*Journal of The British Interplanetary Society, Vol. 42, pp 567-569, 1989*

# SPACE-BASED SOLAR SHIELD TO OFFSET GREENHOUSE EFFECT

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A thin glass shield built from lunar materials and located near the first Lagrange point of the Earth-Sun system could offset the greenhouse effects caused by the $CO_2$ buildup in the Earth's atmosphere.

## 1. INTRODUCTION

Terraforming the near planets of the solar system is a long, complex and ambitious undertaking lying well into Man's future. There are two major problems to be addressed viz global temperatures and atmospheric composition. A suggested method for the control of planetary temperatures is the use of space-based shields to modify the incident solar flux. Terraforming shields for planets such as Venus or Mars would, of necessity, be large, complex structures requiring vast amounts of lunar or asteroidal material and a well established space manufacturing and long-range transportation system. One possible stepping-stone to understanding and mastering the technologies and physical processes involved would be the construction of a shield to offset the greenhouse effect on our own planet, Earth. Such a project would be much smaller in size and scale and not require interplanetary capabilities.

Concern has been expressed worldwide for the changing composition of the Earth's atmosphere. In the twentieth century, increased atmospheric concentration of molecules such as $CO_2$, which absorb infrared radiation, has intensified the trapping of thermal radiation in the atmosphere now referred to as the greenhouse effect. As the concentration of these gases rises, the resulting temperature increases and other climatic effects become more serious. Because of the complexity of the many processes involved, there is considerable uncertainty regarding the rate of build-up of the greenhouse gases and the magnitude of the resulting climatic changes [1]. The time required for removal of these gases from the atmosphere by natural processes is also uncertain: current estimates are several centuries.

The uncertainties in the scale and duration of the climatic changes resulting from the greenhouse effects has led to calls for more research into these problems as well as restrictions on the generation of greenhouse gases. The most important restriction would be on the burning of hydrocarbons for power generation and transportation. Since the build-up of $CO_2$ in the atmosphere is cumulative and as there are no accepted technical solutions to the greenhouse effect, it may prove crucial to restrict the generation of these gases as soon as possible, perhaps in the 1990's. The existence of a possible technical solution could thus have a major short-term impact in influencing short term consumption restrictions, even if the solution could not be implemented until the next century.

A conceptually simple method for offsetting the greenhouse radiation trapping effects would be to decrease the solar heating by the use of a space-based solar shield [2]. Approximately 2% of the solar radiation reaching Earth must be blocked to offset the predicted greenhouse trapping expected in the next century [3]. The shield postulated would be 2000 km in diameter and located $1.5 \times 10^6$ km from Earth, near the first Lagrange point between the Earth and the Sun. A shield $10\mu$ thick would weigh approximately $10^{11}$ kg and may cost from one to ten trillion dollars. It would be fabricated from lunar materials launched by a mass driver.

## 2. SHIELD ORBIT

The space shield must be placed in an orbit where it remains positioned between the Earth and the Sun. This point will be near the classical first Lagrange (L1) point. The location is determined by two requirements. Firstly the angular velocity of the shield around the Sun and of the Earth must be the same so that the shield remains in a line between the Earth and the Sun. Secondly, there must be an acceleration balance on the shield between the centripital acceleration from the orbit around the Sun, the gravitational accelerations of the Earth and the Sun and the proton acceleration on the shield. A photon thrust of zero would locate the shield exactly at the L1 point. Combining these requirements gives,

$$(\delta/R)^3 = (1/3)\left[\frac{m}{M} + \left(\frac{a}{a_o}\right)\left(\frac{\delta}{R}\right)^2\right](1 - \frac{\delta}{R}) + O\left(\frac{\delta}{R}\right)^5$$

$$a_o = GM/R^2$$

where m, M and G are the masses of the Earth and Sun and the gravitational constant. R and $\delta$ are the distances from the Earth to the Sun and from Earth to the shield. The photon acceleration of the shield is a. For zero photon thurst, one obtains the L1 point

$$\delta_o = 1.50 \times 10^6 \text{ km}$$

When there is a photon acceleration on the shield, the balance point becomes

$$\delta \approx \delta_o [1 + (1/3)(a/a_E)]$$

$$a_E \equiv Gm/\delta^2 = 0.0177 \text{ cm/sec}^2$$

where $a_E$ is the Earth's gravitational acceleration at the shield distance.

The shield orbit will be semi-stable as any small radial perturbation towards or away from the Sun will cause the shield to be pulled out of position. However, perturbations perpendicular to the Earth-Sun axis will be stable. Station-keeping at the L1 point requires constant adjustment to the orbit. This is why there will be no dust and natural satellites at the L1 point, as commonly found at the L5 or Trojan orbits. The accelerations required to hold this orbit are very small and well within the capabilities of the shield.

The shield is balanced only at the Earth-Sun axis. All other sections of the shield are drawn to the axis by a radial acceleration $\alpha_r$

$$\alpha_r \approx -G\left(\frac{m}{\delta^3}+\frac{M}{R^3}\right)r$$

where r is the radial distance from the Earth-Sun axis. To be in an orbit around the Earth-Sun axis, the centripital acceleration must balance the radial acceleration

$$\Omega^2 r = -\alpha_r$$

$$\Omega = \sqrt{G}\left(\frac{m}{\delta^3}+\frac{M}{R^3}\right)^{1/2} = 2.0\ cycles/year$$

where $\Omega$ is the angular velocity of a section of the shield. Since $\Omega$ is independent of r, the shield can rotate as a solid body and have each section be in orbit around the Earth-Sun axis. In this condition there would be no stresses in the shield. A faster rotation rate than is required for gravitational balance will create a radial stress in the shield, which may be desirable to help maintain the shield as a flat disc.

The disc rotation will, unfortunatly, act as a gyroscope which keeps the disc orientated with its axis pointed in one direction. Since the disc axis must always point toward the Sun, a torque must be applied to the disc by a control system to cause the disc to precess at one cycle per year. It is not clear if this control system is simpler than using solar sails at the perimeter of the disc to supply a radial tension to balance the radial gravitational acceleration.

## 3. PHOTON THRUST OF SHIELD

When a photon is absorbed or emitted, its momentum is transferred to the shield. If the photon is reflected, the momentum transferred is twice the photon momentum. The solar pressure from incident radiation on the shield is then

$$P = (F/c)\ [\alpha\,(1+\frac{\varepsilon_S - \varepsilon_E}{\varepsilon_S + \varepsilon_E}) + 2r]$$

where $\alpha$ and r are the shield absorptivity and reflectivity for sunlight. $\epsilon_s$ and $\epsilon_E$ are the infrared emissivities of the shield on the Sun and Earth sides. For a shield of thickness t and density $\rho$; the acceleration, a, of the shield is then

$$a = P/\rho t$$

Shield acceleration may be controlled by the optical design. If the shield is opaque, then the Sun side should have a low reflectivity (high absorptivity) for the solar spectrum. The photon thrust from radiated infrared energy can be used to offset the thrust from absorption. The infrared emissivity should be minimised on the Sun side and maximised on the Earth side. An ideal opaque shield would scatter the Earth bound solar energy into diffuse infrared energy.

The shield may also be transparent and simply scatter the visible photons away from the Earth. The required scattering angle, $\Theta$, is 8.5mr or one-half degree. A glass shield may act as a prism to deflect Sunlight away from the planet in accordance with Snell's law. The light beams are deflected as they enter and exit the thin glass shield. If both surfaces of the glass are parallel the deflections cancel and the light beams continue in their original direction. If the two surfaces are at an angle $\beta$ with respect to each other, the glass then acts as a prism. For the near-normal incidence configuration used to minimize shield reflection, the deflection angle, $\Theta$, is equal to:

$$\Theta = \beta\,(n_g - n_{vac}) \approx 0.5\,\beta$$

where

n = index of refraction = 1.0 for vacuum

$\approx$ 1.5 for most glasses

The deflection angle does not depend to first order on the angle of incidence of the light on the shield so the orientation of the shield would not have to be closely controlled.

The shield may have a pattern of shallow parallel grooves on one side and be flat on the other. If the distance from peak to valley is 200 microns, then the required change in thickness is 3.4 microns. If the average shield thickness is 10 microns, this may be an acceptable change in thickness. If a thinner shield is desired the parallel grooves must then be closer together.

A transparent shield would reflect some of the light at both the entering and exiting surfaces. The amount reflected could be minimized by applying complex layered coatings to the glass but the relatively small benefit incurred may not justify the cost. The reflectivity would be 0.04 for an uncoated surface.

The photon acceleration for a 10$\mu$ transparent shield made of glass with a density of 2.5 is

$$a = 0.0030\,cm/sec^2$$

The displaced orbit position is

$$\delta = \delta_o\,(1.0565) = 1.58 \times 10^6\ km$$

## 4. SHIELD SIZE AND EFFECTIVE BLOCKAGE

The effective blockage by the shield is given in Fig. 1 as a function of the shield diameter. For a shield diameter less than 1200 km, the whole projection of the shield area on to the Sun's surface would lie within the Sun's disc when viewed from any point on the Earth's surface. The solar blockage would, therefore, be uniform over the Earth's surface. For a shield diameter of 2000.km, the projected shield disc falls partially off the Sun's disc only for Earth locations on the outer 6% rim of the projected Earth disc, i.e. of the standard circle map showing one side of the Earth. Except for arctic regions, these will be the regions near sunrise and sunset. Thus, the shading averaged over the entire day will be almost constant across the Earth with the arctic regions receiving slightly less shading. This condition should avoid some of the potential political problems associated with having some sections of the Earth shielded more than others.

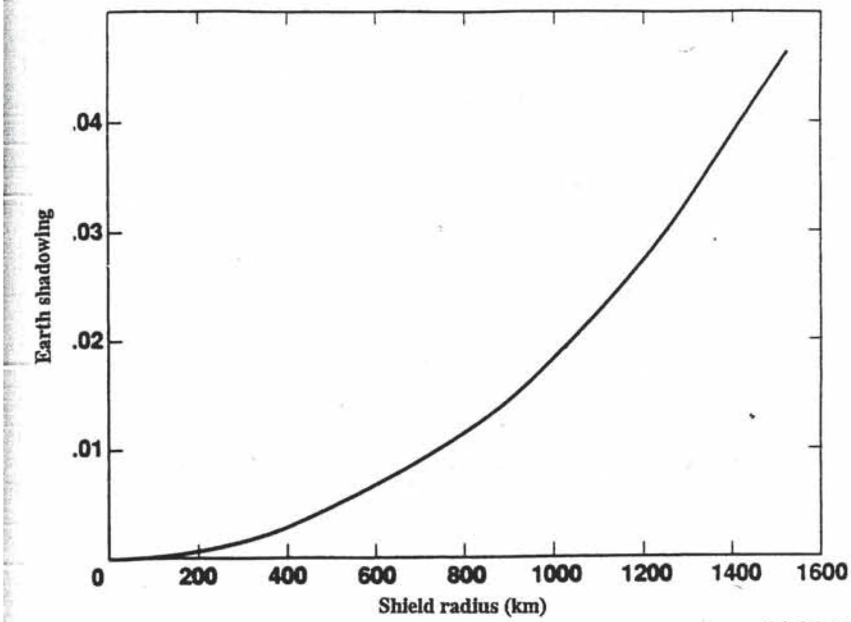


Fig. 1 Effective shadowing of the Earth as a function of the solar shield radius.

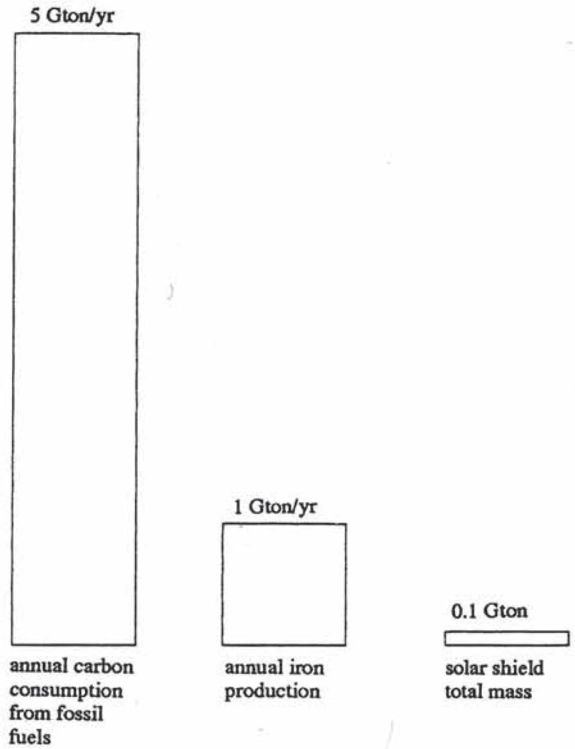


Fig. 2 Comparison of materials consumption

## 5. SHIELD DESIGN

The shield probably would be made from lunar materials. Lunar soil can be formed into glass for either a transparent or opaque shield [4]. The properties of glasses made from various lunar soils must first be determined. Most glasses will be sufficiently transparent in 10μ thicknesses. For an opaque shield, an appropriate coating material would have to be found for the glass substrate. Iron may be obtained from lunar soil with only moderate effort but is probably too dense to use as the base material for an opaque shield. Any material used must be capable of maintaining its properties for centuries in the presence of radiation from solar wind, solar UV radiation and cosmic rays.

The shield material would be processed into glass ingots then drawn into thin sheets. Glass fabrication techniques must be investigated to determine if 10μ is a viable thickness. Commercial plastic wrap is 13μ thick and aluminum foil is typically 13 to 25μ. Designs for advanced solar sails have been proposed using 2μ sail materials [5]. The glass may be launched to the shield location by a mass driver. A number of studies [6] have indicated that mass drivers are feasible and economical for launching unmanned payloads from the lunar surface. If the glass sheet is sufficiently flexible it may be formed into sheet on the lunar surface and launched in rolls.

There are many other design problems such as the fabrication of glass sheet, the impact of lunar perturbations and the required transfer orbits from the Moon to the shield which should be investigated. The shield structural support, the positional control system, the infrastructure to build and maintain the shield and the control of electrostatic charge are some of the major undefined systems.

The scale and costs of this project would be enormous but the economic impact of the greenhouse effect may be much larger. The scale of this project is not beyond the scale of man's activities on Earth (Fig. 2) but it is unclear whether such a massive project could be accomplished in space.

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* This work was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.