

COMMENTARY

Benjamin Franklin – America’s First Civic Scientist Summary of April, 2003 APS Meeting Session

Bo Hammer

The April 2003 Meeting of the APS was held in Philadelphia. Appropriately, the Fora on Physics and Society and on History of Physics, co-organized a session on Benjamin Franklin: America’s First Civic Scientist, to reflect on the impact of Franklin as a scientist immersed in public service. The session was inspired by Neal Lane of Rice University, who, as President Clinton’s science advisor, coined the term “civic scientist” as an appeal to scientists to become engaged in the policy process. A little reflection on the life and career of Franklin reveals that he left his mark in a way that can be idealized as that of the prototypical civic scientist. The session co-organizers were Michael Riordan of the Forum on History of Physics, who served as chair; and Bo Hammer, of FPS, who served as a discussant.

The session began with a wonderful reflection on Franklin’s personality and friendships by Claude-Ann Lopez, former editor of the Franklin Papers project at Yale. Franklin’s was a life lived through the written word. His legacy persists because so much of what he wrote remains accessible to the public. It was Franklin’s scientific accomplishments that gave him entrée into the courts of Europe, making him one of the most well-traveled Americans of his time. His journeys and his joie de vivre left him with friends throughout America, Britain, France, Russia, and elsewhere in Europe. He maintained his friendships through correspondences, which now provide insight into the workings of Franklin’s mind including his thinking on all topics of the day from politics to science, and the great degree to which he valued human contact as a way to propagate and refine his thoughts.

The next speaker was Nobel Prize-winner and science historian Dudley Herschbach, who established Franklin’s scientific bona fides and his life-long calling to public service. Herschbach characterized Franklin as a “curiosity-driven scientist and a service-driven citizen.” Indeed, Franklin’s science was inspired by a combination of inquisitiveness, skepticism of accepted wisdom, a need to constantly improve things, and a deep sense of social responsibility. Herschbach emphasized Franklin’s primary profession as a printer. Upon retirement in his early 40s, Franklin turned his full attention to science and public life.

James McClellan, a science historian from Stevens Institute of Technology, reminded the audience that the term, “scientist,” was not in use in Franklin’s day and that a career in “science” was much different then than it is now. Rather, in the 18th century today’s scientists would be labeled as “natural philosophers”. McClellan asked the audience to take a step back and consider that, despite Franklin’s remarkable contributions to the understanding of natural phenomena and the enthusiastic reception he received from the community of natural philosophers, Franklin really was not a scientist in the sociological sense of the profession. He did not, as McClellan put it, “enter the fray.” He was not fully engaged in the give and take of scientific discourse. And, while he published his work, he essentially ignored his detractors instead of engaging them in scientific debate in order to resolve disagreements on theory, observation, and conclusions.

The last speaker, Neal Lane, provided detail to his concept of the civic scientist, which he originally promoted as President Clinton’s science advisor as a way to encourage scientists to become more engaged in the policy process. Lane described the civic scientist and characterized Benjamin Franklin as America’s first scientist to fit this description: According to Lane, a civic

scientist should be a practicing scientist with sufficient professional standing to have credibility among colleagues, policy-makers, and the public. This individual must possess the wisdom and judgement necessary to understand when it is appropriate to apply scientific authority to policy issues and where the boundaries of this authority exist. A civic scientist should be able to communicate effectively with a variety of audiences in order to convey his or her message most effectively. A civic scientist must not expect to persuade by virtue of scientific authority; rather, he or she should understand the nature of political discourse and decision-making, and realize that progress is made incrementally through a process of compromise and consensus building. Finally, a civic scientist is one who is committed to applying scientific knowledge and experience to the benefit of the public.

Discussion

Biographer H.R. Brands entitled his biography of Franklin, *The First American*. Among his contemporaries abroad, Franklin was the prototypical American, with his somewhat rustic attire, his independent tendencies, his entrepreneurialism, and his creative and tireless drive to forge a new nation. Franklin was the first American, in the sense that he played such an important role in defining our national character. Not only was he instrumental in crafting the Declaration of Independence, the Constitution, and the Bill of Rights, but through his involvement in founding civic organizations, he shaped the role that citizens play in the civic life and governance of our cities and nations. His organizational activities as one of Philadelphia's leading citizens led to the creation of universities, hospitals, libraries, fire companies, and learned organizations -- and their associated philanthropic support -- that functioned outside of government or church control. As a result, Philadelphia became the prototype of the great American cities that persist today. These cities are uniquely American because their strength resides primarily in organizations and people outside of the government and church. In this sense Franklin represented what it means to be American, individually and institutionally.

Franklin's career had three phases. Remarkably, he worked nearly to the day he died in 1790 at the impressive age of 84. Franklin began his professional life as a printer, and throughout his life considered himself to be, above everything else, a printer. Franklin was successful as printer and leveraged his success by providing capital to other printers in Philadelphia and other cities. Income from his own business and from his partnerships was such that he was able to retire in his early 40s so that he could pursue other interests, the foremost of which were his investigations into the nature of electricity. The impact of Franklin's discoveries and inventions made him an international celebrity, so that when he was sent to London as the agent of Pennsylvania, he was received enthusiastically at the highest levels of government and science. Indeed, his scientific reputation and correspondence were such that upon his arrival in London he had an extraordinary network of well-placed friends and colleagues. He exploited this network skillfully on behalf of Pennsylvania and other Colonies.

It was Franklin's scientific reputation that enabled his success as diplomat and public man, his third career. Then, as today, scientific success and the reputation that attends it, can, under the right circumstances of motivation, connection, and interest, endow one with considerable authority. Franklin recognized this, and combined his authority with his keen mind, quick wit, and good cause, in order to effect great change on behalf of the colonies, and later the fledgling United States.

Public policy is infused with scientific and technical issues, perhaps more now than ever before. This may be especially true considering the impact of the questions at hand, such as the potential for global climate change, the need for energy alternatives to fossil fuels, the new ethics of biotechnology, nonproliferation of weapons of mass destruction, and appropriate science education. Franklin's blending of curiosity, questioning of nature, and civic-mindedness provide

an example for scientists to follow today, and we are fortunate that the Forum on Physics and Society provides a locus of activity for physicists interested in these issues and motivated to act. For those who are interested but not quite yet motivated, consider these motivational factors: because of the predominance of public funding that enables our livelihood, scientists have an obligation to account for the public impact of their work. Accordingly, because of the public trust accorded to scientists, scientists are in a position to have a relatively high degree of influence on policy makers.

There are many avenues open to those who wish to become more involved. For example, the Forum always seeks volunteers to organize sessions, write for this newsletter, and become involved in Forum leadership. Additionally, APS, AIP, OSA, AAAS, MRS, AGU, ACS, and many other professional societies sponsor policy fellowships that enable scientists to work as staff in Congressional or Executive branch offices. On a local level, members of Congress or state legislatures are open to well-reasoned advice and would probably appreciate hearing from a professor or industrial scientist living in their district. And for those who really want to get their hands dirty, school boards are, in many ways, the great political finishing school, and can have significant influence on science education matters.

Benjamin Franklin was, as America's first civic scientist, not only an instrumental figure in our nation's founding, but he also provided a model of personal action and habits of mind that are worthy of study and perhaps emulation. His curiosity and love of his fellow humans are infectious, and his words displayed a remarkable breadth of learning, wisdom, and inquisitiveness. Franklin's tercentenary in 2006, presents an opportunity to reflect on his legacy and consider how we can strive to use the privilege of our profession to improve the world beyond our laboratories.

*Phillip W. (Bo) Hammer
Franklin Institute, Philadelphia, PA
Bhammer@fi.edu*

Space Solar Power: An Idea Whose Time Will Never Come?

Steve Fetter

Arthur Smith laments the lack of attention to space solar power (SSP),¹ but SSP cannot compete with solar power based on earth. The advantage of SSP is a large and constant solar flux—1.37 kW m⁻² or 12,000 kWh m⁻² y⁻¹. This is about five times higher than the average flux on a sun-tracking surface in sunny areas on the earth's surface, such as the American southwest.² The larger solar flux in space cannot compensate, however, for the cost of placing systems in space and transmitting the electricity back to earth.

Smith correctly states that earth-based systems suffer from the day-night cycle and cloud cover, and the consequent need for energy storage or very-long-distance transmission. But earth-

¹ Arthur Smith, "Energy for Society from Space," *Physics and Society*, October 2003; Arthur Smith, "Letters: Energy Possibilities: Windows, Windmills, and Satellites," *Physics Today*, October 2002.

² Nearly all of Arizona, Nevada, New Mexico, and Utah, and significant portions of California, Colorado, and Texas, receive more than 2400 kWh m⁻² y⁻¹ of solar radiation on a sun-tracking surface, as do vast areas of northern and southern Africa, west Asia, and Australia, and significant areas in Chile and Argentina. See NASA, "Surface Meteorology and Solar Energy," <http://eosweb.larc.nasa.gov/sse>.

based solar systems could supply up to 20 percent of U.S. electricity demand³—the fraction currently provided by nuclear or hydro—without significant storage or long-distance transmission. Even if solar was used to meet all electricity demand—an unlikely scenario—only about half of the solar electricity produced by earth-based systems would have to be stored or transmitted over intercontinental distances. By comparison, 100 percent of SSP electricity would have to be transmitted wirelessly to earth, at efficiencies optimistically estimated at 40 percent. Moreover, SSP transmission is very likely to be less efficient and more expensive per kilowatt-hour than storage or transmission of electricity generated by earth-based stations.⁴

To see that SSP cannot compete with earth-based solar power, consider only the costs of the photovoltaic arrays. In order for SSP to be less expensive than earth-based systems

$$\frac{C_{pV} + C_L M}{\varepsilon S} < \frac{C'_{pV}}{[1 - f(1 - \varepsilon')] S'} \quad (1)$$

where C_{pV} and C'_{pV} are the installed unit costs of the photovoltaic arrays in space and on earth ($\$ \text{kW}_p^{-1}$),⁵ C_L is the unit cost of placing mass in orbit ($\$ \text{kg}^{-1}$), M is the unit system mass in orbit ($\text{kg} \text{kW}_p^{-1}$), S and S' are the annual solar fluences on arrays in space and earth ($\text{kW}_s \text{h} \text{y}^{-1}$), ε is the end-to-end transmission efficiency of the SSP system, ε' is the end-to-end transmission efficiency or round-trip storage efficiency for earth-based generation, and f is the fraction of earth-based solar generation that is transmitted very-long distances or stored. Assuming $S/S' = 5$ and solving for C_L , we have

$$C_L M < 5\rho C'_{pV} - C_{pV} \quad (2)$$

where ρ , the efficiency ratio, is given by

$$\rho = \frac{\varepsilon}{1 - f(1 - \varepsilon')} \quad (3)$$

The fraction of electricity generated by earth-based stations that is stored or transmitted very long distances, f , depends on ε' and the fraction of total electricity demand met by solar. If the later is small (<20%), then $f \approx 0$ and $\rho \approx \varepsilon$. If solar supplies all U.S. demand, then a comparison of the time correlation between U.S. demand and sunshine in the southwest gives $\rho \approx \varepsilon/\varepsilon'^{0.55}$. If we assume $\varepsilon = \varepsilon' = 0.4$ (an optimistic assumption for wireless transmission efficiency and a pessimistic one for earth-based storage or transmission), then $0.4 < \rho < 0.65$.

Space-based photovoltaic systems cannot cost less than the same systems based on earth systems, so $C_L M < C'_{pV} (5\rho - 1)$. In order to be economically competitive with other sources of

³ H. Ishitani, T.B. Johansson, et al., “Energy Supply Mitigation Options,” in Robert T. Watson, Marufu C. Zinyowera, and Richard H. Moss, eds., *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change* (Cambridge: Cambridge University Press, 1996), p. 617.

⁴ Many options exist for energy storage, including batteries, pumped hydro, compressed air, hydrogen production, and superconducting storage rings. Substantial room also exists for improvements in load management to better correlate electricity supply and demand, such as smart appliances and thermal storage in buildings. Intercontinental transmission is possible using existing technologies (e.g., between Africa and Europe) at efficiencies that are higher and costs that are likely to be lower than SSP transmission. SSP transmission technologies would, in any case, serve as a backstop for intercontinental transmission between earth-based stations via reflectors in orbit, ensuring that SSP transmission could not be cheaper than storage or transmission of electricity generated on earth.

⁵ Photovoltaic costs typically are given in dollars per peak kilowatt, where “peak kilowatts” is the electrical power output when the incident solar flux is $1 \text{ kW}_s \text{ m}^{-2}$; it is equal to cost per unit area ($\$ \text{m}^{-2}$) divided by efficiency ($\text{kW}_e \text{ kW}_s^{-1}$). Thus, $\$ \text{kW}_p^{-1} = \$ \text{kW}_s \text{ kW}_e^{-1} \text{ m}^{-2}$.

electricity generation, it is widely agreed that $C'_{PV} \approx \$1000 \text{ kW}_p^{-1}$. Thus $C_L M < \$1000$ to $\$2300 \text{ kW}_p^{-1}$, where the lower limit is considerably more realistic than the upper limit.

The current state-of-the-art for solar arrays for spacecraft is $M > 10 \text{ kg kW}_p^{-1}$. Although improvements are possible using flexible materials and/or concentrating lenses, it is unlikely that the total system mass, including platforms, power handling and transmission hardware, could be less than 5 kg kW_p^{-1} . Launch costs therefore must be less than $\$200$ to $\$460 \text{ kg}^{-1}$. For comparison, the current cost to low-earth orbit is about $\$10,000 \text{ kg}^{-1}$. Thus, even the most optimistic analysis requires that launch costs fall by a factor of 20 to 50 simply to allow SSP to break even with terrestrial solar power.

If space-based systems cost more than earth-based systems, as seems almost certain, the comparison becomes even less favorable for SSP. As indicated by equation (2), if space-based photovoltaic arrays cost two to three times more per peak kilowatt than earth-based systems, SSP would not be cost-effective even if launch costs were zero. Today, space-based arrays cost about 500 times more than earth-based arrays per peak kilowatt.⁶

If the costs of transmission and operation and maintenance are higher for space-based systems, the situation for SSP is worse still. If c_T and c_{OM} are the costs of transmission and operation and maintenance per kilowatt-hour of delivered electricity ($\$ \text{ kWh}^{-1}$) for SSP and c'_T and c'_{OM} are the corresponding costs for earth-based systems, equation (2) becomes

$$C_L M < 5\rho C'_{PV} - C_{PV} - \frac{S}{F}(c_T - fp c'_T) - \frac{S}{F}(c_{OM} - \rho c'_{OM}) \quad (4)$$

where F is the fixed charge rate (y^{-1}). Assuming, as above, $S = 12,000 \text{ kW}_s \text{ h m}^{-2} y^{-1}$ and $C_{PV} = \$1000 \text{ kW}_p^{-1}$, and also that $F = 0.12 y^{-1}$ (corresponding to an interest rate of 10% y^{-1} and an array lifetime of 20 y) and $c_T = c_{OM} = c = \$0.01 \text{ kWh}^{-1}$ (very optimistic assumptions for SSP)

$$C_L M < 1000 \left(5\rho \frac{C'_{PV}}{C_{PV}} + fp \frac{c'_T}{c} + \rho \frac{c'_{OM}}{c} - 3 \right) \approx 1000\chi(6\rho + fp - 3) \quad (5)$$

where χ is the cost ratio of earth-based systems to space-based systems (assumed to be equal for the array, transmission, and operation and maintenance costs).

In the most optimistic case for SSP, solar supplies all electricity demand and $\varepsilon = \varepsilon' = 0.4$, and $\rho \approx 0.65$ and $fp \approx 0.45$. If $\chi = 1$ (i.e., earth-based systems are no less expensive than space-based systems), then $C_L < \$270 \text{ kg}^{-1}$ for $M = 5 \text{ kg kW}^{-1}$. If, however, $\chi < 0.7$ (i.e., capital, transmission/storage, and O&M costs are more than 30 percent cheaper for earth-based systems), then $C_L M < 0$ and SSP cannot compete regardless of launch costs. Moreover, if solar supplies less than 20 percent of total electricity demand, then $\rho = 0.4$, $fp \approx 0$, and $C_L M < 0$ for all cost ratios less than one.

In summary, SSP could compete with earth-based solar power only if *all* of the following conditions are met:

- solar supplies ~100% of total electricity demand; s
- the cost of space-based solar arrays is reduced to $\$1000 \text{ kW}_p^{-1}$ and that earth-based arrays do not cost less than space-based arrays; t

⁶ The solar arrays for the International Space Station cost about $\$2.4 \text{ million kW}_p^{-1}$ ($\$450 \text{ million}$ for about 250 kW or 180 kW_p); the installed cost of large earth-based arrays is currently about $\$5,000 \text{ kW}_p^{-1}$.

- SP transmission costs no more than $\$0.01 \text{ kWh}^{-1}$ and is no less efficient and no more expensive than storage or intercontinental transmission of electricity generated by earth-based systems; S
- SP operation and maintenance costs no more than $\$0.01 \text{ kWh}^{-1}$ and is no more expensive than operations and maintenance of earth-based systems; *and* S
- launch cost to low-earth orbit (currently about $\$10,000 \text{ kg}^{-1}$) is reduced by a factor of 40, to less than $\$250 \text{ kg}^{-1}$. I

Much of the discussion surrounding SSP has focused on the last of these conditions. A launch cost of $\$250 \text{ kg}^{-1}$ corresponds to a cost of only $\$3$ to $\$5 \text{ kg}^{-1}$ for a disposable launcher—comparable to the cost of the propellants alone.⁷ Propellant for a reusable vehicle is likely to cost more than $\$50$ per kilogram placed into orbit;⁸ achieving a total cost of $\$250 \text{ kg}^{-1}$ would therefore require a total-to-fuel cost ratio of no more than 5:1. Given that the total-to-fuel cost ratio for the U.S. air freight industry is about 4:1, launch costs below $\$250 \text{ kg}^{-1}$ are probably unachievable with chemical rocket technology.

The probability the SSP could produce electricity more cheaply than solar arrays on earth is so small that any expenditure of federal funds for research and development on this concept would be unwise and unwarranted.

Steve Fetter
(*sfetter@umd.edu*)
College Park, MD

⁷ Placing an object in a polar orbit at 1000 km altitude requires a burn-out velocity of 8.4 km s^{-1} . Achieving this velocity requires 50 to 90 kilograms of disposable launcher per kilogram placed in orbit. The lower limit corresponds to a two-stage liquid propellant launcher ($f = 0.93$, $v_e = 3.1 \text{ km s}^{-1}$, $\Delta v_{ag} = 1.7 \text{ km s}^{-1}$); the upper limit to a three-stage solid propellant launcher ($f = 0.88$, $v_e = 2.7 \text{ km s}^{-1}$, $\Delta v_{ag} = 1.0 \text{ km s}^{-1}$, where f is the fraction of launcher that is propellant, v_e is the exhaust velocity, and Δv_{ag} is the velocity lost to air resistance and gravity).

⁸ The propellant-to-vehicle mass ratio for a single-stage-to-orbit vehicle $m_p/m_v = \exp(\Delta v/v_e) - 1$, where Δv is about 10 km s^{-1} for a 1000-km altitude near-polar orbit (including losses due to gravity and air resistance) and v_e is the exhaust velocity. Assuming $v_e = 3.8 \text{ km s}^{-1}$ for O_2/H_2 , $m_p/m_v = 12.6$; assuming $v_e = 2.9 \text{ km/s}$ for $\text{O}_2/\text{RP-1}$, $m_p/m_v = 29$. If 20 percent of the vehicle mass is payload, the propellant-to-payload mass ratios are 63 and 145, respectively. Assuming an O_2/H_2 mass ratio of 6 and O_2 and H_2 costs of $\$0.25$ and $\$4 \text{ kg}^{-1}$, the propellant cost is $\$50$ per kilogram of payload. Similarly, assuming an $\text{O}_2/\text{RP-1}$ ratio of 2.5 and RP-1 cost of $\$1 \text{ kg}^{-1}$, the propellant cost is $\$70 \text{ kg}^{-1}$.