Part I
The Context

Artificial Photosynthesis: From Basic Biology to Industrial Application
Edited by Anthony F. Collings and Christa Critchley

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Artificial Photosynthesis: Social and Political Issues

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1.1
Introduction

All human life is dependent, directly or indirectly, on photosynthesis. Its direct effects provide the source of all our food, either as plant material or as the plants that feed the animals, birds, and fish we eat. The plants that harness solar energy are also the source of the oxygen we breathe and an essential component of the water cycle. At a more abstract level, the plants around us also contribute to our cultural identity, as well as being a source of spiritual sustenance to many people.

The feature that distinguishes modern industrial society from all previous epochs is our use of fuel energy. A modern Australian uses energy at a rate of about 6 kW (Lowe 1989). To express that in human terms, our energy use is equivalent to having about 50 slaves working in relays around the clock for each of us. Fuel energy does for us what slaves did for feudal despots: it cooks our food, washes our clothes, heats our water, entertains us, fans us when we are hot, carries us about, and so on. Most of the energy comes from the stored end products of millions of years of photosynthesis – peat, lignite, coal, oil, and natural gas. Earlier human civilizations depended on short-term stocks of stored photosynthesis products, especially wood. Harnessing the resources of coal, oil, and gas has enabled a dramatic expansion in energy use. The level of energy use per head in Australia is about 50 times that of societies that still use short-term photosynthesis products.

There is a clear link between the level of energy use in different societies and their material living standards, though not the simple causal connection that is sometimes assumed. For example, Hoyle (1978) argued that the standard of living in the U.S. was higher than that in the UK because of greater levels of energy use; therefore, the UK would be able to improve its living standard simply by expanding its rate of energy use. This claim is clearly false. The simplest way to increase energy use would be to make the process of converting energy

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into services less efficient, thus expanding energy use without any improvement at all in living standards; indeed, higher energy costs would probably reduce funds available for other purposes and lead to a perceived fall in material prosperity. This example illustrates an important point. Material comfort does not flow directly from the level of energy use, but from the level of services that the energy provides. As Lovins (1977) argued, people don't want energy; they want hot showers and cold beer – and a range of other energy services. A large four-wheel-drive vehicle uses three times as much fuel to travel one kilometer as an efficient small sedan, but the passengers have been transported exactly the same distance in similar comfort. An inefficient refrigerator uses two to three times as much electricity as an efficient one, but the contents are kept at a similar temperature. As modern technology has developed in an age of cheap energy, efficiency has not been a priority. A recent study suggested that it would be quite feasible to reduce energy use in the industrialized world to 25% of the present level without any significant loss of amenity, a goal that has since been adopted by such European countries as Denmark and Norway (Spangenberg 2000).

1.2 The Need for a Transition to Artificial Photosynthesis

In historical terms, the epoch of stored photosynthesis has been comparatively brief. Coal was seen as an inferior substitute when its use became widespread as a result of a shortage of wood in the late eighteenth century (Wilkinson 1974). The era of petroleum fuels began in the late nineteenth century. There are three reasons for believing that we are approaching the end of the present epoch: resource limitations, environmental problems, and social issues.

In resource terms, it could be said until recently that pessimists feared the peak of world oil production might be only five years away, and optimists thought it might be as far away as 2020 (Deffyes 2001). A special series of reports on energy in *New Scientist* recently pointed out that pessimists now believe that the peak of world oil production was actually in the year 2000 and that we are already on the downhill slope (Holmes and Jones 2003). There are still optimists who think that it might be 10 years away or more, but there is no substantial disagreement with the geological fact that the peak of world oil production, if it hasn't already happened, will happen in most of our lifetimes. After that we'll see the real show for which the 1970s was an out-of-town tryout, coming soon to a planet near you. Make sure you are sitting comfortably, because a long run is assured. In that near-future world, oil will become scarcer and more expensive. We will have to change the basis of our energy use for transport, which is implicitly posited on the assumption that there will always be cheap, readily available petroleum fuels. While current expectations are that we will have cheap petroleum fuels for a few decades, this belief is based on two heroic assumptions. The first is that there will be continuing stability in, and willingness to export oil from, the region we call the Middle East, despite the Bush administration's bumbling interventions. The second assumption is that the majority of the world's population will continue to do without the transport options we take for granted while we dissipate the dwindling supplies of petroleum in such selfish indulgences as car races, jet skis, motor boats, and using heavy four-wheel-drive vehicles for suburban trips. If the entire world used oil at the rate Australians do per person, and it could be pumped out fast enough, the global resources would last less than two years! So the first and most basic reason for moving away from the present pattern of fuel energy use is that we are dissipating a limited resource, making change inevitable.

The second reason for change is that the use of fossil fuels is causing serious environmental problems, at all levels from the local to the global. At the local level, fuel use in urban areas is the main cause of air pollution that is bad enough to pose serious health risks in many large cities (UNEP 2002). Technological change has led to improved air quality despite increasing fuel use in many cities of the industrialized world (UNEP 2002), but these gains are likely to be cancelled out by increasing vehicle use (Brisbane City Council 2002). At the regional level, the problem of acid precipitation has caused policy changes to reduce the production of sulfur dioxide as a byproduct of using fossil fuels (UNEP 2002). At the global level, the burning of increasing amounts of fossil fuels is the main cause of human-induced climate change; concern about this problem led to the development of the Framework Convention on Climate Change and its associated Kyoto Protocol, an agreement to curb emissions of carbon dioxide and other "greenhouse gases." While the science of climate change is still developing, the current scientific opinion is that emissions of carbon dioxide are about 2.5 times the capacity of natural systems to absorb the gas (IPCC 2001). In other words, global use of fossil fuels needs to be reduced to about 40% of the present level to bring emissions into balance with the natural carbon cycle. Even then, the long residence time of carbon dioxide molecules in the atmosphere means that concentrations will continue to increase for decades; thus, global temperatures will continue to increase for about a century and sea levels will continue to rise for several centuries. Recent scientific thinking suggests that climate change is accelerating and influencing other global cycles (Steffen et al. 2004), posing a very serious threat to the future of human civilization.

The third reason for change is an associated social issue. As discussed earlier in this chapter, the present pattern of fuel energy use is grossly unequal. At one extreme, average per capita energy use in the U.S. is more than 10 kW, while the figure in poor countries is about 0.1 kW – lower by two orders of magnitude. Both the resource limits and environmental problems discussed above mean that it is impossible for the entire world to use energy as the U.S. now does. On the other hand, the provision of such basic services as clean drinking water, adequate shelter, and reasonable nutrition in the poorer parts of the world will require increasing energy use. The only feasible way of squaring this circle is to move away from stored photosynthetic products to new forms of artificial photosynthesis. The case for moving in this direction recognizes the scale of the available resources. The natural flows of solar energy are four orders of magnitude greater than the present global energy use and therefore are larger than any conceivable future energy demand. In fact, the amount of solar energy that hits Australia in one summer day is of the same order of magnitude as the global annual energy use for all purposes (Lowe 1994). As other chapters in this volume show, there are many ways of capturing and storing enough solar energy to meet human needs.

1.3 Some Associated Social and Political Issues

The traditional approach in the physical sciences and engineering is a positivist model that sees science as objective knowledge, devoid of social or political content, while technology is seen as an unmitigated good. There are some serious problems with this approach to both science and technology. In the case of science, the great creative scientists always put considerable stock in their instinct or the aesthetic appeal of the theoretical models they derived, thus celebrating the emotional dimension of their science. It is now appreciated more generally, though not yet universally, that our perception of the world is inevitably influenced by our values, our culture, and our predisposition, so that our engagement with nature and the production of knowledge are invariably social processes. Some knowledge is neutral and can be used for good or ill. The laser has no political content in itself, but there is great political significance in the choice to use it for entertainment, for healing, or to guide weapons of mass destruction. Other knowledge has embodied political content: the neutron bomb or biological weapons can only be used to kill people.

Deciding how much public money will go to science is a political choice. Political considerations also influence the mechanisms for allocating research funds, the membership of granting bodies, the priorities for research spending, and even the assessment of specific proposals. Though most researchers would like to believe that the peer review process leads to the funding of the most-deserving applications, there are some serious problems with that belief. The first is that the process can never be objective. We all see the world through the lenses of our values and experiences. Economics is probably the extreme case of a discipline in which one ideological position has effectively crowded out all others, but there are only differences of degree between it and other fields. It is chastening to recall that the peer review process failed to fund the two crucial pieces of research that together showed that the ozone layer was being depleted; the work was done only because the researchers had access to discretionary resources that allowed them to proceed against the considered opinion of their academic peers (Lowe 1989). It is thus very important for the peer review process to be supervised by researchers who are open-minded and who together repre-sent the mainstream of thought in their broad field.

That raises the second problem, namely, that Research Council panels have enormous influence. They choose the reviewers for proposals, and they also have the right to vary the rankings that emerge from the review process. But the choice of the funding panels is always political, in the sense that there are always many individuals who are qualified for appointment to the small number of positions. Governments tend to choose what Sir Humphrey Appleby called "sound chaps" – mostly males, in senior positions and meeting the definition of being "sound" because their values are similar to those making the choice. The Howard government has gone further than any in Australian history to make explicitly political choices in its appointments. While ideology may not play an obvious role in ranking proposals in pure mathematics, it certainly does in some other fields of inquiry – including some of the most obvious forms of artificial photosynthesis.

The range of fields covered poses the third and most intractable problem. If we leave aside the issue of objectivity, it would be possible, in principle, for the peer review process to rank research proposals in a narrow area where accurate comparisons can be made: inorganic chemistry, number theory, behavioral psychology, or medieval history. But there is no way, even in principle, of determining the relative merit of the number theory proposals and the projects in behavioral psychology; there are no polymaths who could make such comparisons. Consequently, the granting process effectively decides the share of funds that will go into each area through a process of horse-trading and then allocates within each area by a ranking process. When I studied the ARC grants going into different fields of science several years ago, I found that the success rate in a discipline like chemistry varied widely from year to year, but the share of the funds going to chemistry stayed remarkably constant (Lowe 1987). Therefore the chance of a research proposal in artificial photosynthesis being funded is affected by the fraction of the total research budget available for the broad field in which the project lies, and that fraction is in turn determined by political considerations.

The final problem is that those allocating limited funds will always tend to err on the conservative side, so that a shortage of funds almost guarantees that there will be no support for radical proposals that cross the boundaries of traditional disciplines or question long-established theories. In the modern world, the most important research problems often involve several disciplines. In areas where conventional wisdom is clearly failing us, we desperately need to be supporting new approaches. Some of the most promising ideas in the field of artificial photosynthesis struggle for funding because they cross the traditional disciplinary boundaries that still shape priorities for research funding. As an extreme example of this problem, funding of energy-related R&D in Australia since the 1970s has consistently been dominated by the two vectors least likely to be significant in the next century: coal and nuclear energy (Lowe 1983). As this chapter was being finalized, greater government support was going to investigate the speculative technology of geo-sequestration, capturing and trapping carbon dioxide in geological formations to allow expansion of coal burning, while support for solar energy was actually reduced by a decision not to renew funding for the Cooperative Research Centre in that field. Clearly, values influence the opinion of decision-makers determining which field is more likely to contribute to solving the problem of global warming. This became a political issue in 2004, with Democrat and Green senators questioning whether it was appropriate for the Australian government to be advised in this area by its current Chief Scientist, who is also Chief Technologist for the mining corporation Rio Tinto (Guilliatt 2004). Since the interests of Rio Tinto are clearly served by an approach that provides for increasing use of coal, those who disagree with this emphasis logically see the Chief Scientist's advice as reflecting his values.

Applying science to produce new technology is even more blatantly political. We can never change only one thing in a complex system, so the use of new technology always produces losers as well as winners and costs as well as benefits. Scientists and technologists have a responsibility to be aware of the consequences of their work and to realize that no technology is ever purely and universally beneficial. It will always benefit some people and some groups more than others. In the extreme case of military technology, its entire purpose is to give one group or nation an advantage over another. In the case of Concorde, a huge R&D budget and large operating subsidies were used to produce a technical marvel that for 25 years allowed a small number of rich people to cross the Atlantic faster, with little benefit to the broader public, many of whom suffered a greater level of noise nuisance. The opposition to some technological advances is based on the perception of some people that they will not actually benefit. In many cases, that perception is clearly accurate; as Alan Roberts says, wherever uranium is enriched, the taxpayer is impoverished! Examining the costs and benefits can often lead to a clear conclusion about the winners and losers. In other cases, the jury is still out. It might, for example, turn out to be true in the long term that the benefits of genetic manipulation of food crops will outweigh the risks, as is now claimed by its proponents. It might also turn out that the negative effects will outweigh the benefits, as is now claimed by opponents. In the short term, all we can do is scrutinize the competing claims and attempt to assess their credibility.

The traditional process for assessing technology has concentrated on its technical efficacy and its microeconomics: whether it is a cost-effective way of achieving the stated goal. We now know that a wider canvas should be used. The former Resource Assessment Commission developed a framework for considering complex issues (RAC 1991). The RAC argued that it is possible to assess separately the economic costs and benefits of a proposal, the environmental risks, and the social costs and benefits, with suitable qualifications on the accuracy of these estimates. The three "columns" cannot be weighted and added together in some sort of modern felicific calculus to show whether a proposal provides a net benefit or not, the RAC said. An appropriate process is to document the three areas and have a public debate to decide whether the net economic benefits justify the environmental risks and the net social costs (or benefits). The political problem is that governments are uncomfortable about making such overt value judgments; as I have argued elsewhere, they prefer to give the impression that “expert advice” leads to a logically compelling conclusion (Lowe 2003).

1.4
Using the Available Photons: Towards Sustainability Science

The various types of artificial photosynthesis are effectively competing for the right to harness incoming photons and use them for the community’s benefit. Other chapters in this book discuss the technical merits of particular possibilities, dealing with such issues as the efficiency of turning the incoming sunlight into useful energy. That is necessary but is not sufficient to enable wise decisions. It is equally important to assess alternative ways of using photons for their social and environmental impacts. Whether we engage in large-scale production of silicon-based photovoltaic cells, polymeric cells, photosynthetic hydrogen production, or bacterial energy production, scaling up the process to meet a significant fraction of human energy needs would have a range of demands on resources and social organization, as well as causing a range of local and global environmental effects. The emerging field of “sustainability science” provides guidance for the research approach that should be used to avoid making some of the past mistakes (Kates et al. 2001).

Sustainability science recognizes that our understanding of nature-society interactions is still limited. Although there have been substantial advances in recent decades through work in the environmental sciences that factors in human impacts and work in social and development studies that takes account of environmental influences, we still have to accept that modern science can be described as islands of understanding in oceans of ignorance (Ehrenfeld 1999). We are constantly engaged in land reclamation, but there is no chance of filling in the oceans. We need to set some broad priorities for our limited scientific effort. At the top of the list should be the urgent need for a better general understanding of the complex dynamic interactions between society and nature. That will require major advances in our ability to analyze the behavior of complex self-organizing systems, as well as developing better understanding of the irreversible impacts of interacting stresses. We need to work at multiple scales of organization and consider the impacts on natural systems of various social actors with different agendas, ranging from environmentalists standing in front of trees to bulldozer drivers pushing them over and Cabinet ministers telling us it is justified because it promotes economic growth.

Case studies from all the inhabited continents show that many of our serious environmental problems are the direct result of applying narrow, specialized knowledge to complex systems (Kates et al. 2001). Agronomists have advised farmers on fertilizer use to improve pasture, but the changes have put unacceptable nutrient loads on waterways. Expert advice has allowed fishing vessels to catch more seafood, leading to depletion of fisheries. Irrigation systems have made it possible to grow new crops but have also deprived streams of the flows needed to maintain riverine ecologies. Species introduced to control one pest have driven other native biota to extinction. Coal-fired power stations provide cheap electricity, but their carbon dioxide emissions are now changing the global climate. So there can be no doubt about the worrying conclusion that great damage can be done by the application of narrow, specialized science without an appreciation of the complexity of natural systems.

We need to address these issues through integrated scientific efforts that focus on the social and ecological characteristics of particular places or regions. Therefore, sustainability science must differ fundamentally from most science as we now know it. The traditional scientific method is based on essentially sequential phases of scientific inquiry such as conceptualizing the problem, collecting data, developing theories, and applying the results. But these familiar forms of developing and testing hypotheses have run into difficulties as we study complex nonlinear systems with long time lags between actions and their consequences. The problems are complicated by our inability to stand outside the nature-society system; thus, we cannot even in principle be objective observers of the system. Think of the parallel of two people with different allegiances watching a football match. If you talk to them, it can be difficult to believe they are watching the same game. They will differ about matters of fact, such as whether the ball was over the line, about matters of judgment, such as whether a foul was committed, and sometimes even about the visual acuity of the official in charge, or the official's integrity. Our situation is worse than those biased observers, because we are actually out on the muddy field! We can't see the whole game and we have an interest in the outcome that affects the way we see the action around us. As part of the nature-society system, we cannot stand outside it and be an objective observer.

We therefore have to accept that our engagement with complex natural systems cannot be based on the old model of rational objective science. The traditional sequential steps must become parallel functions of social learning, additionally incorporating the elements of action, adaptive management, and policy as experiment. Sustainability science therefore needs to employ new methods, such as semi-quantitative modeling of qualitative data and case studies, or inverse approaches that work backwards from undesirable consequences to identify pathways that avoid those outcomes. Scientists will need to work with other interested parties, such as land users or manufacturers, to produce trustworthy knowledge that combines scientific excellence with social relevance.

Meeting the challenge of sustainability science will also require new styles of institutional organization to foster interdisciplinary research and to support it over the long term, to build capacity for that research, and to integrate it into coherent systems of research planning, assessment, and decision support. Around the world, researchers are working on the core questions of sustainability science: the fundamental character of nature-society interactions, our ability to guide those interactions along more sustainable trajectories, and ways to promote the social learning we will need to navigate a transition to sustainability (Kates et al. 2001). We urgently have to develop mechanisms that will nurture those research activities. This is essential if we hope to change to social practices that will allow us to use natural systems sustainably.

1.5 Conclusions

As other chapters in this volume show, there are many technically promising avenues of artificial photosynthesis. The entire field deserves urgent support as we near the end of the era of dependence on stored photosynthetic products. Past practice shows that development and use of technologies on a large scale will have economic, social, and environmental consequences. A broader assessment of new technologies is demanded by the increasing capacity of human activity to perturb the natural systems on which our survival depends. The emerging field of sustainability science suggests an approach for handling these complex and difficult issues. They are a challenge not only to the scientific community but also to our political institutions. It is no exaggeration to say that the survival of human civilization depends on our ability to respond to this challenge.

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