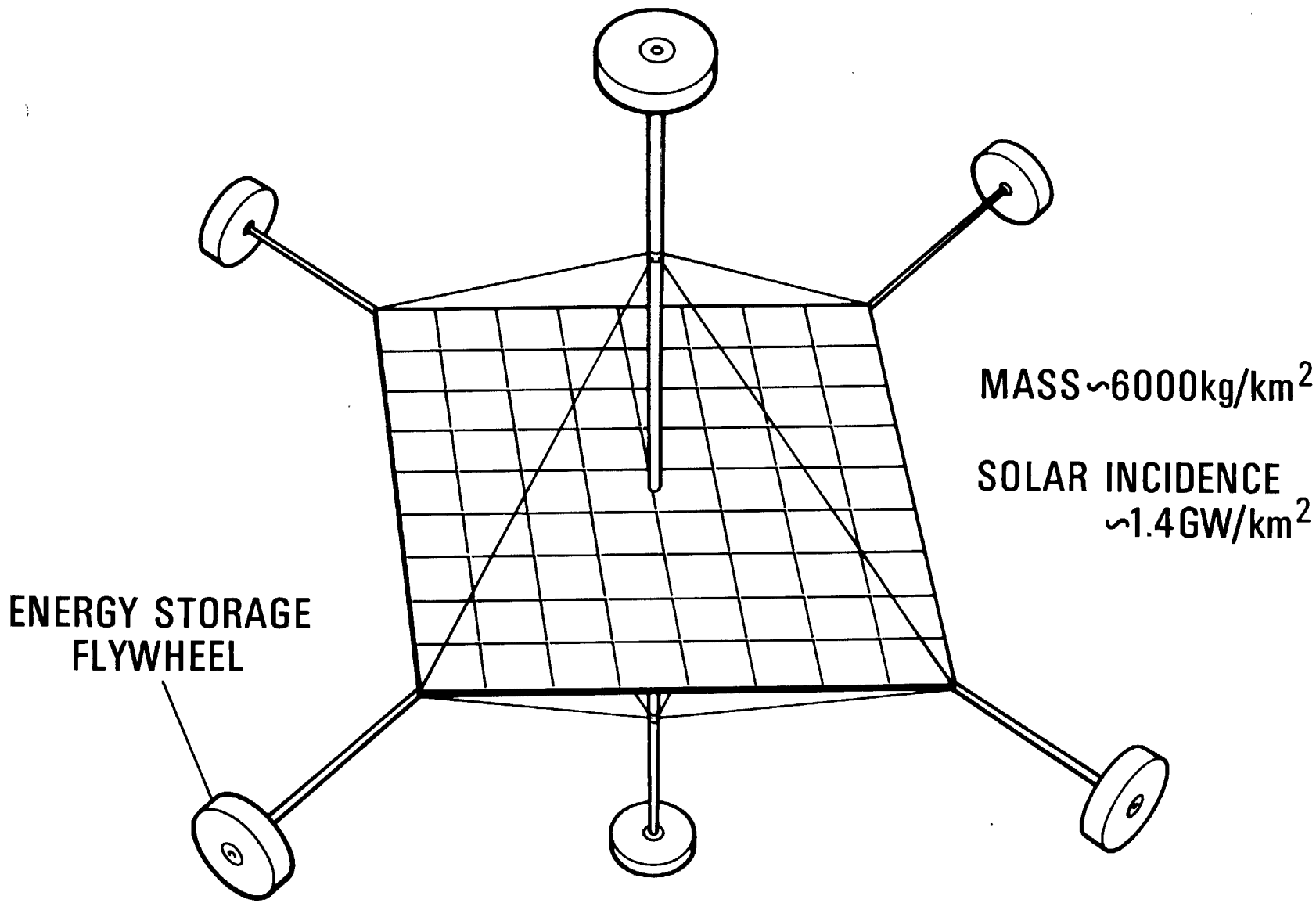
SOLARES
RELAY MIRROR CONCEPT



SCHEMATIC OF A CLUSTER MIRROR

A possible configuration of a mirror, probably faceted, is shown. The proper size has not yet been determined nor the number or placement of control devices (thrusters). Flywheels, which could be charged with small motors operating off of solar cells or by radiation pressure, are advantageous because of their low weight to energy storage ratio (requiring less than 1% of the total system mass) and they require no renewable propellants. For one solar constant radiation at the ground station a number of these free flyers would be required to act together as a single parabolic mirror.

SOLARES
SCHEMATIC OF A CLUSTER MIRROR

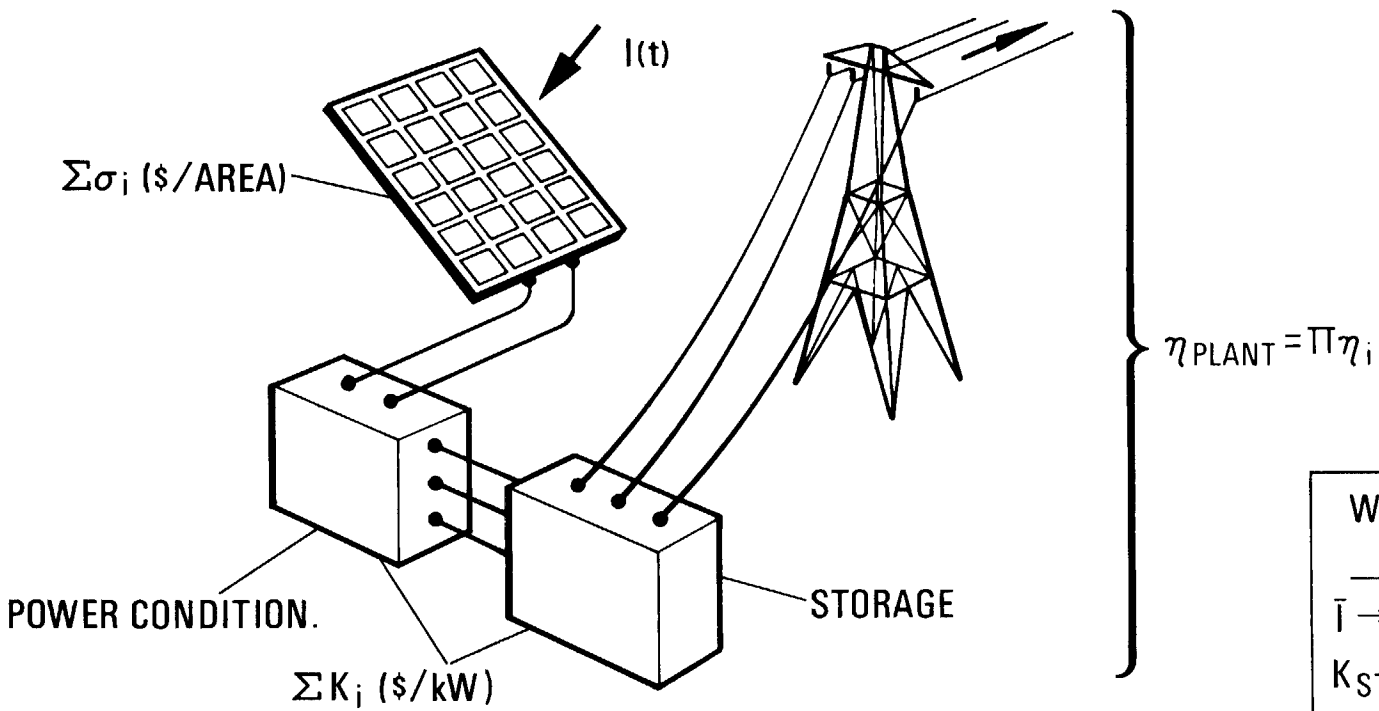


IMPACT ON ECONOMICS OF SOLAR ENERGY PRODUCTION

Conventional solar farms require three major components for operation: 1) Sunlight collection/conversion devices (solar cells or reflectors and a heat engine); 2) power conditioners for proper cycle, phase and voltage; and 3) energy storage to lengthen the power supplying hours of the facility. Power plant capital investment for a given rated power is the sum of the collector cost per unit area σ times the power it produces (duty factor, D, divided by the product of average insolation, $\bar{I}$ and overall efficiency η) plus storage, power conditioning and R&D expenditures. The energy cost, mills/kWh, is the sum of operation and maintenance charges and amortized capital investment - all divided by the hours of duty per year. The space mirror concept provides continuous insolation, which increases $\bar{I}$ by about a factor of six, reduces $K_{storage}$ to nearly zero and operates at nearly unit duty factor.

SOLARES
IMPACT ON ECONOMICS OF SOLAR ENERGY PRODUCTION

$$\frac{\text{CAPITAL INVESTMENT}}{\text{RATED POWER}} \left(\frac{\$}{kW}\right) = \frac{CI}{P} = \sum_i \left(\sigma \frac{D}{\eta \bar{I}_{in}} + K\right) + RD$$



WITH SPACE MIRRORS

$\bar{I} \rightarrow 6\bar{I}$

$K_{STORAGE} \rightarrow \sim 0$

$D \rightarrow 1$

CI RECOVERY AND PROFIT: $\frac{CI}{P}\mathcal{R} = \frac{CI}{P}\left[\frac{r}{1-\left(\frac{1}{r+1}\right)^y}\right]$

$$\text{COST OF ENERGY } \frac{\text{mills}}{\text{kWh}} = \left[\left(\frac{CI}{P}\right)\mathcal{R} + K_{OM}\right]\frac{1}{8.767\ D}$$

SOLARES
IMPACT OF ORBITING MIRRORS ON SOLAR ENERGY FIELD
II. COST REDUCTIONS

ECONOMIC LEVER	TYPICAL VALUE	VALUE WITH MIRRORS ($\bar{I}_R = 1.4$ kW/m^2, CONT.)	IMPROVEMENT FACTOR, POSSIBLE COST REDUCTION, AND OTHER BENEFITS
INSOLATION $\bar{I}$ (kW/m^2)	0.26 (U.S. MAXIMUM)	1.66	6 EASES DEMANDS ON σ, η
ENERGY STORAGE (in ΣK_i), \$/kW	$> 1/2 \left(\frac{CI}{P}\right)$	≈ 0	$> 1/2 \left(\frac{CI}{P}\right)$
DUTY FACTOR $0 \leq D \leq 1$	1/6 NO STORAGE 1/2 STORAGE	1	6, 2 } REDUCTION OF $\frac{C}{E}$
POWER DEMAND VALUE $1/3 \leq \mathcal{P}_{(t)} \leq 1$	1 U.S. NORTH 1/3 U.S. SOUTH	$\approx 1/3$	1-3 CAN MATCH OUTPUT TO PEAK LOAD DEMAND

CONCLUDE:

OM'S WILL MAKE SOLAR ENERGY AN ECONOMIC REALITY IF $(C/E)_{SPACE}$ REASONABLE.

REPRESENTATIVE SOLAR ENERGY COST REDUCTIONS

Because of low average insolation the conventional solar farm produces energy at about four times the cost of fossil or nuclear plants. The mirror system concept with continuous duty, higher average insolation and minimal storage requirements reduces the ground station energy costs by an order of magnitude. The orbital mirror itself, depending on space transportation system available, the number of ground stations it can power, and assuming one mill/kWh operation and maintenance, adds several mills/kWh to provide the nominal totals shown.

SOLARES
IMPACT OF ORBITING MIRRORS ON SOLAR ENERGY FIELD
III. REPRESENTATIVE COSTS

ALL-CASE VALUES ASSUMED

$$\begin{cases} RD=0 \\ \eta_{PLANT}=\Pi\eta_i=0.75\,\eta_{PV} \\ K_{EN.\ STOR.}=\$230/kW \\ K_{OM}=4\ mills/kWH \end{cases} \qquad \begin{matrix} r=15\%\,YR^{-1} \\ y=30\ YRS, \\ \mathcal{P}_{(t)}=1 \end{matrix}$$

	PHOTOVOLTAIC SYSTEM	η_{PV} (%)	$\sigma_{MAT.}$ ($/m^2)	$\sigma_{INST.}$ ($/m^2)	$\bar{T}$ (kW/m^2)	D	C/E (mills/kWH)
SOLAR GOAL	ERDA PHOTOVOLTAICS 'PROGRAM 1985' GOAL: $500 PEAK/kW (FIXED, TILTED ARRAY)	15	75	42.5_{av}	0.26	0.5	83.5_{av}
TYPICAL SOLAR PV	CdS HETEROJUNCTION PV (FLAT ARRAY)	7.8	2.58	22.5_{av}	0.26	0.5	70.5_{av}
SOLAR PV WITH ORBITING MIRRORS	CdS HETEROJUNCTION PV (FLAT ARRAY, CONTIN. INSOL.)	7.8	2.58	22.5_{av}	1.66	1	7.4_{av}
	ORBITING MIRROR COSTS (INDEPENDENT OF D)	(35.7)	1.50	5.4 (1980 SH) 0.57 (1992 HLLV)	1.40	D	1.24-3.36 (STS) 1.07-1.71 (HLLV)
	TOTAL SYSTEM COSTS						8.6-10.8 (STS) 8.5-9.1 (HLLV)

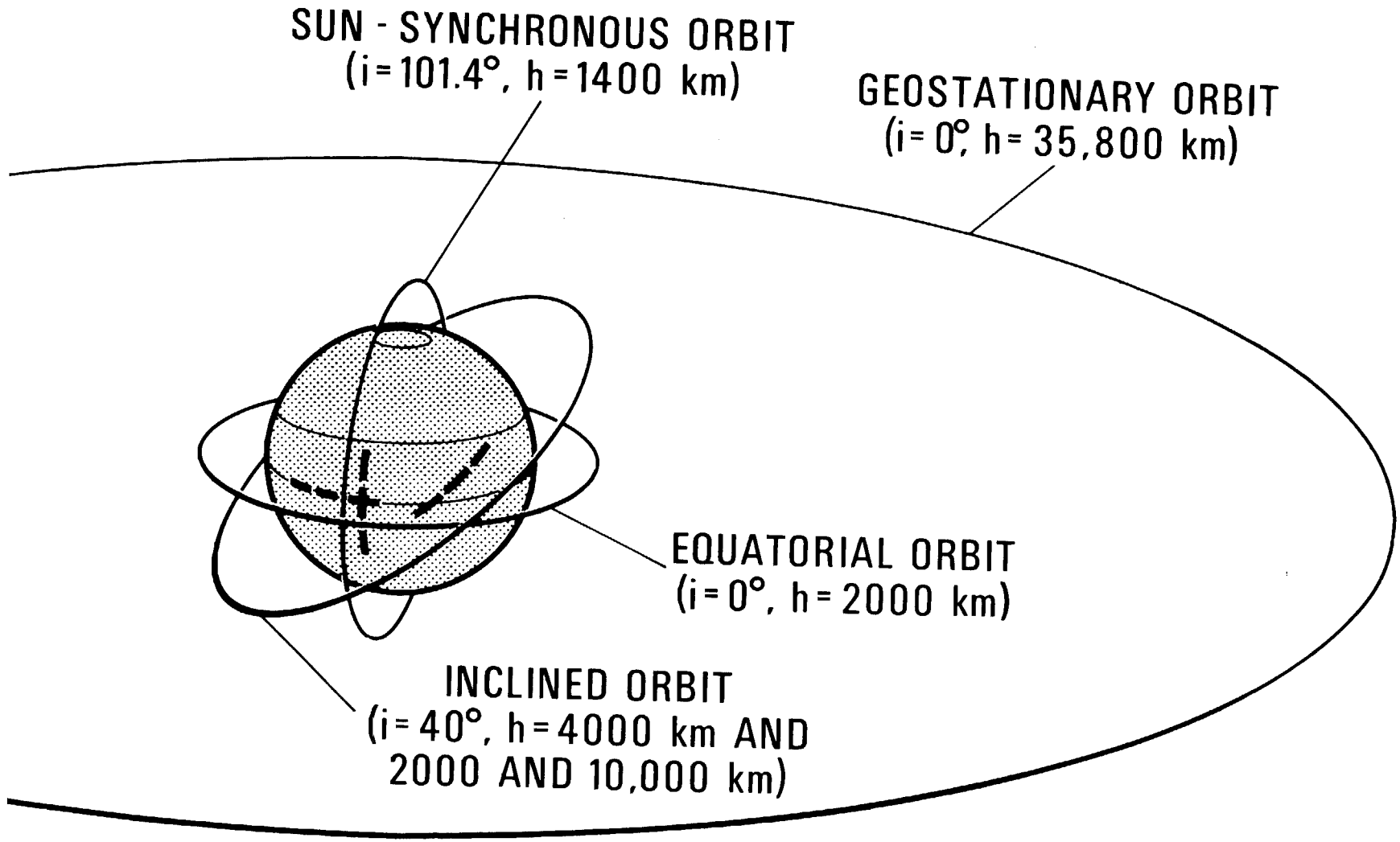
SOLARES
MIRROR CONSIDERATIONS AND CONCLUSIONS

• LARGE AREAS NEEDED	– FACETS, FREE FLYERS ($\approx 4 km^2$), SATELLITE ARRAYS – POSSIBLE REDUCTION WITH RELAY
• STRUCTURE	– SOLAR SAIL TECHNOLOGY $\sim 10^3$Å METAL OVERCOATED PLASTIC $\sigma \leqslant 6$ gm/m^2
• ENVIRONMENTAL EFFECTS	– GRAVITY GRADIENT AND CENTRIFUGAL FORCES TEMPERATURE STRESSES DURABILITY (EVAPORATIVE FIX) VAN ALLEN BELTS (?) ATMOSPHERIC DRAG
• CONTROL	– NEED $\lesssim 250 \mu$rad POINTING – RADIATION PRESSURE ASSIST
• TRANSPORTATION	– SOLAR SAIL FROM LEO ($\sim$800km) TO FINAL ORBIT

ORBITS EXAMINED

A number of potential orbits exist for the mirror system, depending primarily on the ground station location and energy desired. Thus far, the four classes illustrated have been studied.

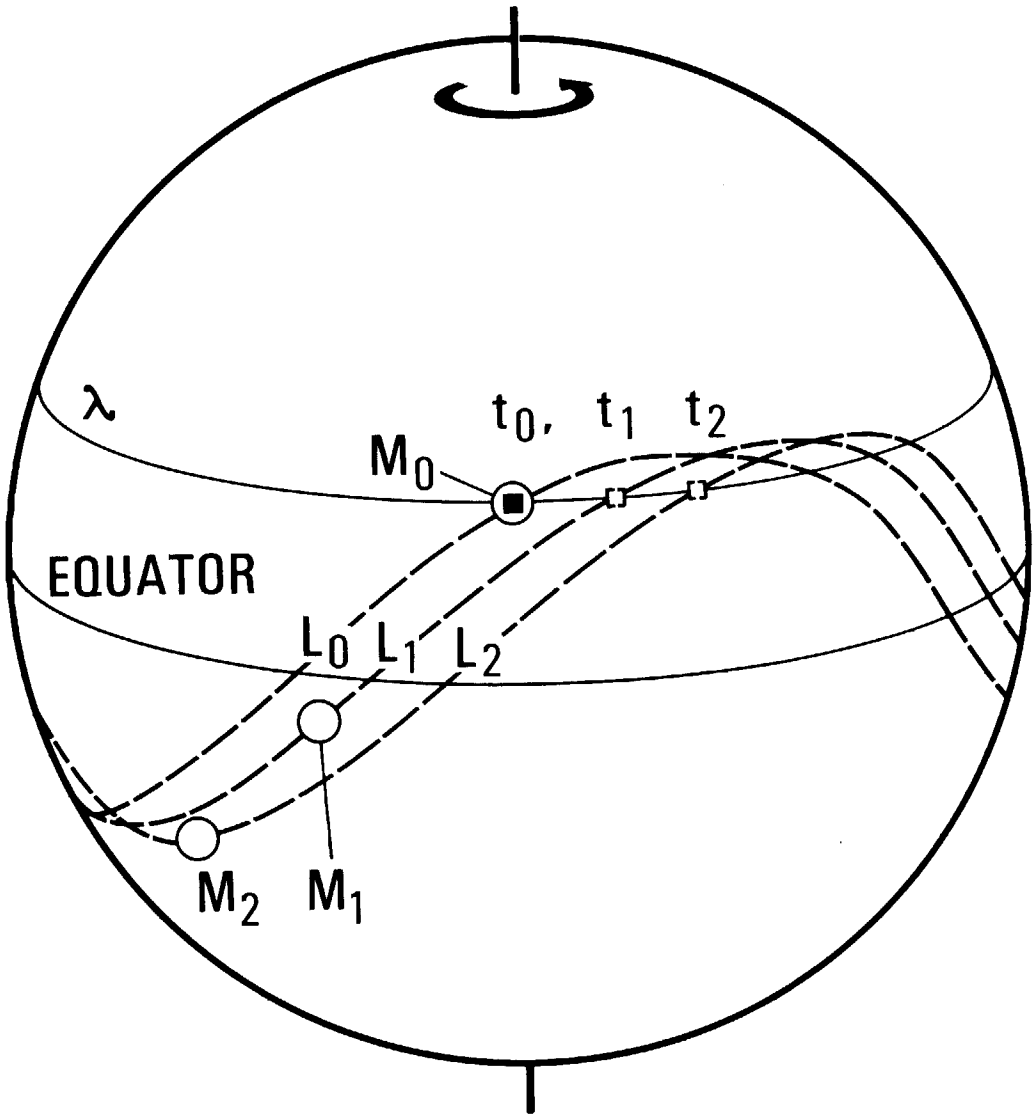
SOLARES
ORBITS EXAMINED



SEQUENCED RENDEZVOUS ORBITS

It appears that early systems, in order to supply the mid-latitudes, must use orbit planes which have about the same inclination as the maximum latitude ground station serviced. Since the Earth rotates with respect to these inclined planes, it is necessary to separate the satellite mirrors both in longitude (time) and anomoly such that successive mirrors enter the site's viewing cone as the previous one exits.

SOLARES
SEQUENCED RENDEZVOUS ORBITS

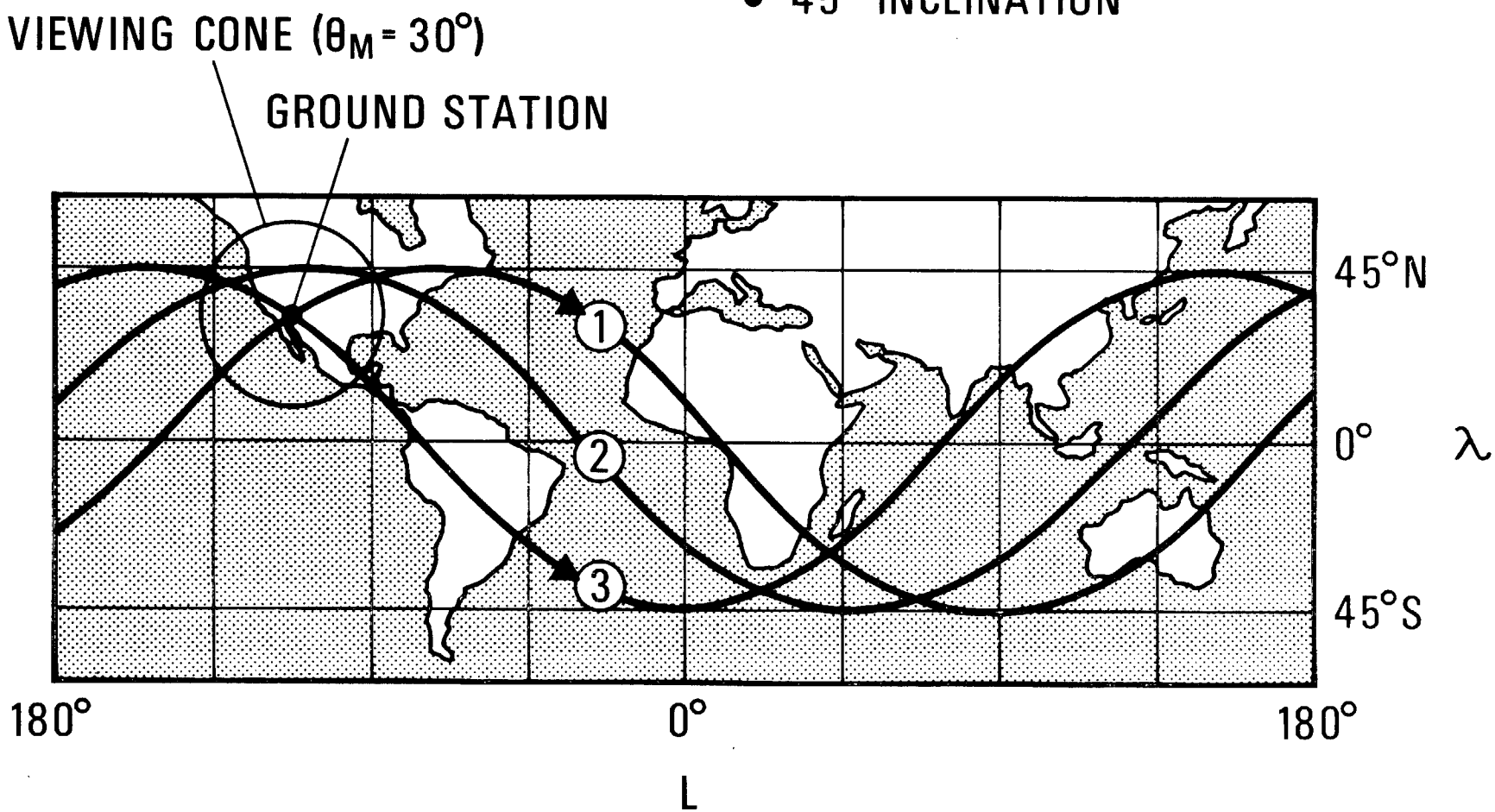


SUCCESSIVE MIRROR PASSES

The ground trace is shown from three successive mirror passes of an integer orbit mirror with a three hour period (i.e., eight orbits per day). In a 24 hour period three orbits will occur such that the mirror will be in view (above a 30° elevation) of the ground station. Two of these orbit passes, one descending and one ascending, will transit the site's zenith.

SOLARES
SUCCESSIVE MIRROR PASSES

- 3 hr PERIOD
- 4185 km ALTITUDE
- 45° INCLINATION



SOLARES
COMPARISON OF REFLECTOR POWER SYSTEM CHARACTERISTICS

ORBIT		MIRROR CLUSTERS		GROUND STATIONS		BUS POWER	CAPITAL COSTS+, $BILLIONS: EACH GROUND STATION		CAPITAL COSTS+, $BILLIONS: N CLUSTERS
ALTITUDE (km)	INCLINATION (deg)	NO. REQ'D, (N)	AREA OF EACH (km^2)	AREA OF EACH (km^2)	POTENTIAL NO., (N_t)	EACH GRD. STA. (GW)	MODEL 1 SOLAR -THERMAL	MODEL 2 CdS	MIRRORS & TRANSPORT
2000	40	54	220	370	24	48	24	14	30
4000	40	27	830	1300	11	185	88	52	56
10,000	40	9	7300	6800	5	1170	520	285	165
35,800	0	1	158,000	87,000	1	16,250	7100	3750	395
2000	0	7	500	300	7	46	21	12	8.6
1400	101.43	19	265	355	2	41	21	13.5	12.6

+DDT&E AMOUNTS TO AN ADDITIONAL $20B.

ALTITUDE SCALING LAWS FOR INCLINED ORBITS AND FULL UTILIZATION

Most principal system characteristics appear to scale directly with altitude for a system employing mirrors in an orbit(s) of given inclination. However, higher orbits do provide somewhat higher average concentration, have less shadowing problems and reduced control needs. These factors act to produce lessened energy costs (mills/kWh) from mirrors at higher altitude.

SOLARES
ALTITUDE SCALING LAWS FOR INCLINED ORBITS AND FULL USE

- TOTAL MIRROR AREA
- TOTAL GROUND STATION AREA
- TOTAL SYSTEM BUS POWER
- TOTAL CAPITAL INVESTMENT

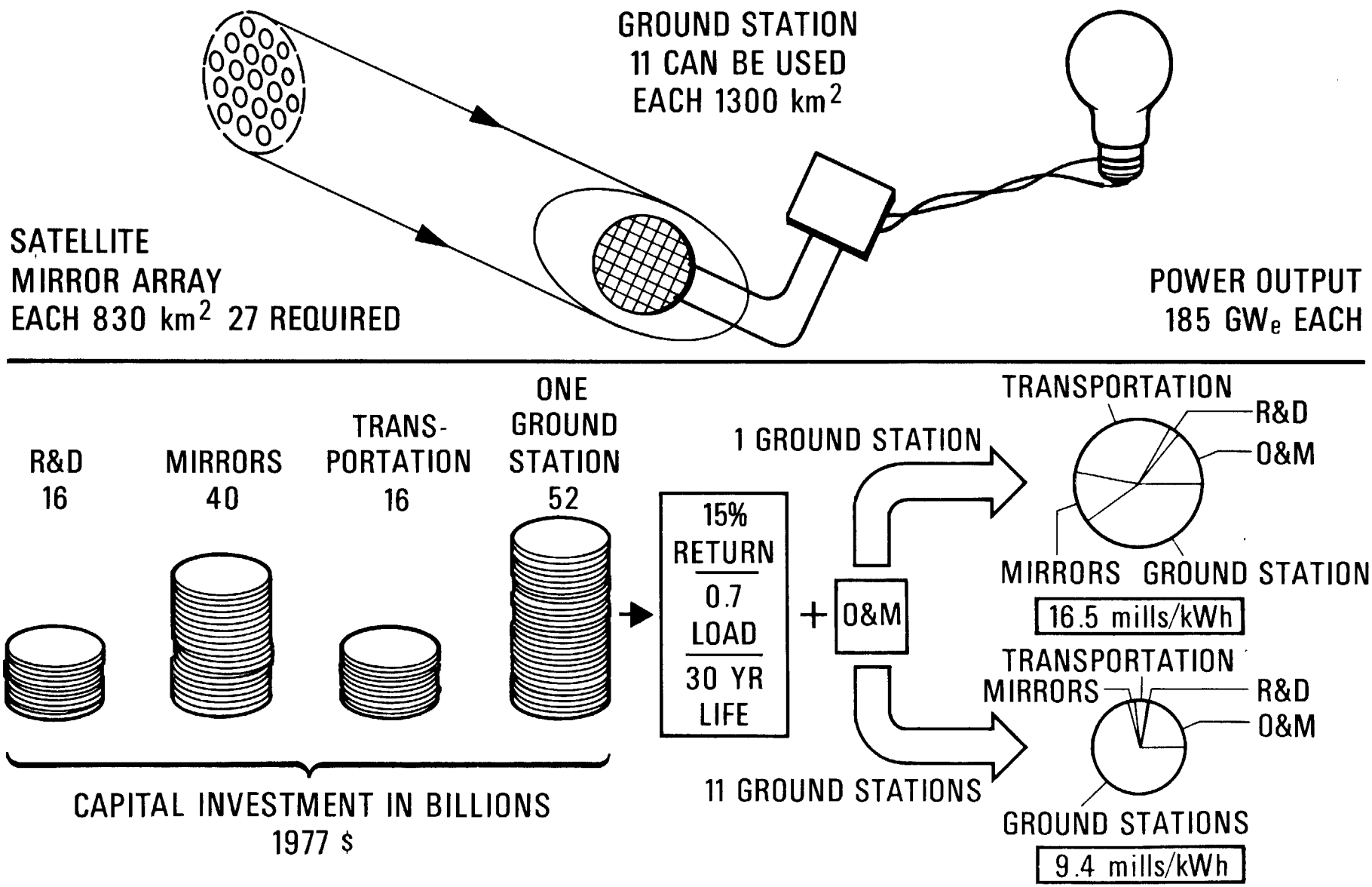
} SCALE ALMOST DIRECTLY WITH ALTITUDE

- HIGHER ALTITUDES GIVE LESS TEMPORAL AND SPATIAL VARIATION OF INSOLATION

SPACE MIRROR POWER SYSTEM CHARACTERISTICS

Resultant system characteristics as predicted for post-1990 operation, are shown for a particular orbit option taking into account transmission losses, beam spread, ground station efficiency, etc., (overall direct sunlight to bus power conversion is about 5%). Eleven ground stations, each producing 185 GW, provide more energy than all the world's presently installed generating plants. Bus power cost for the optimum system (eleven stations) is about one-half that of nuclear or fossil plants in the U. S.

SOLARES
SPACE MIRROR POWER SYSTEM CHARACTERISTICS ~ 1990
FOR A 4000 km, 40° ORBIT AND PHOTOVOLTAIC GROUND STATION



ORBITING REFLECTOR SYSTEM COST BREAKDOWN

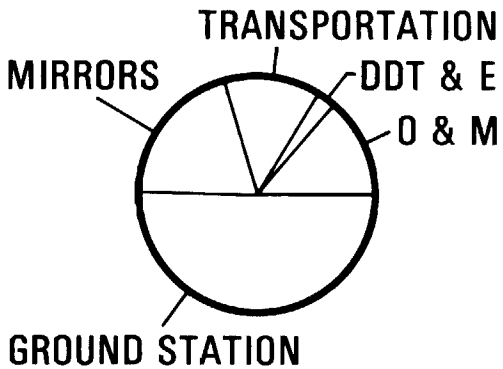
Using the orbit case of the preceding chart, cost breakdowns for several development options are indicated. Ground station costs are seen to be the predominant component. Area of the pies represent relative energy costs. (Somewhat higher O&M and R&D charges were assumed in the costing model employed here, than were used in the previous chart.)

SOLARES
ORBITING REFLECTOR SYSTEM COST BREAKDOWN

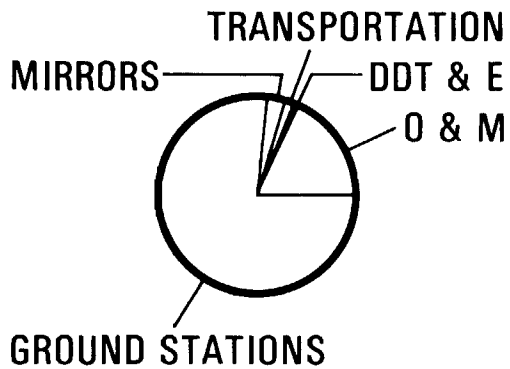
• 4000km ALTITUDE • 40° INCLINATION

SOLAR THERMAL CONVERSION

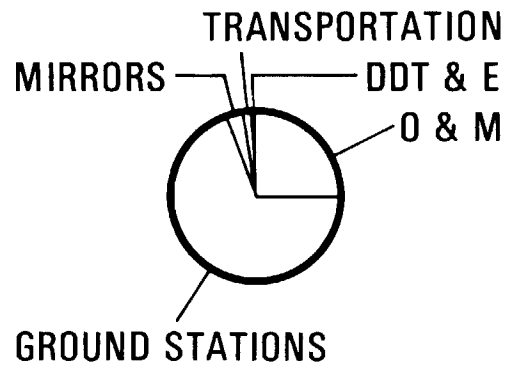
22.9 Mills/kWh



15.5 Mills/kWh

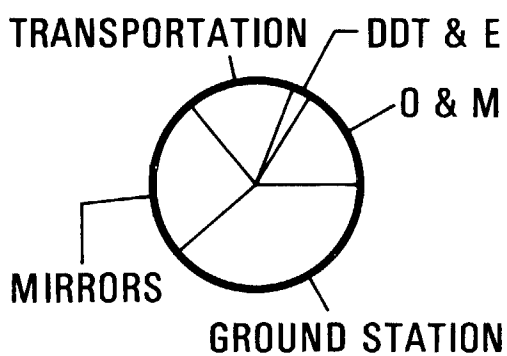


12.1 Mills/kWh

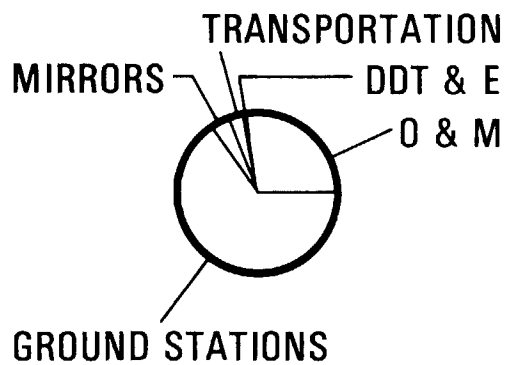


$CdS\text{-}Cu_2S$ PHOTOVOLTAIC CONVERSION

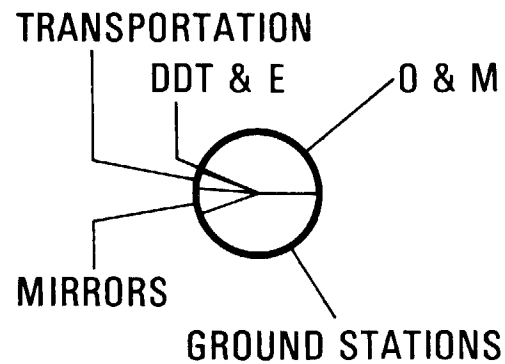
18.1 Mills/kWh



10.7 Mills/kWh



6.6 Mills/kWh

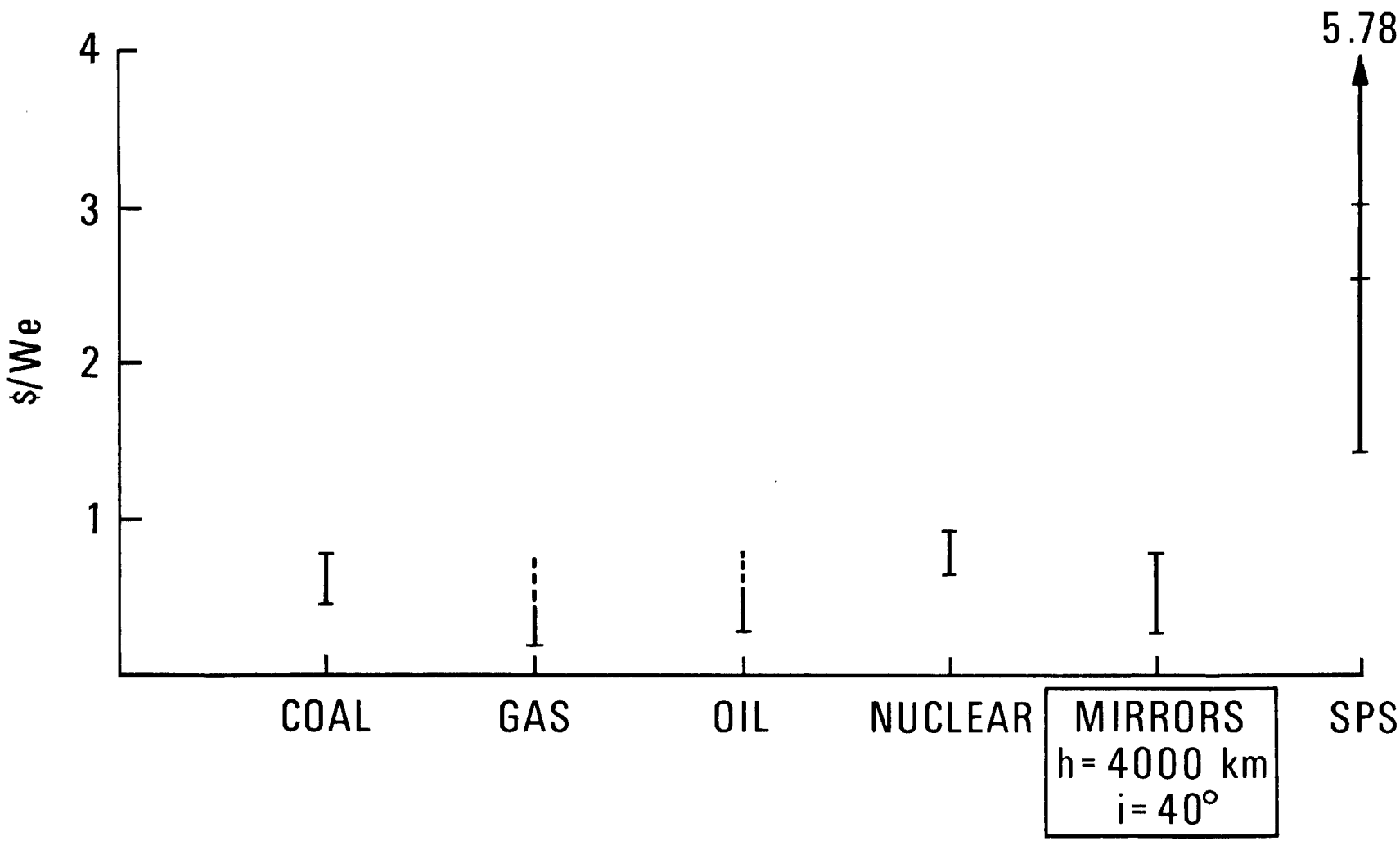


SINGLE STATION	ELEVEN STATIONS	ELEVEN STATIONS FIVE SOLAR CONSTANTS

ELECTRIC PLANT CAPITAL COSTS

Capital investment requirements for unit rated capacity are compared for variously fueled electrical generating facilities. The SPS value was taken from "Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts," Vols. I & II, JSC-11568, NASA, L. B. Johnson Space Center, Aug. 31, 1976. For the SPS the middle bands represent the nominal cost range.

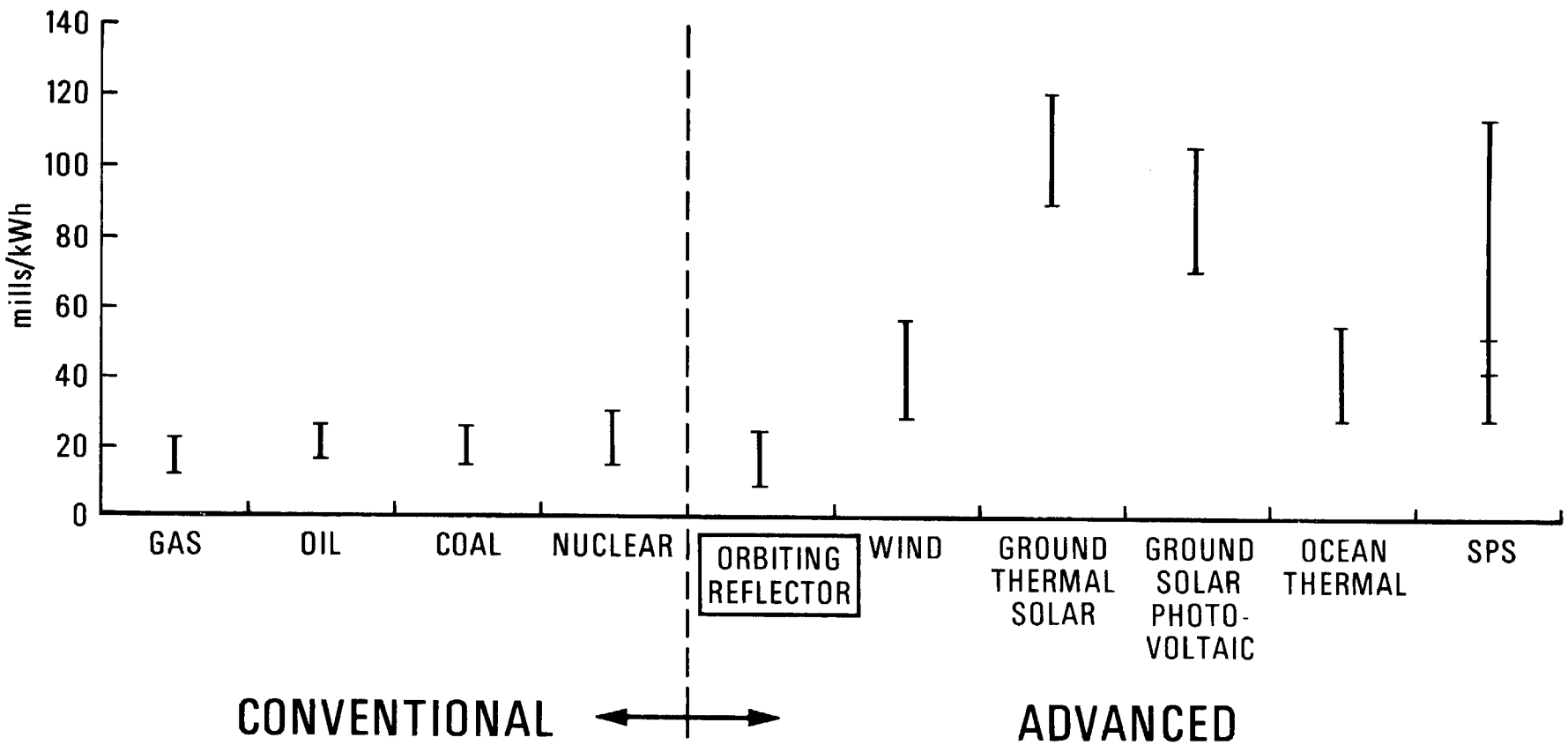
SOLARES
ELECTRIC PLANT CAPITAL COSTS (1976 DOLLARS)



ELECTRICAL ENERGY BUSBAR COST

Expected energy costs derived from SOLARES are highly competitive with both conventional and future systems. The illustration was taken from the previously referenced JSC report with the bar representing the orbiting reflector concept added.

SOLARES
ELECTRICAL ENERGY BUSBAR COST (1976 DOLLARS)

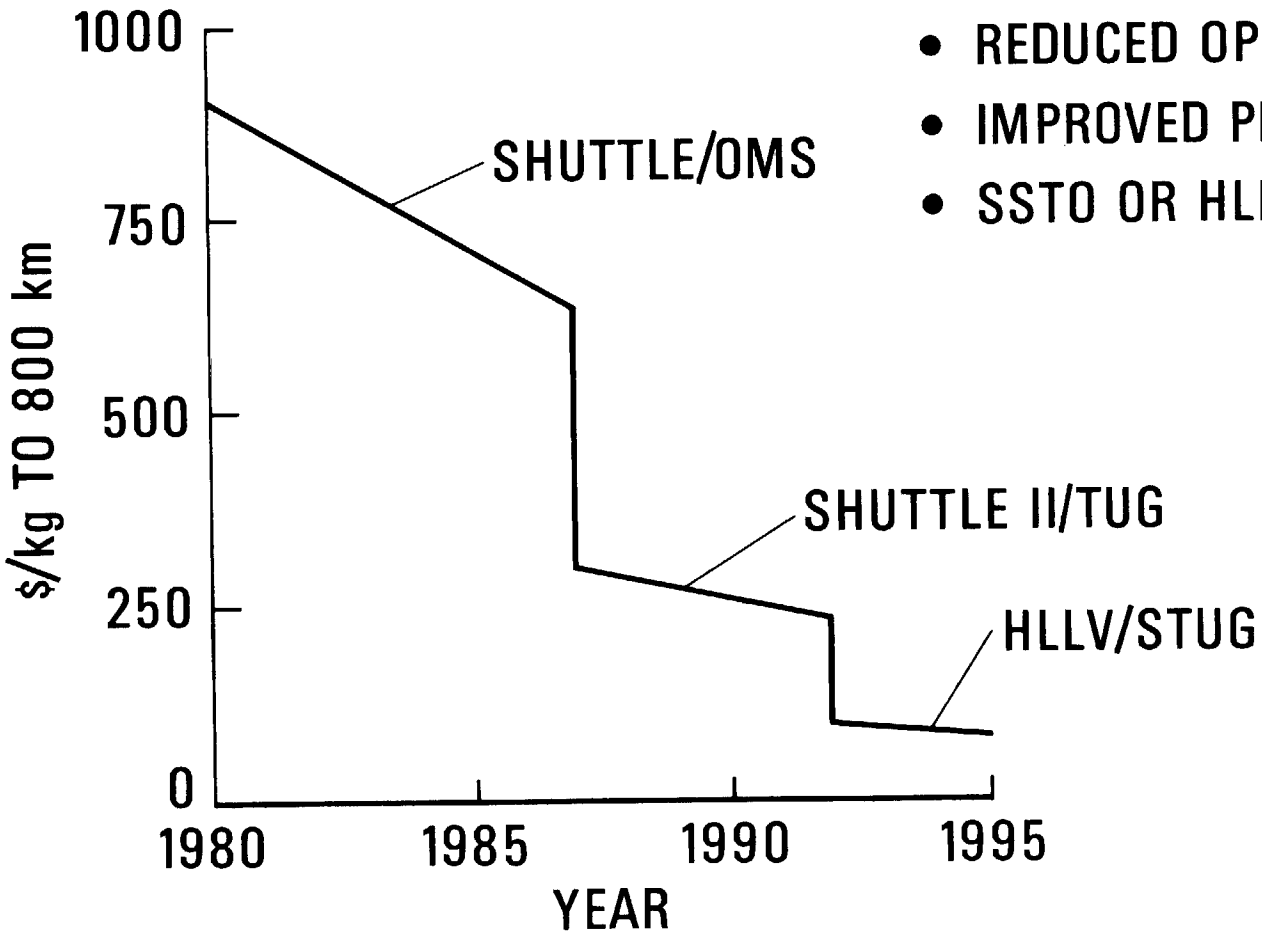


SPACE TRANSPORTATION COSTS

The following four charts present principal costing elements of SOLARES; transportation, mirrors, ground stations and operation and maintenance. These are given as a function of time to gauge the cost of implementation of the full system at a given period and to illustrate the impact of expected technology growth and improved operations on the overall costs.

Future transportation costs were derived from "Outlook for Space" and other mission scenarios. The plot reflects both improvements expected in operation of a given space transportation system and step advances made as new generations of craft are introduced. HLLV costs based on the SOLARES traffic model are roughly twice that of SPS costs. It is expected that achievement of 800 km altitude will permit the mirrors to be solar sailed to operational orbit.

SOLARES
INCREASE EFFECTIVE POWER THROUGH REDUCED TRANSPORT COSTS

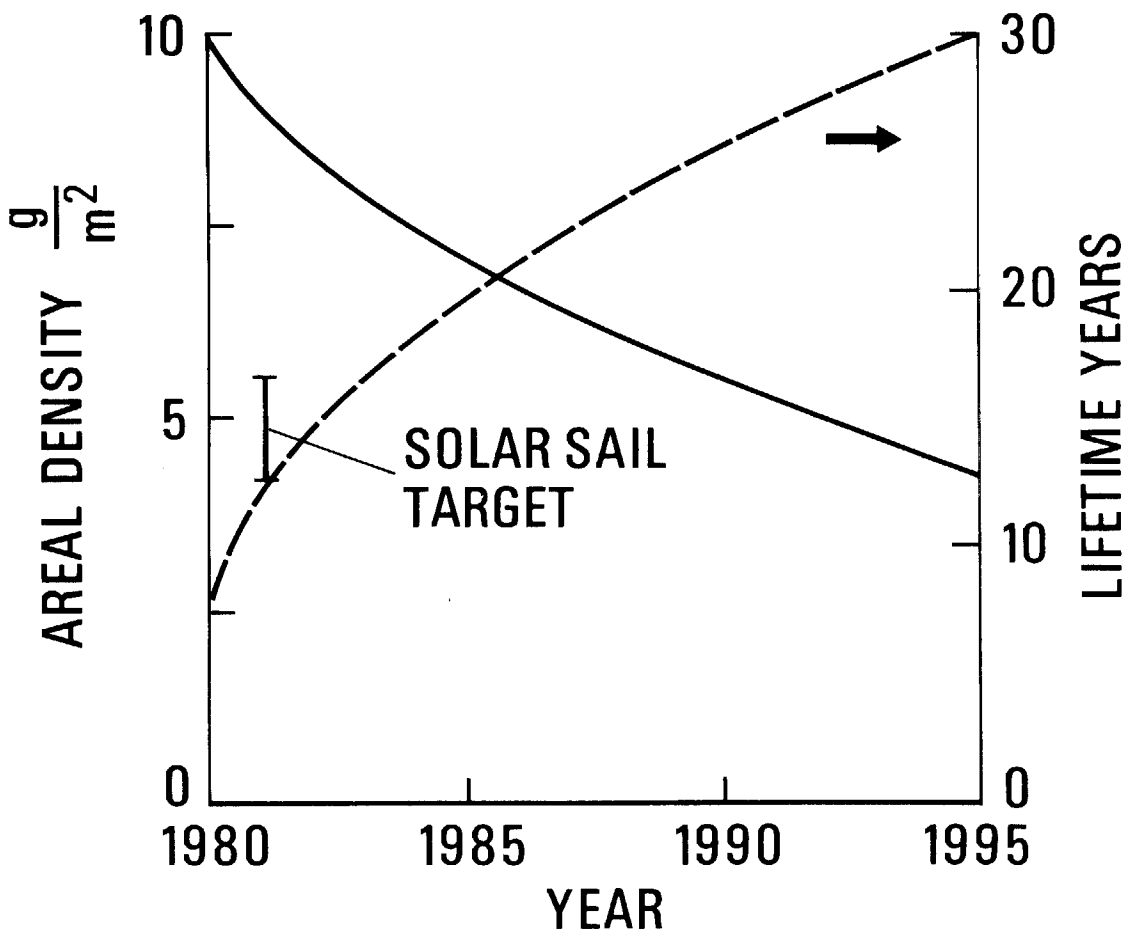


- LONGER LIFE, HIGHER LOAD SHUTTLE
- REDUCED OPERATIONS COST
- IMPROVED PROPULSION SYSTEMS
- SSTO OR HLLV DEVELOPMENT

REFLECTOR COST IMPACT

Besides the intrinsic material cost the areal density and lifetime of the mirrors to a large extent control the reflector cost into orbit. It is assumed that overall material costs of about $\$1.50/m^2$ can be achieved (aluminized mylar is $\$.40/m^2$) and that improvement will be chiefly made, in the near term, in the lifetime of such inexpensive materials. Since much thinner materials are presently available than indicated by the areal density requirement curve, it is expected that the projected development, as shown on the chart, of materials optimized for the present application will also be rapid. Improved space construction techniques and more easily deployed structures will also reduce cost, as will improvements in reflectivity. The relay technique, described earlier would greatly increase effectiveness as would better control characteristics. The target areal density of the solar sail (sail material, structure, control, etc.) is shown.

SOLARES
INCREASE EFFECTIVE POWER WITH IMPROVED REFLECTORS

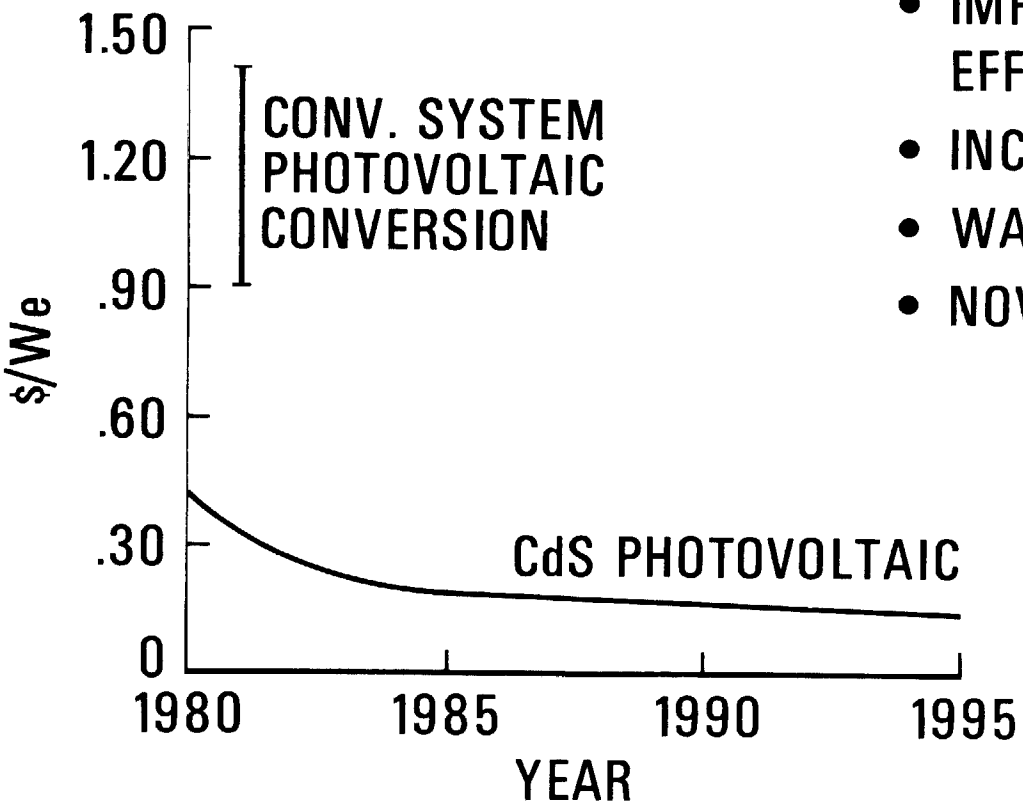


- LIGHTER WEIGHT
- LONGER LIFE
- LOWER CONSTRUCTION COSTS
- HIGHER REFLECTANCE
- MORE PRECISE CONTROL
- DEVELOP RELAY TECHNIQUE

OPTIMIZED GROUND STATIONS

Expected capital investment requirements for the ground station component of SOLARES is based in the near term on conventional photovoltaic system costing (from DeMeo of EPRI) and the immediate refinements possible. Near term values shown are expected from nearly continuous duty cycle, large scale operation, 7.5% CdS solar cells and approximately one added solar constant of radiation. Further term improvements are expected in these four areas, principally by achieving 15% conversion efficiency with the low cost CdS photovoltaic devices. Further cost reductions, not plotted, might be accomplished by providing waste heat utilization or by a breakthrough in conversion technology.

SOLARES
INCREASE EFFECTIVE POWER WITH OPTIMIZED GROUND STATIONS



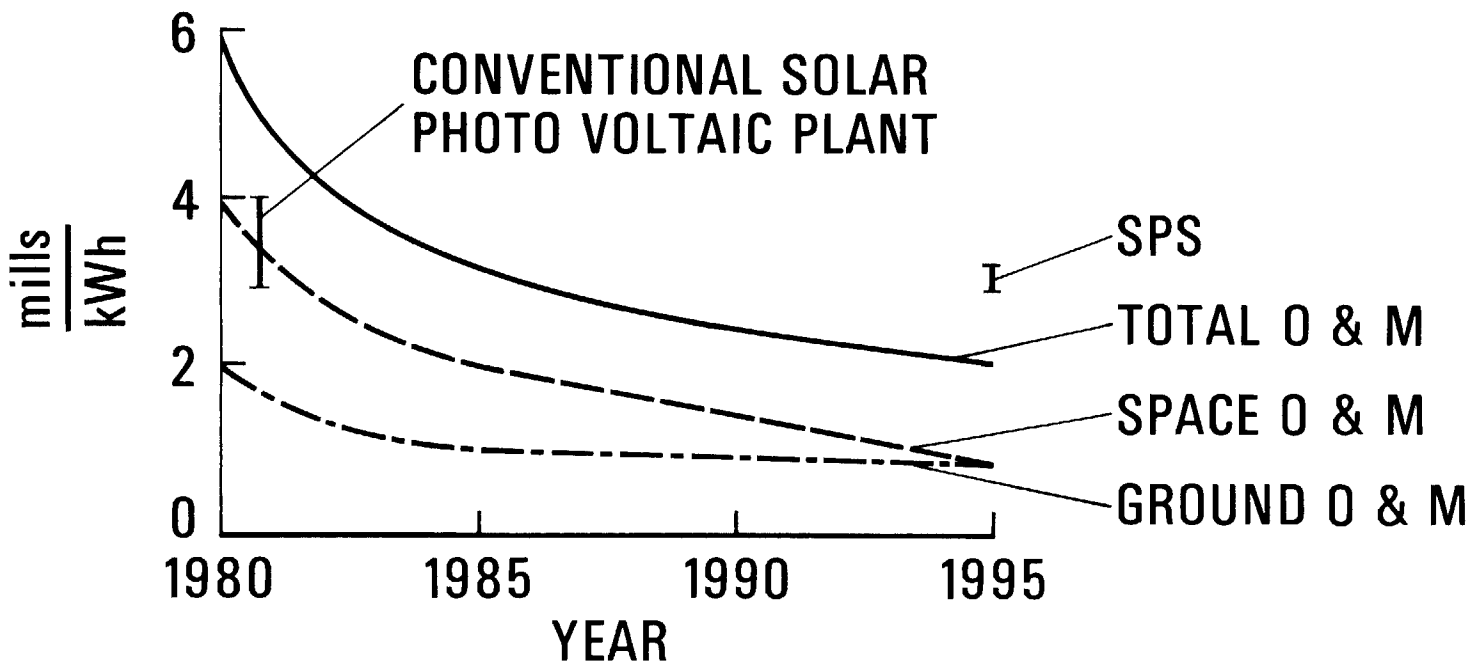
- CONTINUOUS DUTY
- INCREASED SCALE
- IMPROVED CONVERSION EFFICIENCY
- INCREASED INSOLATION
- WASTE HEAT UTILIZATION
- NOVEL CONVERSION DEVICES

OPERATION AND MAINTENANCE COSTS

O&M, particularly in the further term, are expected to comprise a large fraction of the total bus energy cost. The ground component of O&M is based on those improvements that would attend the implementation of continuous and higher average insolation in conventional solar plants. Presently, space O&M costs are uncertain. Because of the lesser complexity of the reflector system relative to SPS, the 1995 estimate shown is reasonable.

SOLARES
INCREASE EFFECTIVE POWER WITH REDUCED SYSTEM OPERATION AND MAINTENANCE COSTS

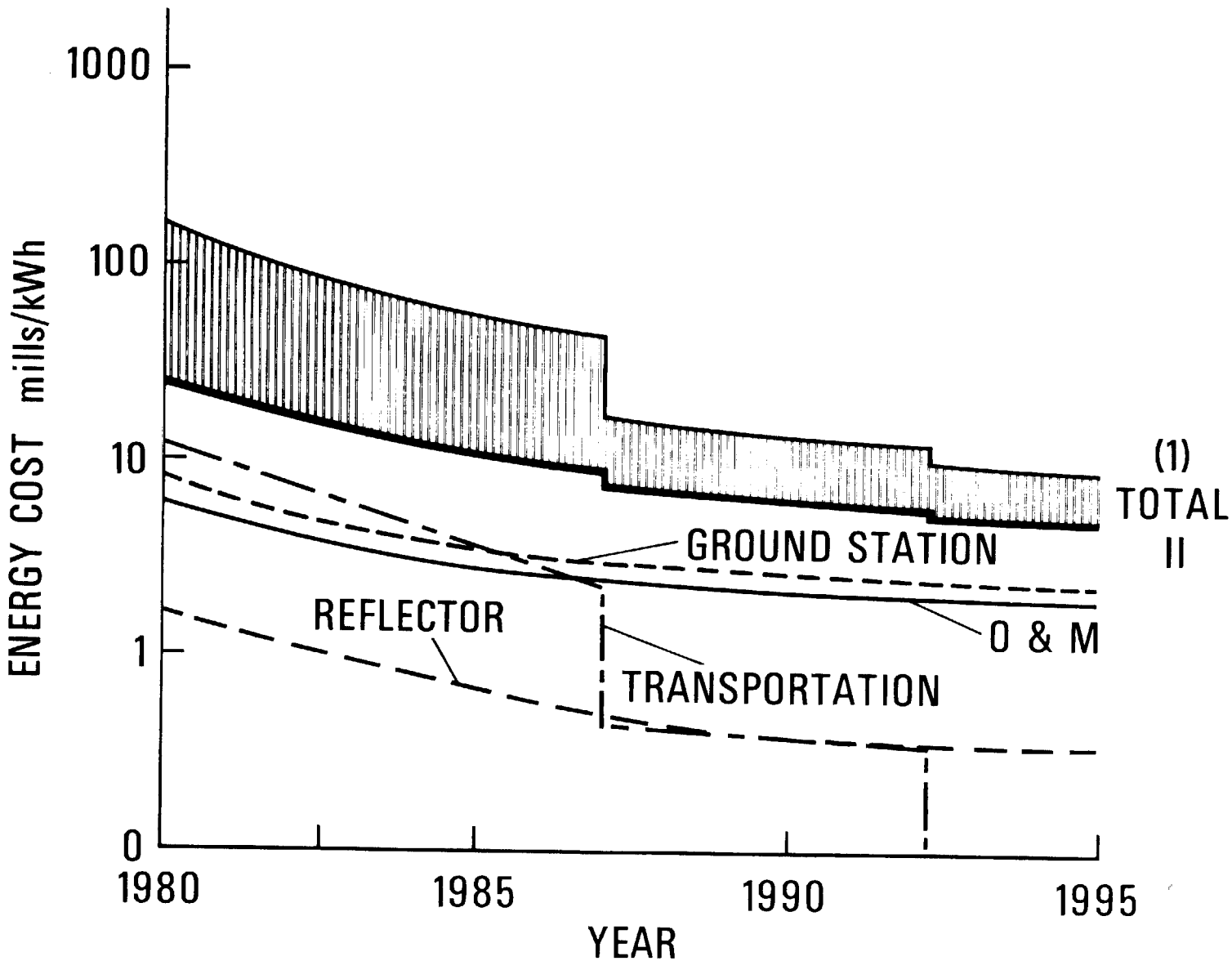
- LONGER LIFE MATERIALS
- CONTINUOUS DUTY CYCLE
- HIGHER INSOLATION
- IMPROVED SPACE OPERATIONS



TECHNOLOGY DRIVEN COMPONENT COSTS

Component cost factors from the previous charts were converted, as necessary, to capital costs and thence to busbar energy costs, and are again presented as a function of epoch. Elements of the previous charts were combined to derive the components presented here (e.g., the areal density from the mirror chart effects the transport charge). The heavy "total" curve represents predicted energy costs if eleven ground stations were installed and is the actual total of the components. The top of the total band is the cost if only a single ground station is utilized. In actual implementation the energy cost would likely start at the top of the band and with passing time approach the lower eleven station bound.

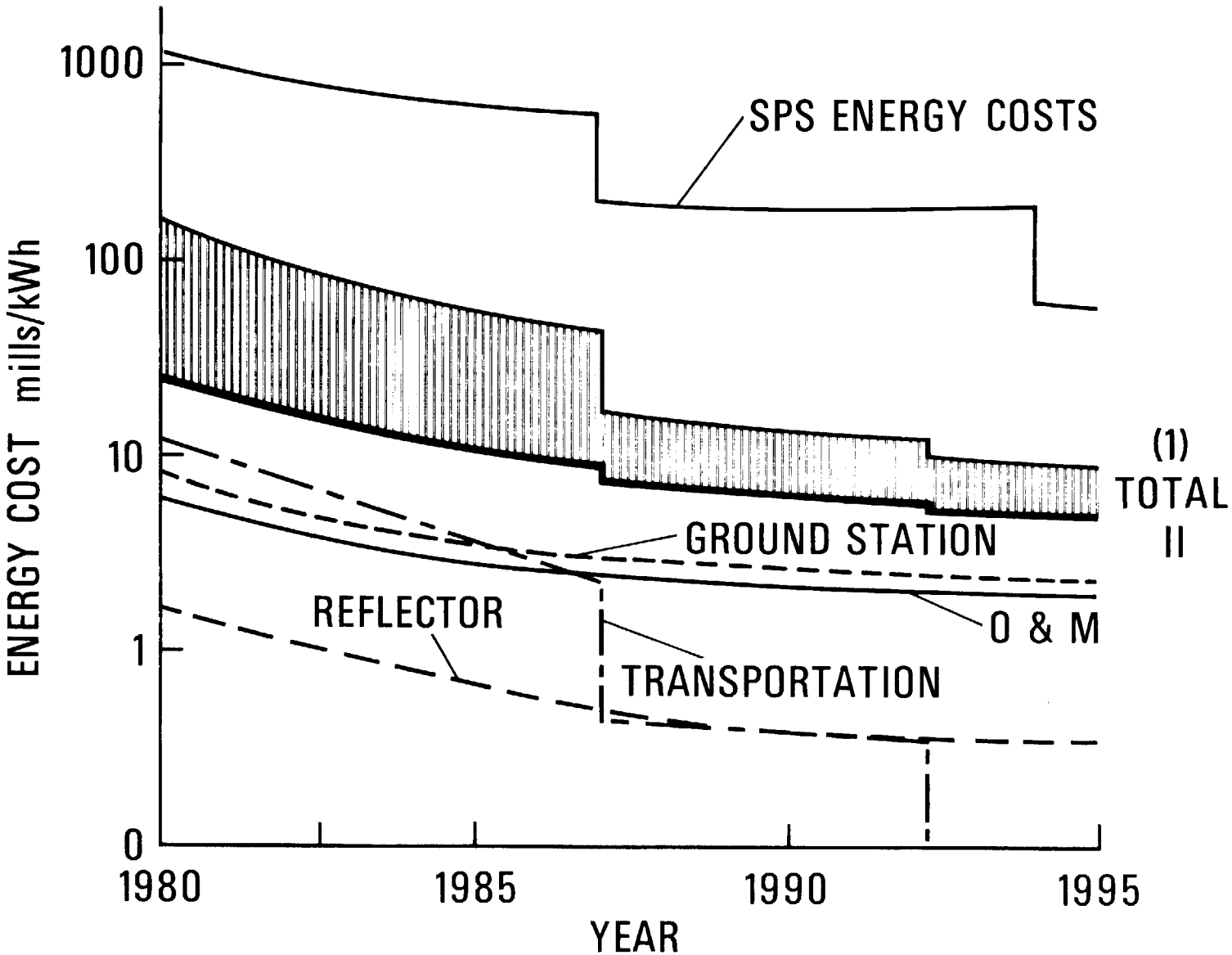
SOLARES
TECHNOLOGY DRIVEN COMPONENT COSTS



SPS ENERGY COSTS

Using the JSC 1995 SPS energy cost of 55 mills/kWh and the best available systems at a given point in time the epoch cost curve was derived for comparison purposes. The SPS curve shown overlaid on the previous chart does gain on the full implementation SOLARES with time, principally because improved transport has a much larger effect on the former system.

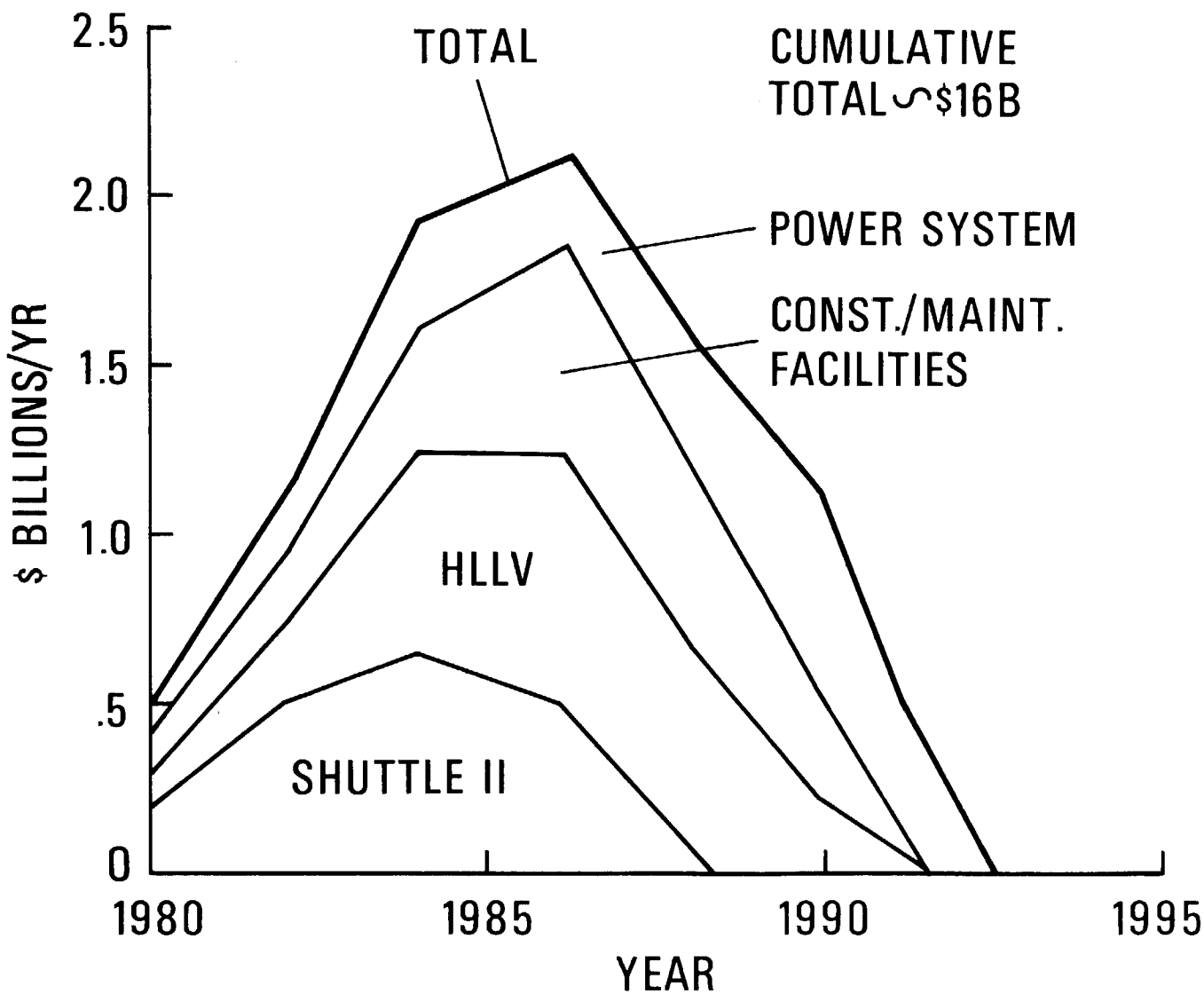
SOLARES
TECHNOLOGY DRIVEN COMPONENT COSTS



DDT & E COSTS

The magnitude of expected components comprising design, development, test and evaluation costs, are presented by year. For a terawatt size project these expenditures, totaling about sixteen billion dollars, when factored over the power output life of the system have little effect on total busbar energy costs.

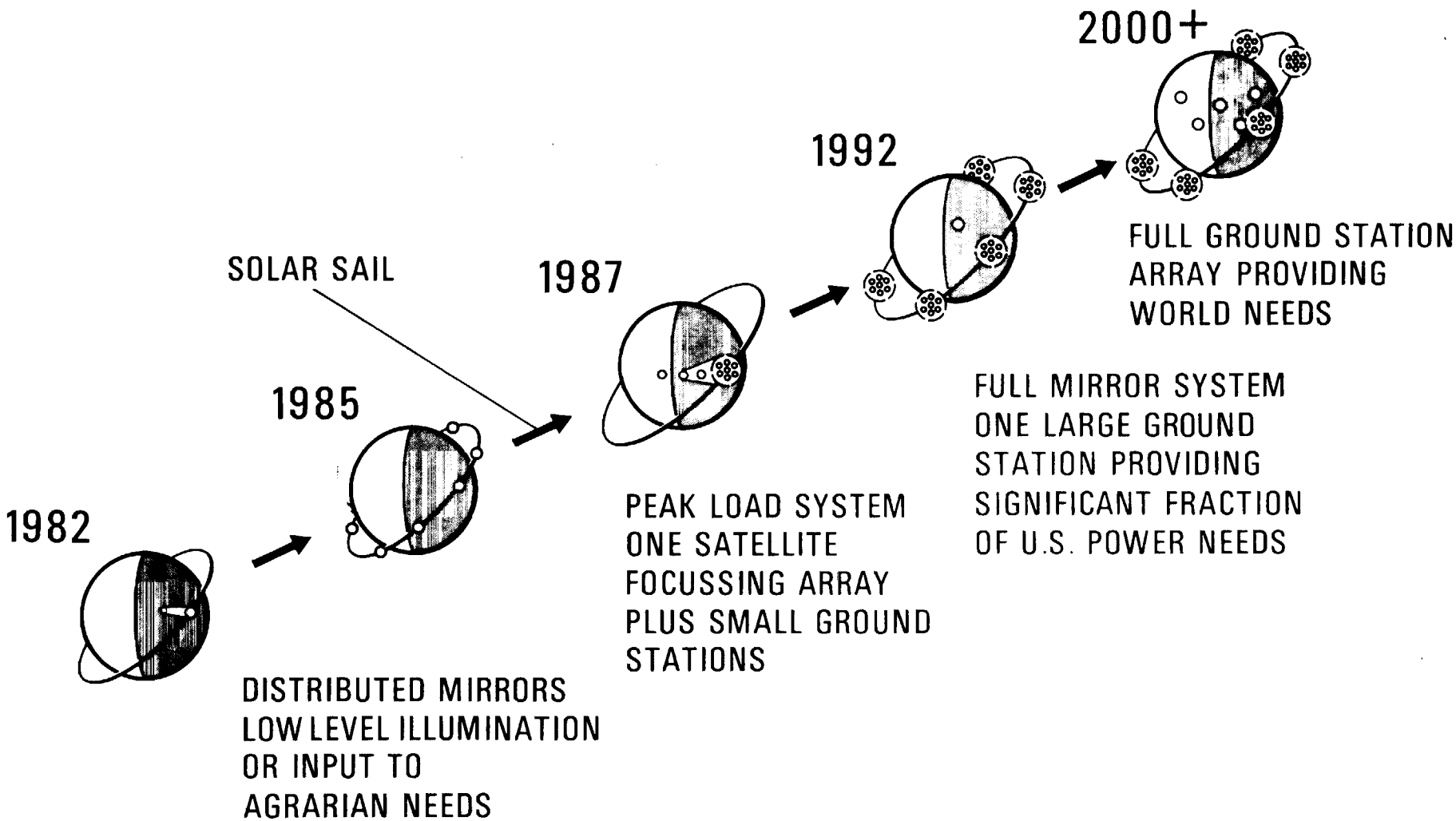
SOLARES
SPACE REFLECTOR POWER SYSTEM DDT & E COSTS
1977 DOLLARS



INCREMENTAL IMPLEMENTATION APPROACH

A possible time-phased scenario for the implementation of SOLARES assuming a directed technology and development effort.

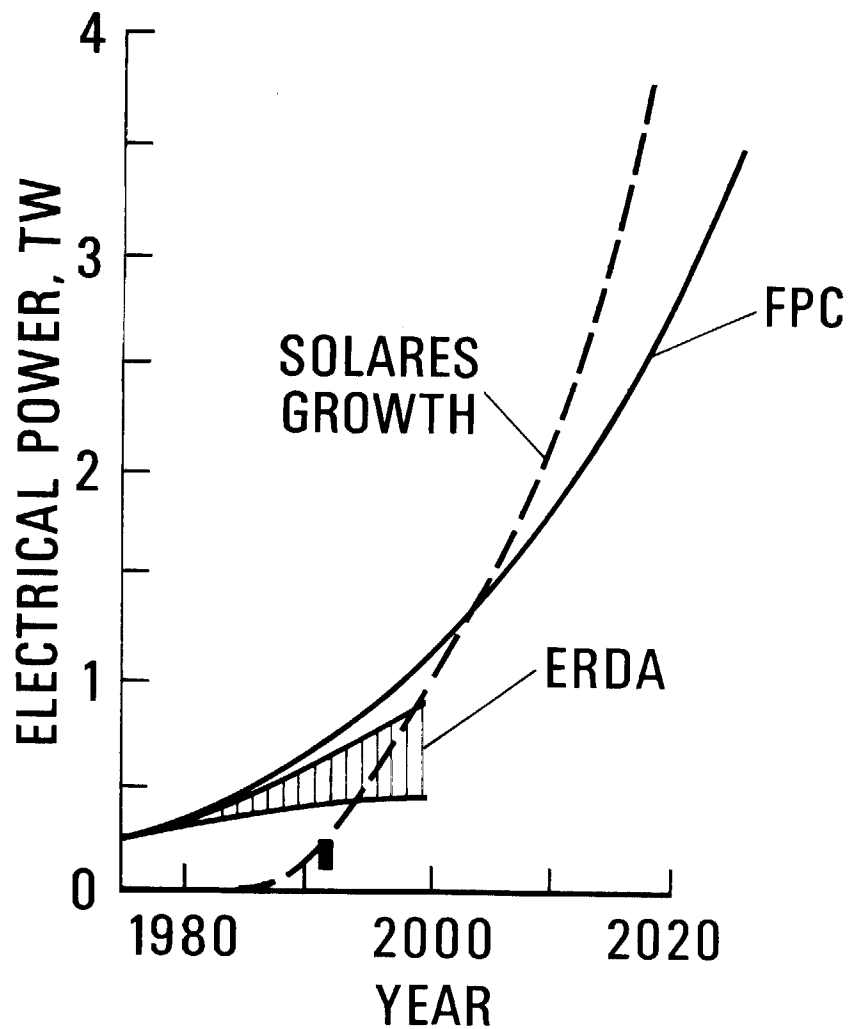
SOLARES
INCREMENTAL IMPLEMENTATION APPROACH



U.S. ELECTRICAL ENERGY REQUIREMENTS AND ORBITING REFLECTOR IMPACT

The possible impact of SOLARES on the U.S. electrical energy sector compared to the Federal Power Commission 1975 predicted demand curve and ERDA 1976 availability scenario is shown. The solid bar at 1992 represents the power output of a single ground station (one added solar constant provided from a 4000 km, 40° inclination mirror belt). The growth curve shows the effect of added ground stations and higher insolation. Similar curves, about three times higher, can be constructed for the world's needs, availability and possible supply via SOLARES.

SOLARES
U.S. ELECTRICAL ENERGY REQUIREMENTS AND ORBITING REFLECTOR IMPACT

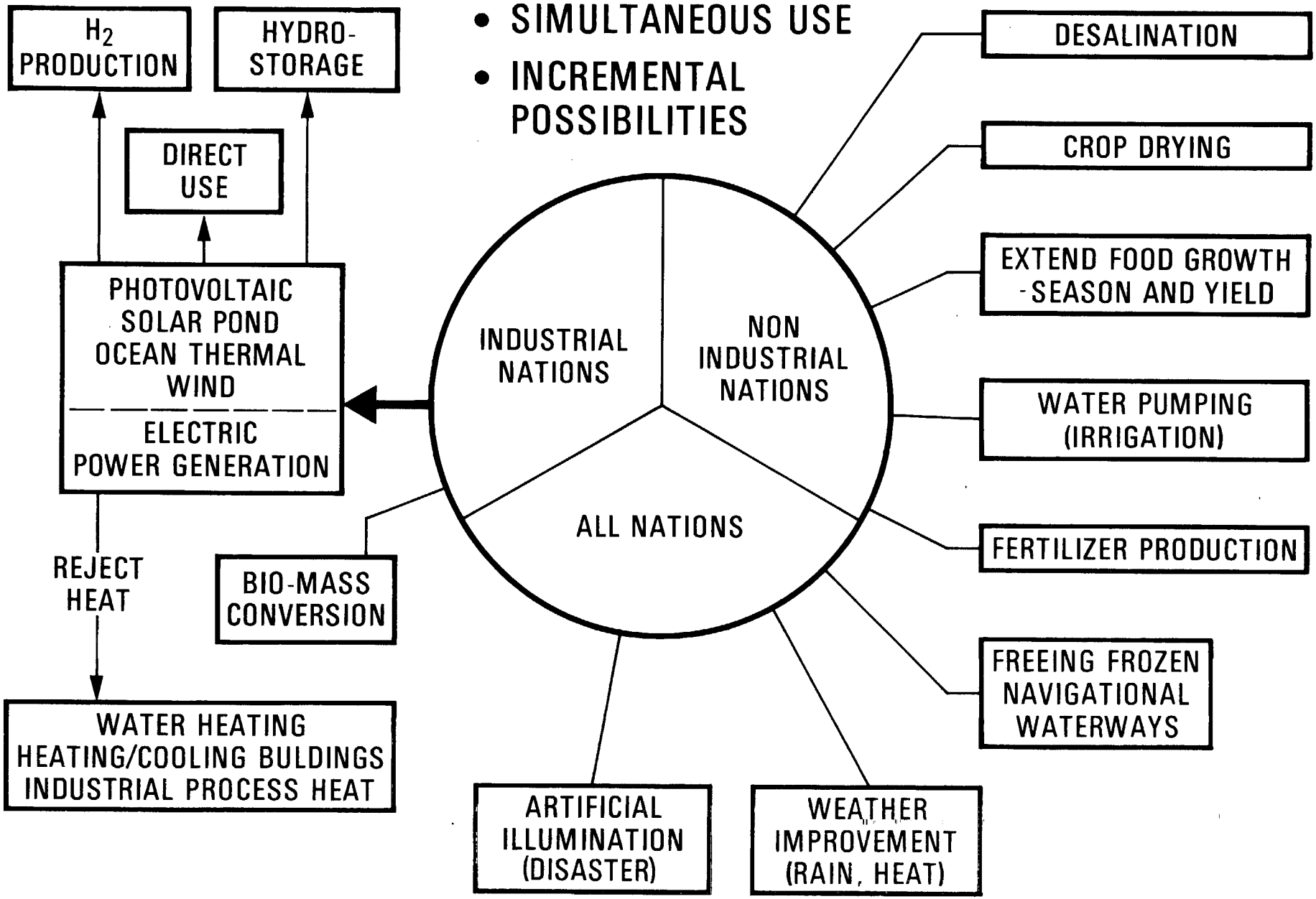


SOLARES APPLICATION

Some of the possible applications of SOLARES are shown, indicating the probable preference of non-industrial nations toward agrarian uses. This particular service could be provided those nations with the same belt of mirrors that would produce electrical power in other countries. Non-electrical uses could probably be implemented on a cost effective basis before electrical energy generation reaches that state. Based on cost effectiveness, emergency needs (e.g., frost prevention) and electrical supply/demand industrial nations would also be expected to employ some of these alternate applications. Although the presentation has only addressed the possibility of photovoltaic ground conversion it should be noted that other techniques for producing electricity from sunlight might prove superior.

SOLARES APPLICATION

- MULTIPLE USE
- SIMULTANEOUS USE
- INCREMENTAL POSSIBILITIES



SOLARES
ENVIRONMENTAL IMPACT

POSITIVE

- CONSERVE FOSSIL FUELS FOR NON-ELECTRICAL NEEDS
- USE ELECTRICITY FOR NEW USES NOW ONLY PROVIDED BY FOSSIL FUELS
- POSSIBLE WEATHER IMPROVEMENT

} DECREASE CHEMICAL POLLUTION DUE TO BURNING OF FOSSIL FUELS

NEGATIVE (?)

- NEW SOLAR HEAT INPUT (CONCENTRATION EFFECTS)
- DISTURBANCES TO '-SPHERES' (NEEDS STUDY)
- ATMOSPHERIC PHOTOCHEMISTRY (NEEDS STUDY)
- LAND USAGE (INVESTMENT TO FUTURE LAND CONSERVATION?)
- CONTINUOUS INSULATION (SCANDINAVIANS OK BUT ASTRONOMERS?)

SOLARES
AREAS OF FUTURE STUDY

MIRRORS

- MATERIALS - FIGURE+, OPTIMUM SUBSTRATE, POSSIBLE REFLECTIVITY, LIFETIME, GRAVITY GRADIENT/THERMAL/ VAN ALLEN BELT/AND OTHER EFFECTS.
- STRUCTURE - POINTING AND TRACKING CONTROL+, ANGULAR MOMENTUM TRANSFER, OPTIMIZED OPTICAL, RAPID DEPLOYMENT, SPACE MANUFACTURE, OSCILLATIONS.
- OPTICAL INNOVATION - RELAY OPTICS*, SYSTEM TO REDUCE SPOT SIZE, GLINT ELIMINATION.

ORBITS

- RADIATION PRESSURE - SOLAR SAILING OPTIONS*/REQUIREMENTS.
- SCALING LAWS - ECONOMIC AND TECHNICAL.
- OPTIMIZATION - END USE: λ, NUMBER OF SPACING OF GROUND SITES.
- INCREMENTAL - ORBIT TRANSFER POSSIBILITIES/OPTIMIZATION.
- STATION KEEPING - IMPACT ON DUTY CYCLE.

GROUND STATIONS (USE)

- FIND SOLAR CONVERSION TECHNIQUE OPTIMIZED FOR ORBITING MIRROR SYSTEM*.
- SYNERGISTIC EFFECTS ON EXISTING SOLAR SCHEMES.
- MILITARY VULNERABILITY SOLUTIONS (ENERGY STOCKPILE).
- SITE LOCATIONS - CLOUD MINIMIZATION, POLITICS.
- MASS PRODUCTION ADVANTAGES.
- TERRESTRIAL ENERGY TRANSPORTATION.

ENVIRONMENT

- '-SPHERE' DISTURBANCES - MICROWEATHER STUDIES+, ATMOSPHERIC PHOTOCHEMISTRY, SCATTERING, TRANSPORTATION DISTURBANCES, OTHER?
- LAND USE.
- WASTE ENERGY CONCENTRATION AT GROUND SITE.

+~CRUCIAL AREA - NEEDS NEAR-TERM ANSWER. *~LARGE PAYOFF AREA

SOLARES
ACTION OPTIONS

I. SOLARES

1. IN DEPTH ANALYSIS AND SYSTEM OPTIMIZATION
2. IF FAVORABLE, INITIATE R&D

II. OTHER SPACE ALTERNATIVES

1. SURVEY, IDENTIFY, BOUND POSSIBLE CANDIDATES
2. IN DEPTH STUDY OF PROMISING CANDIDATES

III. FUND SPS, SOLARES, AND OTHERS BASED ON COST-RISK/BENEFIT