POWERING CIVILIZATION AFTER FOSSIL FUELS

John Barber

SUMMARY

The civilization we have created needs a great deal of energy to sustain it. To date, we have largely depended on burning fossil fuels for this, but the scale that we have been doing so is now threatening the very livability of our planet. To preserve our civilization, and perhaps even our existence, we need to find an alternative source for the energy we require. Of the options, solar energy, collected in space and beamed down to Earth via microwaves, seems the best option. Using the Moon as a base for establishing a ring of solar energy collectors orbiting the Earth appears the best way to proceed. The concept has been evolving, practically under the radar, for over a half century, with considerable work being done to evaluate various of the technical features. This discussion draws on that past work, to make the case that the time is now to bring it to a point of broad awareness, and to begin serious steps to make it a reality. While time is still available.

OUR PROBLEM – WE NEED THE ENERGY, BUT IT IS MAKING US HOT

Our world is in trouble; it is heating up in response to the huge amount of carbon dioxide we are injecting into the atmosphere by burning fossil fuels. This warming threatens to make sizable portions of the planet uninhabitable. Virtually the entire scientific community recognizes that in order to limit this change, or at least slow it down, we must find alternative sources for the energy our civilization feeds on – sources that don't involve burning fossil fuels. The question, then, is to what do we turn? This problem is intensified by the sheer magnitude of energy that our civilization requires. The estimated global energy consumption in 2018 was 163,000,000 gigawatt hours. For those unfamiliar with the terminology, this is a big number. Very, very big. And without this diet of energy, our civilization can't continue to exist. And that was only the number for 2018. Estimates for global energy consumption in the future vary considerably, but the general consensus is that it will be substantially larger. For several reasons:

- The population will continue to grow (uncertainty here: birthrates are falling below replacement values in many areas, but in others, baby production continues apace – how does it balance out?). For a given energy consumption per capita, if the capita grows, so does energy consumption.
- A large portion of the world's 7.7+ billion people still live in relatively low levels of prosperity, and their energy usage is correspondingly lower than ours. As they move up the economic development scale, they will come closer to matching us.

- As the planet heats up, ever greater amounts of energy will be required to provide the cooling necessary to live.

SO, WHAT TO DO?

That energy number above, 163,000,000 gigawatt hours, corresponds to an hourly rate of18,600 gigawatts. Typical powerplants are in the ½ - 1 gigawatt range (some variation here, there are both larger and smaller ones, but this range is common). Taking a 1 gigawatt plant as a basis, this roughly corresponds, then, to about 18,600 new energy plants. The options for non-fossil energy sources are limited, even more so when attempting to meet this scale. They include the following:

<u>Nuclear power</u>

> Nuclear power is indeed non-fossil fueled, but it consumes a finite resource. It has been estimated that at the present rate of use, nuclear fuel supplies would last perhaps another 80 years. If sufficient nuclear plants were built to power the entire globe at our present level, the fuel would be gone in 5 years. And 18,600 new nuclear plants is a lot of construction. And there is the matter of figuring out what to do with all the waste.

<u>Geothermal</u>

> The earth's interior is hot, and it is possible to generate electricity by using it as a heat source. There is a great amount of energy available this way, and today there are local applications of geothermal energy, especially in regions where the heat is conveniently near the surface, such as hot springs, etc. Generally, though, deep drilling would be needed. Essentially, a process combining drilling and fracking. And considering the concerns currently expressed about fracking for oil and gas, on a global level for the scale of energy production we need, this could well be problematic.

<u>Biomass</u>

> Burning biomass, while releasing carbon dioxide into the air, is simply releasing that which it already absorbed while growing. Thus, it isn't considered a contributor to the atmospheric carbon dioxide content, and thus not an aggravator of global warming. However, growing vegetative material requires land and water. The coming climate change is anticipated to make water supplies problematic in many parts of the world, even more so than they are now. And with increasing global temperatures, much land now used to grow food will become unusable. Food producing areas will become ever more limited; using this land to also try to grow sufficient biomass to burn to supply the power we need may simply not be feasible.

Wind

Wind can provide power, but it is inconsistent. In order to be able to rely on the winds to supply a continuous and reliable supply of power, vast storage capacity would be needed, along with the ability to move large quantities of electricity long distances to compensate for local shortages. Additionally, wind turbine farms consume a lot of land. It has been estimated that to power the globe today solely by the wind, over 2 billion acres of land would have to be devoted to wind farms.

Solar

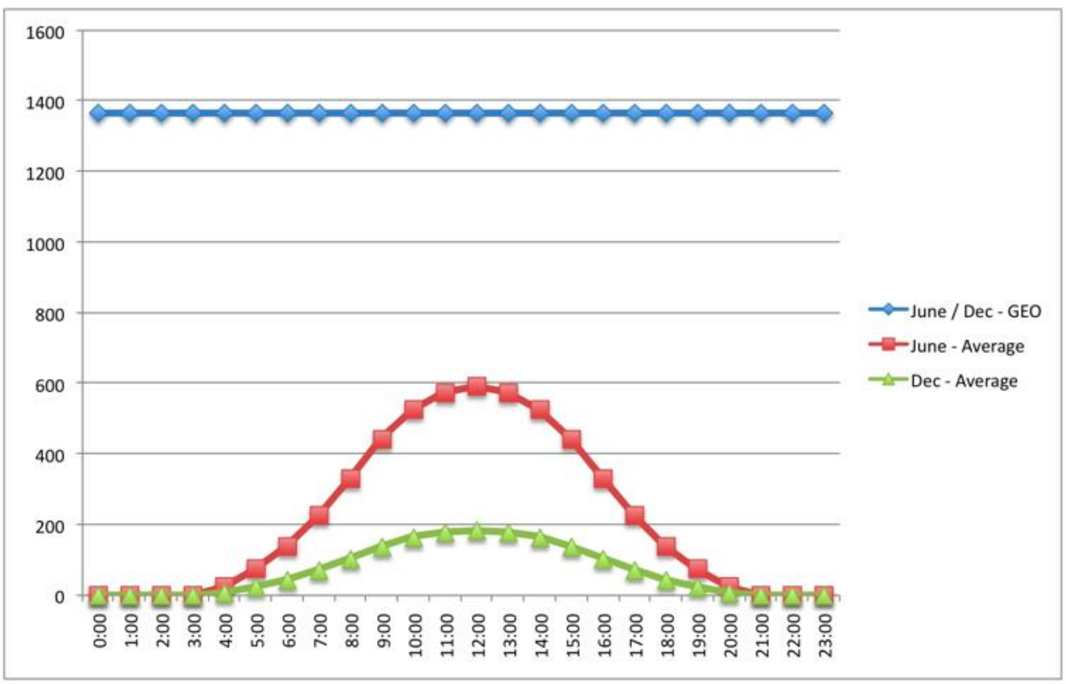
The sun is an enormous source of power, has been shining for some 4 ½ billion years, and is expected to continue doing so for billions more. The efficiency of our solar cell technology is increasing, making us ever more capable of capturing and utilizing this energy. It demands substantially less land area than wind. But even so, its appetite for land is considerable. With our present technology, it has been estimated that to power the globe today, about 124 million acres of land would be needed for solar collectors. Capturing solar energy here on the Earth's surface presents a similar disadvantage to wind: it is variable. Nights, weather and short winter days all combine to prevent an energy supply that is continuous and reliable.

A BETTER WAY TO CAPTURE SOLAR ENERGY

The above options are valuable in the nearer-term, as a glide path to getting to a non-fossil fuel diet. But for a long-term solution, a better option presents itself. The sun shines continuously, 24 hours a day, every day of the year, and at a constant rate. Rather than attempting to capture its energy here on the ground, the alternative is to capture it in space, before it is diminished by all the effects noted above. In space, the sunlight is also more intense, not having been filtered by the Earth's atmosphere. Solar cell satellites orbiting the Earth, capturing the incoming solar energy and beaming it to Earth-based receiver stations via microwave, can provide a much more effective means of providing continuous, constant and reliable energy at the quantities we need. The solar collectors would be located in geosynchronous orbit about the equator, the orbit at which an object remains over the same spot of the ground all day long.

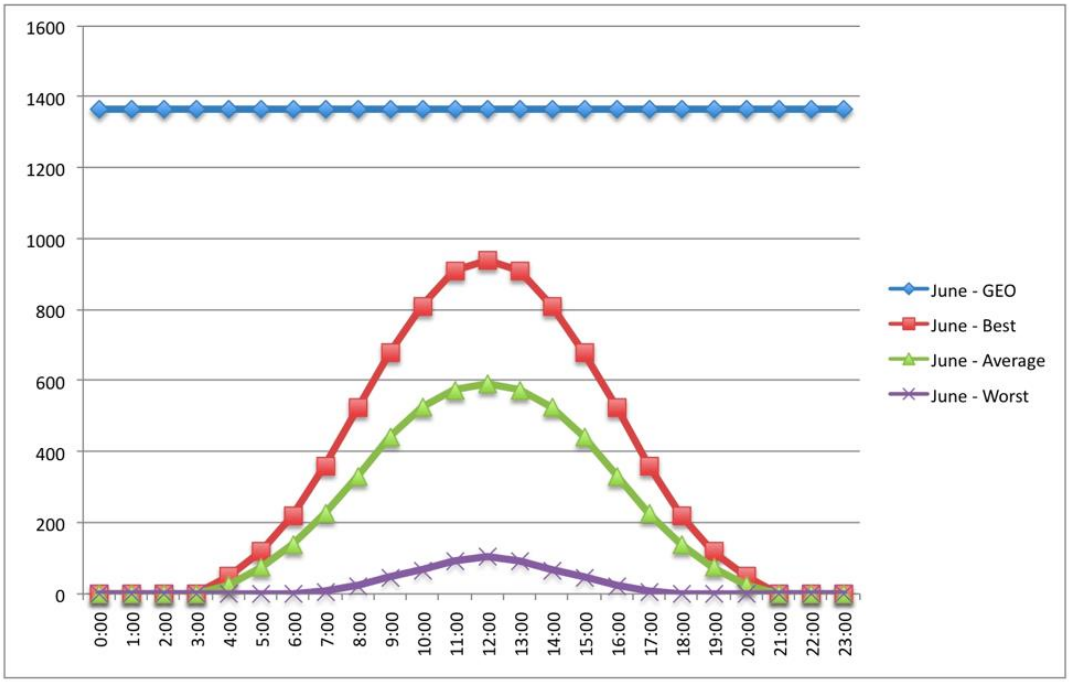
This concept has been evolving (quietly) for over 50 years. While the necessary technology has not yet been developed (i.e., no construction drawings yet), the scientific and technical principles are known and often used in other applications. No show-stoppers have emerged; the technical feasibility has been pretty much established. The idea has been more or less limited to those within the space industry; there appears to be little awareness of the possibility and potential of the concept out in broader circles. Within the space industry itself, it has been in and out of favor over the years; recently it has surfaced again as a topic of interest. The National Space Society, an organization of persons interested in helping humanity shake off the shackles limiting us to Earth and promoting our venture on into space, has recently issued a position paper advocating the development of space solar power: "Space Solar Power: Enabling a Green Future with Economic Growth," July 2019. Recently, several excellent books and papers have been written on the subject, by authors Flournoy and Mankins among others, as noted in the references. Illustrations presented in this writeup are from Mankins' works.

The advantages of collecting solar power in space rather than here on Earth are numerous. For one, the intensity of sunlight reaching the collectors is more than 37% greater in Earth orbit than the best case on the Earth's surface: a square meter of collector in space receives about 1366 watts, continuously, whereas the best that we can get on Earth is about 1000 watts (equator, high noon, no clouds). The following illustration shows the comparisons between winter and summer, vs the constant energy received in orbit. The blue line in the picture, labeled "GEO," represents the energy received at the satellite in geosynchronous orbit. The Earth location is about 30 degrees north, roughly central Texas. Looking at the figure, the advantage of collecting in orbit is apparent.



SOLAR ENERGY IN NORTH AMERICA: SUMMER AND WINTER, THROUGHOUT THE DAY
Credit: "The Case for Space Solar Power," by John C. Mankins

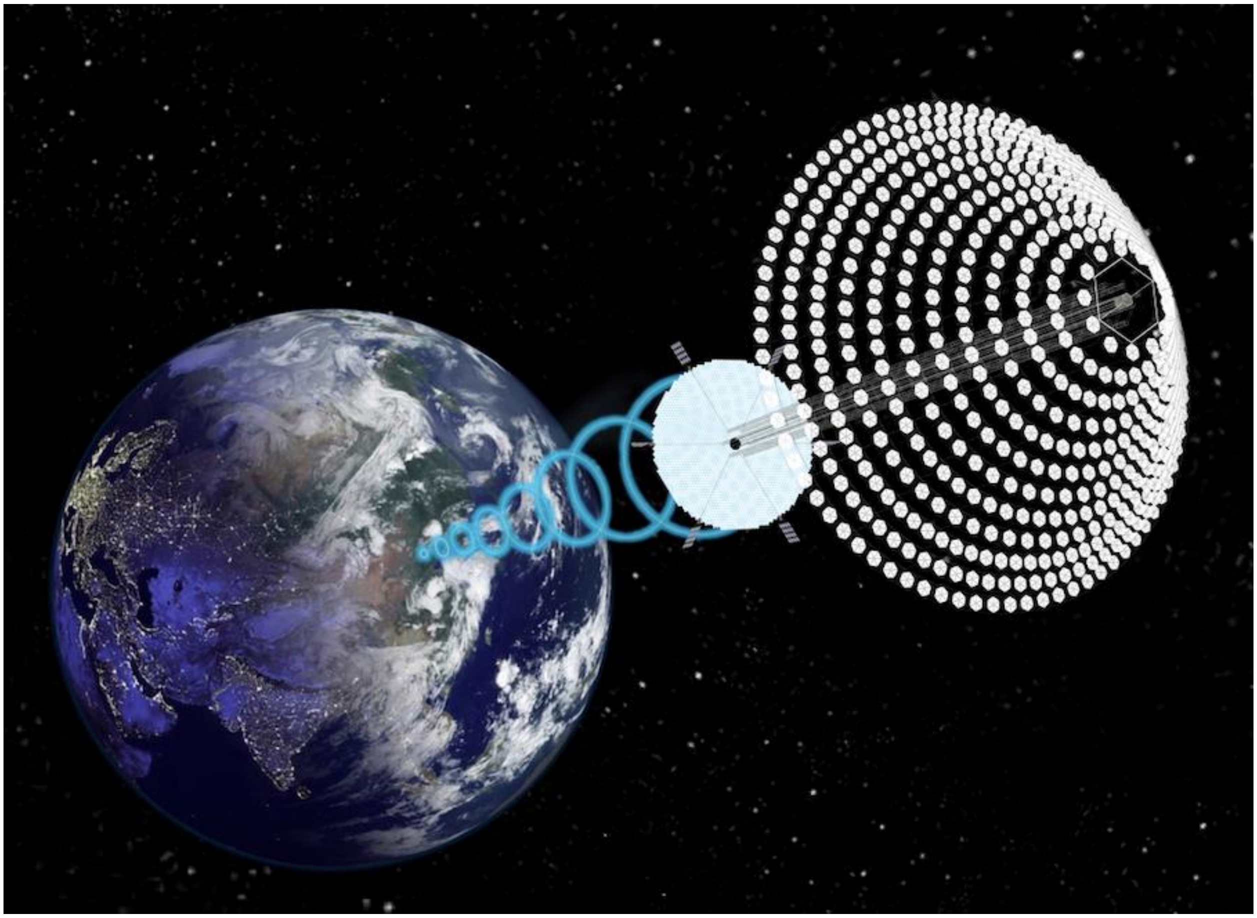
Weather effects intrude into the picture also, degrading the amount of solar energy reaching the surface, as shown in the following illustration:



SOLAR ENERGY IN NORTH AMERICA, TYPICAL JUNE DAYS, THROUGHOUT THE DAY
Credit: "The Case for Space Solar Power," by John C. Mankins

The advantages offered by the satellite energy collection translate into a much reduced need for land area. It is estimated that the microwave receivers for a space power system will need perhaps $1/10^{th}$ or less of the land area required by ground-based solar cell arrays.

What might the orbiting solar collection satellites look like? Various design concepts have been put forth over the years. One concept shown below, sized for a 2 gigawatt output, consists of a large array of mirrors, concentrating the incoming solar energy onto a smaller array of solar cells (running the solar cells themselves at higher output, reducing the amount of cells needed), which convert the sun's energy into electricity, which is then beamed as microwaves via an array of antennas to a receiving antenna on the ground below. It is large in size, perhaps 6 km in diameter across the mirror array, and 13 km long, top to bottom. While large, it is mostly empty, open space.

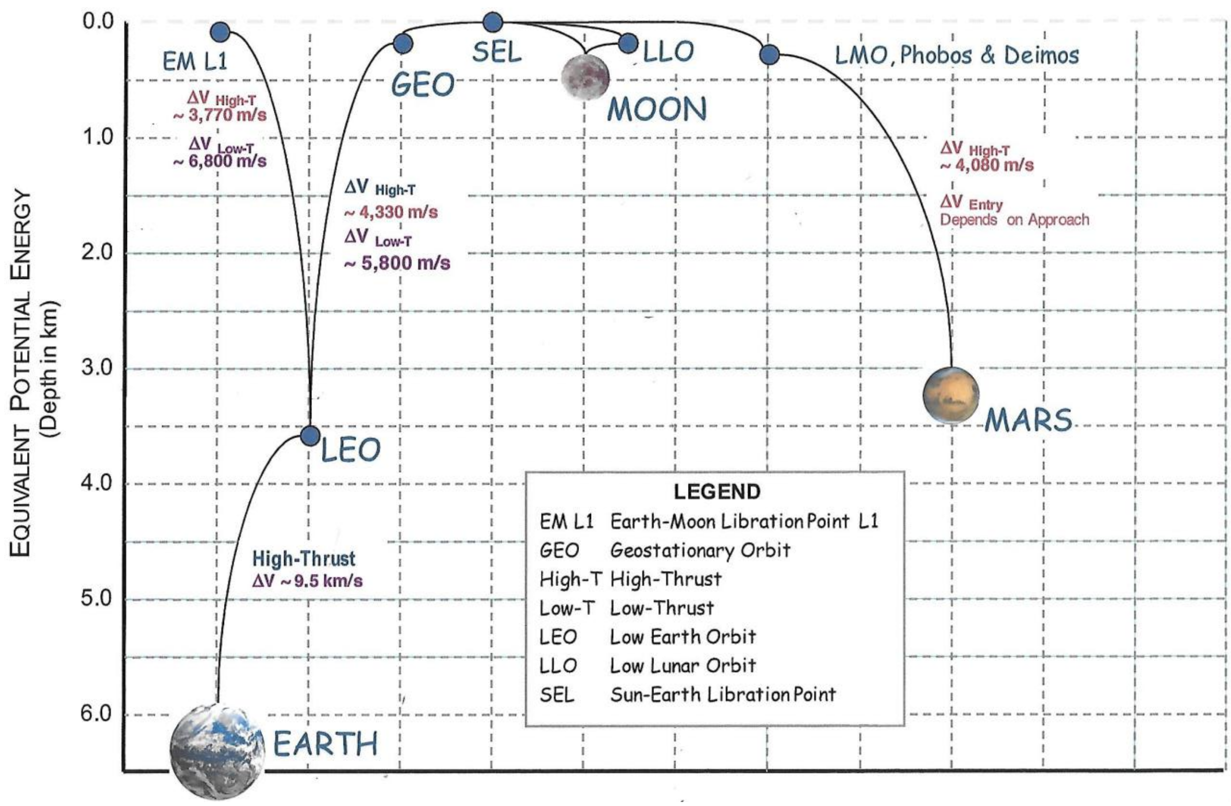


CONCEPT: 2 Gigawatt SOLAR ENERGY COLLECTOR ORBITING THE EARTH
Credit: "New developments in Space Solar Power," by John C. Mankins

WHERE AND HOW TO BUILD THEM?

The orbiting solar collectors would be very large in size and, to serve needs of the entire globe, numerous. If the space power satellites were sized at a 2 gigwatts level of power, the current global power budget of over 18,000 gigawatts would require over 9,000 of them. The concept illustrated above, while predominantly empty space, is nonetheless estimated to weigh on the order of 10,000 tons. Placing that magnitude of apparatus into a geosynchronous orbit from the Earth's surface would be a difficult matter. Perhaps the most capable and economic launch vehicle in today's lineup is the SpaceX Falcon Heavy, with reusable boosters. Several hundred launches would be required to get the materials for one of these stations into orbit for assembly. Transporting the materials necessary to establish enough of these to satisfy our energy needs, in a reasonable time frame, does not seem realistic. The scale of launch activity would be overwhelming, and considering the numbers of times launches are delayed by the weather, starting from Earth simply doesn't appear a feasible way of doing it.

A better way would be to set up shop on the Moon, using it as a base for the implementation of the system. The Moon possesses many of the raw materials necessary for the fabrication of the equipment and structures. Without even prospecting for deposits of valuable minerals, just by scooping up the lunar dirt (regolith is the preferred term), we find abundant quantities of silicon (solar cells), aluminum (mirrors, wiring, structures), iron (structures) and oxygen, among other materials. We know there is water near the polar areas, perhaps abundant. It appears that a substantial amount of the weight that must be hauled around to build the solar power stations could come from the Moon, rather than being trucked up from Earth. And coming in from the Moon to Earth orbit is considerably easier than climbing up to Earth orbit from down here on the ground. Navigating through space is essentially a matter of climbing up and down what is often referred to as the "gravity well," illustrated below.



THE "GRAVITY WELL"

CREDIT: "The Case for Space Solar Power," John C. Mankins

This illustration represents the amount of energy required to get from one location to another throughout the solar system. The higher the climb up and down the well, the greater the energy. More energy means the trip is harder – bigger rockets, more fuel. In this figure, the

Earth is at the bottom of the well. Climbing up to low Earth orbit (LEO) requires a substantial amount of energy. Climbing further, up to geosynchronous orbit (GEO) requires another substantial amount. But from the Moon to GEO is only a very modest (relatively) amount: up a small amount, down an even smaller amount. Much easier getting to GEO from the Moon than from the Earth.

We know we can get to the Moon; we did that 50 years ago, with a technology base that is relatively primitive compared to what we have today. While not a walk in the park, setting up shop on the Moon to support the construction of an orbiting solar energy system is within our present capabilities. And these capabilities are continuing to grow.

CONCLUSION

There is suddenly renewed interest in returning to the Moon. NASA has identified that as a goal, and other countries are expressing interest. To date, NASA's objectives revolve around exploration, and learning how to live on a later thrust to Mars. So far, nothing is evident in NASA's thinking about actually using the Moon for practical purposes, such as a functioning base for providing something of tremendous importance and value here on Earth. This would be such a thing. And it should be factored into the planning.

To accomplish this, voices way beyond just those of the space industry will be necessary. It is not merely a local issue, nor even just a national one. It is a global issue, affecting everyone. There is no organized plan or program at present to pursue this avenue. No organization, commercial venture or government agency is promoting it. Rather, dedicated individuals, often working alone, have over the years been pushing forward with the concept, developing various of aspects of the technologies involved, taking advantage of technology advances in related fields where possible. Making this a reality will require a broad-based push from those who:

- Recognize the perils to civilization presented by Earth's changing climate
- Understand that to mitigate this, civilization must change, to obtain the energy it needs from non-greenhouse gas emitting sources
- To this end, the sun is the logical source of large scale, continuous, reliable energy
- The most effective way to collect the sun's energy is with orbiting solar collectors
- The most effective way to establish an orbiting solar energy collector system for the Earth is by using the Moon as a base of operations

We should press forward with this with determination. While there is still time.

EPILOGUE
A couple of closing thoughts:

After our ancestors discovered how to grow crops and settled down into permanent villages, population growth and changing climate forced them to band together, to cooperate, to establish and manage who got what parcels of land and the available water. Out of this grew what we call civilization. Currently, we face another changing climate crisis, one that is global in nature. Now, the vital commodity is energy. For an enterprise like this to succeed, it will require cooperation on a global scale, not just villages, not even just individual nations. The entire global population has a stake in this. An opportunity for another step upward in this thing we call "civilization?"

Long ago, the human race appeared in Africa. About 60,000 years ago, when we were still confined to Africa, the world was in the midst of a severe ice age, with so much of the water locked up in the polar areas that sea levels were much lower than now. At the same time, Africa was becoming drier. The mouth of the Red Sea, between what is now Somalia and Yemen, narrowed from its approximately 17 miles to a considerably smaller distance, perhaps 7 or 8 miles. Still open water, too deep to wade and too far to swim. Today, on a clear day, one can see across it. Back then, it would have been even more apparent that "over there" was another place, another place to live. A small group went; how we don't know, and the details of their decision and journey we don't know, but they went. Things must have been desperate where they were, to motivate the band to make that trip. With only their primitive stone tools. A big enough group that they began humanity's expansion around the world. Today we, their descendants, have covered the globe, and are facing another crisis, with times becoming desperate in many areas, and about to become more so. We stand on a new shore, so to speak, looking at another place, this time not over there, but out there. Not across several miles of open water, but across 240,000 miles of empty space. We have been out there before, we know we can get there, set foot on it, and do things there. Will we repeat what our ancestors did, and continue the journey? Or is this the end of the story?

SOURCES

- "Solar Power Satellites," Don M. Flourney, Springer, 2012
- "The Case for Space Solar Power," John C. Mankins, The Virginia Edition, Inc., 2013
- "New Developments in Space Solar Power." John C. Mankins, NSS Space Settlement Journal, December 2017
- "Space Solar Power: Enabling a Green Future with Economic Growth," National Space Society position paper, July 2019

AUTHOR

John Barber was a NASA engineer with the Apollo program. With the dismantling of the lunar exploration effort, he went into the field of public transit, first with the U.S. Department of Transportation, and then with private industry. He helped plan, design, build and operate rapid transit systems in the U.S. and throughout the world. Now retired, he is active with a number of charitable and non-profit organizations, and maintains a strong interest in both humanity's efforts to move into space and in preserving the habitability of this planet for future generations. He resides in Spokane, WA and can be reached at magneglide@comcast.net.