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Historical Corner

Robert Emerson's 1949 Stephen Hales Prize Lecture: "Photosynthesis and the World"

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Robert Emerson (1903–1959; Fig. 1) was awarded the Stephen Hales Prize by the American Society of Plant Physiologists (ASPP; now the American Society of Plant Biologists, ASPB) in 1948 for his work on photosynthesis. His lecture was delivered at the 1949 ASPP annual meeting and is transcribed here.

Key words: American Society of Plant Biologists, Stephen Hales, Quantum Yield Controversy, Photosynthesis, Eugene Rabinowitch.

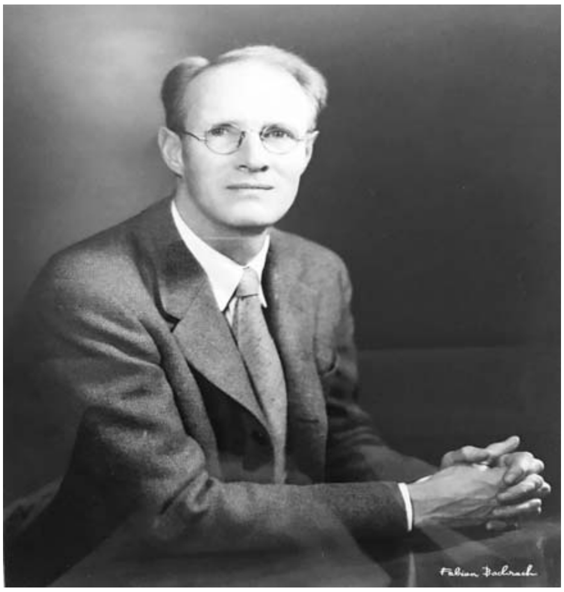
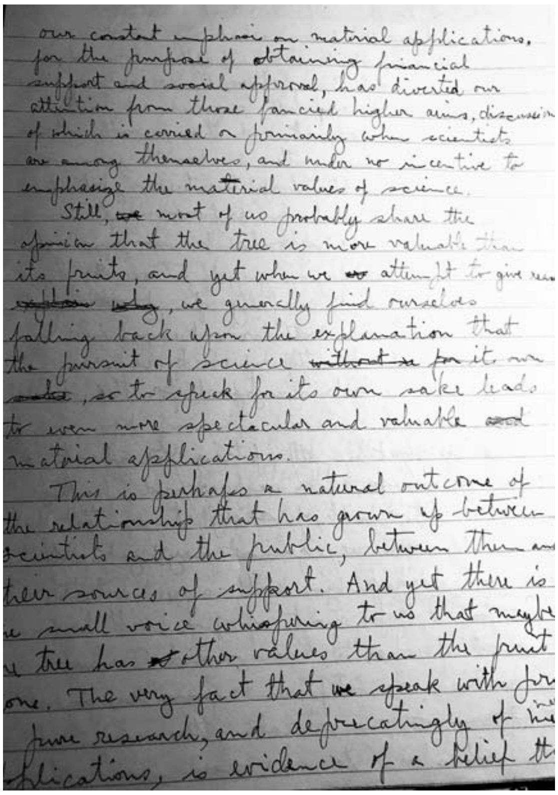


Fig. 1. A portrait of Robert Emerson. (The original was provided to Govindjee in 1959 by Emerson's wife, Tita. It was published in Rabinowitch (1961).)

Among Robert Emerson's achievements were (1) the very first experiments leading to the concept of a photosynthetic unit, that is, a collection of a large number of antenna molecules serving one "photoenzyme" (in today's language, reaction center) (Emerson and Arnold, 1932); (2) the correct minimum value of 10–12, not 3–4, for the quantum requirement for the evolution of one oxygen molecule, and the existence of a sudden drop in the quantum yield of oxygen evolution beyond 680 nm in green algae (the "Red drop"; Emerson and Lewis, 1943); and (3) the existence of an enhancement in photosynthesis (called the *Emerson Enhancement effect*) when two light beams, one in the red drop region and another at a shorter wavelength, are given together rather than separately (Emerson *et al.,* 1957), leading to the concept of two light reactions and two pigment systems, a precursor to the Z-Scheme (see Govindjee *et al.,* 2017). For a fuller story on the life and research of Robert Emerson, see Rabinowitch (1961) and Govindjee (2004). Presented here is a transcript of the lecture by Emerson on "Photosynthesis and the World," transcribed from his original handwritten text (see Figure 2 for a sample page). At places, I have annotated the lecture using brackets. I have done that for two reasons: (1) history (how we thought about things 75 years ago) and (2) because most arguments are still valid. Further, the lecture has not only historical, but philosophical and educational, values. At the end, I have provided the quotes that Emerson included in his notes.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This is perhaps a natural outcome of
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plications, is evidence of a belief th

Fig. 2. A photograph of one of the original, handwritten pages of Emerson's notes.

A note about the lecture

Robert Emerson received the 1948 Stephen Hales Prize, which is given annually by the American Society of Plant Biologists in honor of Hales for his pioneering work as reflected in his 1727 book *Vegetable Staticks*. The prize was established in 1927 "for a scientist who has served the science of plant biology in some noteworthy manner." The recipient of the award is invited to address the Society on a subject in plant biology at the following year's annual meeting. The text presented here is taken directly from the personal notes of Emerson for that speech. The lecture reminds me how Emerson and I would discuss science and the world around us; it starts with mention of the "maximum quantum yield of oxygen evolution," without any details (see Govindjee, 1999; Nickelsen and Govindjee, 2011; Hill and Govindjee, 2014). At the end, Emerson mentions traveling to the eastern sector of Berlin after World War II to see a glassblower. I know that all the glassware he ever used in his lab came from Germany, because he had the highest regard for the skills of those who made equipment for him there.

Photosynthesis and the World, by Robert Emerson, 1949

[Maximum Quantum Yield of Oxygen Evolution in Photosynthesis] Doubtless I am expected to say something about photosynthesis. Most of you are aware that there has been some disagreement as to the quantum yield of photosynthesis, and perhaps some of you are curious to know my present opinions concerning this controversy. I do not wish to minimize the importance of this disagreement. *Controversy over a scientific problem may serve a useful purpose, especially if it focuses attention on an important issue of principle, or even on matters of technique.* [italics added for emphasis] However, it seems to me that the questions at issue in connection with the quantum yield of photosynthesis are too complex for discussion at this occasion. Many of you have already listened to a number of scientific papers today, and perhaps all of you will be grateful if I do not inflict upon you the discomfort of further mental effort after a full dinner.

Many of you may be more curious about why we should concern ourselves with the quantum yield of photosynthesis, than you are in the precise value that I or others may believe to be most nearly correct. The question of why we concern ourselves with the quantum yield is perhaps a suitable one for our attention at the end of a busy day, *and which leads not unnaturally to the question of why we devote ourselves to any scientific problem.* [italics added] This last is a question to which all of us, from time to time, have given some thought. I cannot claim to have anything novel or profound to tell you, indeed many of you may have reached much the same conclusions that I have. Nevertheless, I would like to take this occasion to share these thoughts with you, for the matter is timely. Any of us may soon be called upon (if we have not been already) to search our innermost souls for an answer to the question whether we (or our students) can best serve the defense of democracy by devoting ourselves to the study of plant physiology along the lines of our own interests; or by entering the armed forces or government service and doing whatever some higher authority assigns us to do, be it weapons development, bacteriological warfare, or just plain "police action" for the United Nations.

To begin at the beginning, with photosynthesis, why are we concerned with the quantum yield of this process? Its place in the ecology of the world has been understood for about 100 years. During this 100 years, the world has witnessed a revolutionary industrial development. This has been accompanied by an enormous increase in the per capita consumption of power, and a correspondingly phenomenal increase in the human population. [Thomas Robert] Malthaus [https://en.wikipedia.org/wiki/Thomas_Robert_Malthus] was prematurely alarmist in predicting the failure of agricultural production to keep up with the population pressure. It is generally conceded that a considerable increase in agricultural production is still possible, though we dare not promise ourselves that the increase will keep pace with the still expanding population. But a new factor, not anticipated by Malthaus, has entered the picture: the expanding need for power as compared to food supply. Since long before the time of Malthus, the need of human beings for food has remained essentially unchanged. Each new member of the population, in ancient or modern times, required only some 2 to 3 thousand [2,000 or 3,000] calories per day. But the industrial revolution has brought about an enormous increase in the per capita need for power, and the curve is still rising at a sharply accelerating rate. To compare the present-day consumption of food and power, we may express both in the same energy units, for example kilowatts. Two slides show data gathered by the [U.S.] State Department. [Information on these slides has been deleted.] It is significant that the State Depart[ment] uses energy as a basis for foreign policy. You can see that the per capita food consumption is dwarfed by the power consumption.

These slides bring out one point not usually emphasized. While both the food and the power resources are drawn originally from the photosynthetic activity of plants, *the food resources are annually renewable through current agriculture, while the power resources depend almost entirely upon the products of photosynthesis remaining from past geologic periods*. [italics added] These resources are non-renewable.

There is no doubt that these facts are closely related to the political and economic problems which beset mankind today. Democrat, Republican, Communist, or Socialist may offer different interpretations, but certainly what we call the American standard of living depends primarily upon the power side of the statistics rather than the food side. Americans, though better nourished than most other nations, consume only a little more than their share of the world's food resources (Chinese 2200 cal/day, U.S. 3000 cal/day [this information is for the late 1940s]). But they [Americans] consume a much greater proportion of the power resources. In certain areas of the world (like parts of Arabia), the per capita power consumption is far below the world average, while in the U.S. it is considerably above, –25 to >10,000[KWh]. The per capita power consumption in America is 400 times what it is for Basutoland [https://en.wikipedia.org/wiki/Basutoland], which represents the minimum. [For a current estimate, see: http://www.nationmaster.com/country-info/stats/Energy/Electricity/Consumption/Per-capita]

The hope of the [certain] peoples of the world that they may raise their standard of living, to something even remotely approaching the American level, depends of course partly upon their access to food resources, but to a much larger extent upon their access to power resources. The threat of world war, which hangs over us today, stems, I believe, from the struggle for access to these resources, which are very narrowly distributed. One may doubt whether the improvement and extension of agriculture will be sufficient to provide an American standard of nutrition for all the peoples of the world. But one can hardly question that the world's power resources are far from sufficient to provide everyone with an American standard of nutrition for all the peoples of the world. [And] one can hardly question that the world's power resources are far from sufficient to provide everyone with the American standard of mechanization and power consumption. If this were attempted, it is estimated that known world power resources would be exhausted in 25 years.

Now that we have placed these two applications of photosynthesis in perspective, we may consider some of the reasons for studying the efficiency of the process. We often read in the Sunday supplement [of leading newspapers] that *as soon as we have found out how photosynthesis works, we shall be able to do it artificially, and then there will be no more food shortages. Alternatively, it is suggested that photosynthesis by plants be greatly expanded, for example by the growth of algae on a large scale, and that in this way the food shortage will be alleviated. Actually the world's food problems are in the field of distribution rather than production.* [italics added]

It may be that the first practical application of our knowledge of photosynthesis will be directed toward some sort of artificial food production. To me this seems unlikely, and also relatively unimportant, *since mankind's most pressing need is for a renewable power resource, and here an understanding of photosynthesis might help us a great deal. This seems to be the only example known to science of the large-scale conversion of energy in the form of radiation into energy in the form of chemical potential.* [italics added] The sun's radiation brings us abundant energy, but we do not yet know how to use this energy, except by first allowing green plants to convert it into a more available form. We cannot use it directly to make steel from iron ore, or to generate electricity, or to run prime movers such as automobiles and locomotives, except indirectly by using the products of photosynthesis-wood, coal, or petroleum-for doing these things. [see **note** 1 at the end of this article]

The ability of the green plant to convert radiant energy into energy of chemical potential appears to us more remarkable the more the sciences of physics and chemistry advance. The study of the relationship between the color and the temperature of sources of radiation led to the recognition of the quantum nature of light, and this in turn made the interpretation of photosynthesis seem more baffling, for a single quantum of visible light falls far short of providing enough energy to convert carbon dioxide and water to carbohydrate and oxygen. *We hope that through a closer study of the energy exchange of the plant, we may uncover the secret of how it makes the energy of several small photons serve to achieve so large a gain in chemical potential.* [italics added] If one must have a practical reason in mind for the study of the number of quanta used by the plant per molecule of carbon dioxide reduced, this should satisfy us.

Of course there is plenty of precedent for research with a practical objective. Stephen Hales, whose memory we honor here, was more gratified by his achievements in the ventilation of gaols [jails] and ships, and by the results of his efforts to restrict the sale of distilled liquors, than by his contributions to plant physiology. The founding of the Royal Institution was strictly for the purpose of making science serve the material needs of man. No one doubts that the expansion of industry, the increase in world population, and the rise in the standard of living, in short, the development of the American Way of Life, are the direct result of the application of scientific discoveries to the material needs of man. It is not surprising that the part played by applied science in the expansion of industry has led to a change in the attitude of scientists toward their profession. Stephen Hales in the early 18th century supported himself in the ministry, and did his scientific work on the side. Industrialization was in its infancy. He sought royal, not industrial patronage for his researches. [Sir Humphry] Davy by the end of the 18th century is credited with initiating the movement to make science the servant of industry [https://en.wikipedia.org/wiki/Humphry_Davy]. Both he and [Michael] Faraday [https://en.wikipedia.org/wiki/Michael_Faraday], his successor at the Royal Institution, earned substantial fees as consultants.

The financial support of scientific research has grown with the recognition of the value of research to industry. One of the things which worries us is the growing recognition of the service of research to war potential, although this is really nothing new. But whether our science serves the needs of war potential or medicine or industry, we are all proud of our profession, and certain that it merits financial support. It is natural that we seek the support from sources which are most obviously benefited by our work. Often we tell ourselves that in seeking to obtain financial support for research by emphasizing practical applications, we are doing so only because this is the most effective way to get the money which we feel we deserve for other reasons. We proudly tell ourselves that we are really interested in knowledge for its own sake—pure research. But pure research does not bring in very much money until we can persuade others that it leads to valuable applications. It has become easier and easier to do this, and I think it is not wrong to say that many of us have grown to believe that the practical applications of pure research are indeed the social justification for its financial support, even if we stoutly maintain that we study photosynthesis merely to add to human knowledge. As a matter of fact, it would be a great deal more difficult for us to explain why our additions to knowledge, or the pursuit of truth, should justify the support of our work. No matter how deeply rooted is our feeling that science has higher aims than its applications, our constant emphasis on material applications for the purpose of obtaining financial support and social approval, has diverted our attention from those fancied higher aims, discussion of which is carried on primarily when scientists are among themselves, and under no incentive to emphasize the material values of science.

Still, most of us probably share the opinion that the tree is more valuable than its fruits, and yet when we attempt to give reasons, we generally find ourselves falling back upon the explanation that the pursuit of science so to speak for its own sake leads to even more spectacular and valuable material applications.

This is perhaps a natural outcome of the relationship that has grown up between scientists and the public, between them and their sources of support. And yet there is the small voice whispering to us that maybe the tree has other values than the fruit alone.The very fact that we speak with pride of pure research, and deprecatingly of mere applications, is evidence of a belief that science must lead to other values in addition to the self-evident material applications. What can we have in mind? We must be thinking of ethical, moral, artistic, or aesthetic values. Of course, many of us devote ourselves to science partly because we enjoy it, and there is no harm in recognizing this as something separate from material applications, but it does not help us much in explaining to society why we should be so generously supported. People enjoy golf, too. So I think we must look carefully for possible moral, ethical, or aesthetic values, and see if we can honestly represent ourselves as deserving of public support for the sake of such values. [Several sentences in the original were crossed out, and, thus, deleted.]

So far, I hope most of you will agree with most of what I have said. Perhaps I can go one more step, and suggest that one reason the small voice whispers to us more insistently than it did to some of our predecessors is because our spectacular material progress seems to fall short of the hopes held out a few decades ago. Instead, the relations between science and destructive warfare is ever more inescapable, and we cannot help wondering whether, in formulating our views on the social relationships of science, we have overlooked some important point.

These considerations lead inevitably to the question of whether there are moral or ethical or other non-materialistic values to be derived from the pursuit of science. Even if you have agreed with me up to this point, I must expect that many of you will disagree with me from here on, and this should be a warning to me to say very little.

To me, it seems that science merits social support more because of its potential effect on the men who pursue it, than because of the material improvements which it brings about. I think the tremendous emphasis on material advances make it more difficult for us to either understand or harvest these potential dividends. Certainly if we give a productive scientist the most generous possible financial support, experience has shown that a veritable Niagara of valuable applications is obtainable. But what about the development of those human qualities which come under the heading of moral or ethical? Devotees of the separation of truth from its web of prejudice should develop qualities of humility, restraint, forbearance, etc. On the other hand, we see in our materialistic civilization, the development of self-indulgence, pride, and an admiration of the avoidance of work for its own sake. Scientists may not be the most self-indulgent of our social groups, and their self-indulgences may seem relatively innocuous compared to some others. But if their indulgences improve their output of results, they tend to approve of them, along with the rest of society. European society is probably not fundamentally different from American society in this respect, but it is sufficiently different in degree to afford us some pointers. Certainly, their intellectual achievements are not inferior to ours, in spite of the obvious material disadvantages under which most of them work. How can we continue to urge upon them the material advantage of our way of life, in the form of electric refrigerators, new model cars every few years, etc., when their interests are centered rather on the attainment of just a very modest and unmolested subsistence.

I am reminded of my conversation with a glassblower in the Russian sector of Berlin last summer. I told him of my difficulties in getting certain glass blowing done in the U.S., because so many glassblowers were making television tubes, night and day. I had some trouble explaining what television was, but he finally understood, and said yes, he remembered making some tubes, many years ago, for scientists who studied the principles involved in image transmission, but of course there was no public sale for such equipment in Germany, because people were so much more concerned with mere subsistence.

I could not help remembering that the factor, which had sent me to visit him, was the quality and integrity of his workmanship. I would draw a parallel with the quality and integrity of scientific workmanship.

[There are additional pages in the file that seem to be mixed up with large parts crossed out. Thus, they are not included here.]

Of what good is knowledge unless it serves human ends, and to what conclusion does this lead us, beyond the material advantages derived from applied science? We should ask, rather, are there ethical or moral ends? What is the effect of science on those who pursue it? I believe this is the best reason for the support of the profession. Science seems to me a valuable part of our civilization because it may serve to develop certain human qualities, which are valuable for ethical rather than material reasons. Science is not unique in this respect. Creative work of many kinds (literary, artistic, etc.) may serve the same ends. But science seems to offer a certain advantage. Whatever may be these ethical values to which I refer (and if anyone challenges me to specify them I shall have to agree it is very difficult), I believe they are especially developed through the pursuit of excellence. Excellence in art or literature is difficult to judge, because of the lack of objective standards.

In science, the quality of achievement may be judged on more nearly objective standards, that is to say, more of us are likely to agree, and with less lapse of time, than in the case of literary or musical or artistic creations.

Let us say then, that science affords opportunities for the development of the highest human qualities [see **note** 2 taken from another lecture in 1951]. We would soon find ourselves in disagreement if we were to attempt specific definition of these qualities, but maybe we can all agree that there are such qualities. To me it seems certain that this is a more cogent reason for the support of science than the material benefits derived from science.

My Reminiscence

I end this historical paper on Emerson's 1949 Stephen Hales lecture by giving a glimpse of my personal recollections of Robert Emerson, my first professor in the area of photosynthesis. To me, he was Professor Emerson, then Doc Emerson, but never Bob Emerson. He was a wonderful human being, and a highly considerate and caring teacher. He was the most highly skilled researcher I have known in my life. I learned a lot from him about laboratory techniques: culturing of algae, column chromatography for pigment separation, calibration of manometer vessels, using mercury, and above all Warburg manometry (along with measurement of absorbed photons) with a precision unmatched in the world—with the goal of measuring precise maximum quantum yield of oxygen evolution. His training included how to cook egg omelets so that I would not starve in the United States after I had arrived in his lab in September 1956. From September 1956 till September 1958, I was guided by Professor Emerson to become a biophysicist: taking all the possible courses in basic *mathematics* (analytical geometry, algebra, and differential calculus), *chemistry* (physical chemistry, including thermodynamics and biochemistry) and *physics* (basic atomic physics and optics). Professor Emerson and his wife Tita were wonderful hosts from the first day I arrived in Urbana, Illinois; he came to receive me at the Urbana train station and offered his home for us to stay on the day Rajni arrived in September 1957. Fig. 3 is a photograph of Professor Emerson with Rajni and me, taken in 1958. Unfortunately, he died in a plane crash on February 4, 1959. Rajni's and my greatest regret is that neither of us could publish any research paper with him. However, both of us are indebted to him for all our research training that led us to our own successful research life.

I now present some quotes Emerson used in his lecture.

***James Prescott Joule**

"The scientist must be humble, diligent, energetic, patient, and zealous. The first object of natural science is to elevate humanity in the scale of creatures, and the second is to promote well-being."

May Sarton

"...unable to disentangle truth from its web of prejudice. Discoveries are evanescent, because they are soon replaced by better ones. Discoveries may be important, but personalities are infinitely more so."

Samuel Taylor Coleridge

"The tree is more valuable than its fruits. The intellect itself–has it evolved? The methods of discovery, the mental experiences, the hidden mechanism of intuition –have they not remained somewhat the same?"

Alfred North Whitehead

"Throughout history, there have been men of 'philosophic temperament' who have been absorbed in the weaving of general principles. This has become a recognized and self-sustaining profession, only since the industrial revolution demonstrated its practical value."

[Unknown source; cf. Note 2]

"At present the improvements Science has supplied are sporadic, they deal only with material things, they are all geared to our physical well-being. And they have not made us happy."

Fig. 3. Left to right: Govindjee, Rajni, and Robert Emerson, Spring 1958.

Acknowledgment

I am highly obliged to Robert Blankenship for reading this paper and providing **note** 1. Emerson's handwritten material was provided to me in December 1999 by Ruth Emerson, daughter of Robert and Tita Emerson. I thank Jana Lenz of the Department of Plant Biology at UIUC for typing the text used here.

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I was not supported by any funding agency. Further, I declare no conflict of interest.

Notes

[1] The reader may be surprised that Emerson does not refer to photovoltaic (PV) cells in this paragraph, since they do precisely the things that he says that nothing else besides photosynthesis can do. However, in 1949, when this lecture was presented, commercial PV cells were not yet available. They were introduced in 1954 by scientists from Bell Labs in the United States. A detailed comparison of the properties and efficiencies of PV cells and photosynthetic organisms is given in Blankenship et al. (2011).

[2] From Emerson's unpublished lecture (handwritten on note cards) to the Layman's League on December 4, 1951, "Different Ideas of Truth in Different Professions, Even in Single Profession," which ended: "Science ought to serve primarily the man rather than his comforts. Science can be one of the ways, like music, poetry, painting, in which man discovers his spritual limitations, learns to put down his vanity & selfishness, makes himself and fellows into higher rather than lower form of life."

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