

Case History of R&D Project

Lessons learned in commercializing solar collector research by university relevant to many situations

BY R.E. COLLINS*

Research on solar energy at the University of Sydney began in 1974, although planning for this work had commenced many years earlier. In the 1970s the university had available money entitled "University Development Grant." This money was specifically allocated to enable the university to establish new research activities in worthwhile areas. The work that began in 1974 was funded from such a University Development Grant and jointly by the Science Foundation for Physics within the University of Sydney.

At the beginning of the research a decision was made to concentrate on solar thermal collectors capable of delivering heat at temperatures significantly above those obtainable with conventional solar collectors. In approaching this problem the group placed considerable emphasis on the development of selective surfaces—surfaces that absorb most of the radiation that falls on them (and therefore are quite "black") but which, unlike most black surfaces, radiate energy at a very low rate.

Within a couple of years the group had indeed made major advances in selective surface technology. They had developed a surface which had excellent optical properties and, moreover, which was quite simple to produce. It appeared to be very stable in a vacuum environment. The combination of selective surface and vacuum insulation enabled the group to produce solar collector tubes which heated to temperatures of around 300°C in nonconcentrating sunlight.

The University Development Grant ended after four years, at the end of 1977. As this time approached, there was a very real prospect that the group would cease to exist and that the promising developments that had been made would be carried no further. Around this time Professor Harry Messel, the head of the School of Physics and Director of the Science Foundation within the University of Sydney, generated a great deal of interest and enthusiasm for the advances that had been made.

Professor Messel approached the New South Wales Government for support. As a result, New South Wales Premier Neville Wran announced that he would

*School of Physics, University of Sydney, Sydney, Australia; paper presented at Annual Conference, LES Australia/New Zealand, March 1983.

grant \$1.083 million to support this project for the period 1978 to 1980. The purpose of this grant was to enable the research in this promising area to continue with the hope that a commercially-viable product would emerge. The University of Sydney signed an agreement with the New South Wales Government giving the government certain rights in return for this funding and undertaking to perform appropriate research.

Second Grant

Very shortly afterward a second large grant was received by the university. This grant for \$5 million was made by His Royal Highness Prince Nawaf Bin Abdul Aziz of the Kingdom of Saudi Arabia. Initially, \$3.5 million was paid to the university in return for licensing rights to inventions made by the university in many countries around the world. The remaining \$1.5 million was received some years later after extensive negotiations that resulted in an extension of these licensing rights.

In a very short period, the Solar Energy Group within the School of Physics went from having the prospect of imminent extinction to being one of the best-funded research groups within Australia. This is not to imply that the group has an infinite amount of money or has squandered the money that is available to it. Indeed, the funds that are available are carefully managed to ensure proper expenditure and long-term viability of the research activity.

The funds available, however, have enabled the group to extend its activities into areas related to the selective surface including collector development and applications of solar collectors. These funds have also given the research workers a great deal of flexibility in directing their efforts in a way that is most appropriate for the benefit of the project.

In return, however, the availability of these funds brings with it a requirement to succeed. That most useful excuse for failure—lack of financial support—is not available to us. Having stated our goals publicly, and being provided with sufficient funding, we have no excuse for failing to meet those goals. I personally find this a most satisfactory environment in which to work.

In 1981 the New South Wales Government extended its original grant by a further \$800,000 for 1981-1982. This funding was granted specifically to enhance the prospects of commercialization. It was argued that the work was moving very rapidly toward the stage of being commercially viable and that a cessation of funds at that point could be quite damaging.

Funding from the New South Wales Government ceased at the end of 1982. It is appropriate at this time

to acknowledge the contributions that this funding have made, and to express the gratitude of the University to the New South Wales Government for its foresight and initiative in providing such funding. We believe that the confidence expressed in the University was not misplaced.

Major Aim

Since its inception, a major aim of the research work at the University of Sydney has been to develop surfaces and solar collectors that will find commercial application. This project is therefore somewhat different from the average university research project in that it has always been highly oriented toward the end application.

Indeed, right from the start, attempts were made to establish liaison and collaboration with industry in order to stimulate commercial interest in the work of the group. These attempts were intensified when I joined the group in July 1980. I came to the university from the New South Wales Institute of Technology after having about 14 years industrial experience where a principal interest was technology generation and transfer into a production environment. I intensified the efforts of the group to commercialize its work and placed a very high priority on industrial interaction at every possible level.

In March 1981, the university signed a licensing agreement with a Japanese company, Nitto Kohki Co. Limited. This company has now established a large-volume production facility in Japan and is manufacturing collector tubes under basic patents obtained by the university.

His Royal Highness Prince Nawaf has established a company in Spain—Solar Science Corporation—which is exploiting the developments in the territories that he controls around the world. Finally, the university hopes shortly to conclude an agreement with a large Australian company—Rheem Australia Limited—for commercialization of the developments in Australia. These licensing activities are discussed in more detail below.

TECHNICAL

The first major advance made by the research group at the university was development of a new selective surface with outstanding properties. The existence of this selective surface has been the stepping stone from which all work proceeded and the basis of funding.

As stated above, a selective surface is a surface that behaves differently in different parts of the optical spectrum. In a solar collector, a selective surface is required to be highly absorbing in the visible part of the spectrum. Very little of the radiation that falls on it is therefore reflected. The surface is very black.

Most black surfaces, however, radiate energy rapidly when they get hot. For once nature was kind to us and arranged that the part of the spectrum in which energy is radiated for objects up to a few hundred degrees Celsius is essentially distinct from the part of the spectrum in which solar radiation occurs. Energy is radiated from hot bodies at a few hundred degrees Celsius in the infrared at wavelengths greater than

about 2 μm . Virtually all the solar radiation occurs in the visible and near infrared at wavelengths less than 2 μm .

It is possible to use this fact to produce a surface which behaves differently in the two spectral regions. To do this one must incorporate structure on the surface the size of which is of order the transition wavelength between the two regions, that is about 1 μm .

There are many selective surfaces available for solar collectors. The surface developed at Sydney University differs from these in several ways. In the first place, it is highly selective, i.e. almost completely black in the visible (absorptance of around 93%) and radiates at an extremely low rate in the infrared (emittance around 3.5%). In addition, the surface is very cheap to produce and it is extremely stable at high temperatures. From our research, we know a great deal about why this surface is so stable, and what degradation modes are important.

The stability of the selective surface is extremely important for two reasons. In the first place, solar collectors with a good selective surface and vacuum insulation can achieve very high temperatures—in excess of 300°C—in nonconcentrated sunlight. At these temperatures, permanent degradation of the surface will occur if it is not very stable. The surface will literally destroy itself.

All solar collectors at some stage of their life are subject to such stagnation conditions. In fact stagnation may occur for considerable periods of time. In addition, a surface that is stable at very high temperatures gives rise to a number of options in manufacturing that can result in significant cost reductions. For example, our selective surface is baked out at 500°C during tube evacuation. This greatly reduces the time (and therefore cost) of this step in the manufacturing process.

Selective Surface

The Sydney University selective surface, as it is now called, is a multilayer surface that is deposited onto a glass tube. The underlayer of the surface is a thin layer of copper that has a very low emittance and is responsible for the low radiation rate observed from the surface. Copper, however, is not highly absorbing and it is therefore necessary to put a layer over the copper that will reduce the reflectance in the solar part of the spectrum while not increasing the infrared emittance too much. This layer in the Sydney University surface is a metal carbide.

The metal is a combination of nickel, iron and chromium—the constituents of stainless steel—and it is deposited in non-stoichiometric proportions with carbon. In fact, the ratio of metal to carbon varies through the thickness of this upper layer. The layer is metal-rich on the inside near the copper and is virtually pure carbon on the outside where the solar radiation strikes. This grading of composition results in greater absorptance in the visible.

The surface is formed by a vacuum deposition process called sputtering. Sputtering is a word used to describe the erosion of a metal surface by energetic-charged particles from a gas discharge. Positively

charged atoms, called ions, bombard the negative metal electrode in the discharge and remove atoms from this electrode by a momentum-transfer process. The removed atoms are deposited on surfaces located near the discharge.

In our case, these surfaces are the glass tubes. Initially, the layer of copper is deposited by bombardment of a copper electrode in pure argon. After a sufficient thickness has been deposited (about 0.1 μm) the discharge is switched off and the copper electrode replaced by a stainless steel electrode.

The discharge is then run with a gas mixture consisting of argon and hydrocarbon, normally acetylene. In the discharge the acetylene decomposes to carbon and hydrogen. Much of the hydrogen is removed by the pumps of the vacuum system, although some is incorporated in the surface. The carbon is deposited together with sputtered metal atoms from the stainless steel electrode.

The ratio of carbon atoms to metal atoms can be controlled simply by varying the amount of reactive hydrocarbon gas in the discharge. In this way, the desired proportions of metal to carbon, and therefore the refractive index profile, in the surface can be obtained.

Equipment has been built at the university to deposit the selective surface on many glass tubes concurrently. The Sydney University "batch coater" is capable of producing 20 tubes at a time. In Japan, Nitto Kohki has taken this concept and re-engineered it for larger production rates and easier tube handling.

The Nitto Kohki batch coater can produce 50 tubes at a time and about 1,000 tubes per shift. The technology to do this is fairly standard and uses conventional vacuum equipment. Specialized engineering techniques are of course involved in the design of this specific equipment.

Optimum Size

There is controversy about the optimum size of the glass tube for a solar collector. At present, the absorber tubes made at Sydney University and at Nitto Kohki are about 1.5 m long and 30 mm diameter, and sealed at one end. They are therefore about the size of a 40 watt fluorescent light tube and look like an elongated test tube.

It is necessary for vacuum insulation and for stability of the selective surface to locate the selective surface in a vacuum. This is done by inserting the absorber tube into a second glass envelope, 38 mm diameter, and joining the two tubes together at the open ends. The air is then removed from the space between the tubes and the outer tube sealed off. The construction is identical to that of a conventional thermos flask. There is very little new under the sun. Indeed, a basic patent on such a thermos flask construction for a solar collector was lodged and granted around 1910.

The vacuum is an extremely important part of the solar collector. The Sydney University surface is not air stable. At high temperatures in the presence of oxygen it degrades rapidly. In a vacuum its stability is extraordinarily good. Moreover, the vacuum eliminates conduction and convection losses from the hot selective surface. In a good-quality flat plate collec-

tor with a nonselective surface such losses are about the same order of magnitude as radiation losses. The vacuum is therefore an essential requirement if high temperatures are to be produced.

The university has undertaken extensive research on the stability of the vacuum and on various ways in which it may be degraded. This can occur as a result of leaks in the glass envelope and from outgassing of the surfaces within the tube including the selective surface.

Another possibility is diffusion of gas directly through the glass envelope walls. Helium, in particular, is a gas that can move through pyrex glass at a fairly high rate and there is a small proportion of helium in the atmosphere. Our work indicates that with suitable precautions, all of these effects can be reduced to negligible levels.

Combined with a very extensive research program that has yielded information on the structure, properties and degradation modes of the selective surface, we are therefore very confident that the evacuated double-tube thermos flask assembly is a highly stable and reliable component that is suitable for incorporation into solar collectors.

Analogy

This component analogy for the glass absorber tubes is a good one and is paralleled very closely by the component nature of the fluorescent light tube. The economics of fluorescent light tubes depend on the existence of large centralized manufacturing facilities. The availability of fluorescent light tubes enables many manufacturers to set up and make light fittings which use such tubes. Similarly, with evacuated solar collectors, economic pressures will result in centralized manufacture of the tubes and use by many solar collector manufacturers in different designs and possibly for different applications.

In order to produce a solar collector it is necessary to design a system that will extract the heat from the open ends of several evacuated tubes in a cheap and reliable way. All heat extraction techniques involve the circulation of fluid into and out of the tube. The emerging fluid carries with it heat that has been produced by absorption or sunlight.

There are several basic approaches to solar collector design. In one method the glass tube is simply filled with liquid that flows into and out of the tube by external pumping or by natural convection. This approach has the advantage of using the minimum of metal hardware. However, breakage of a single tube can result in liquid loss from the whole collector array. The system has a "hard-failure" mode.

An alternative approach is to contain the circulating liquid within a metal pipe. A U-tube is one suitable geometry for this design. Heat absorbed by the selective surface is conducted through the glass inner tube and transferred to the metal U-tube and thence to the circulating liquid. Such a design is less susceptible to breakage. However, there is considerably more hardware involved and the costs are greater.

Other approaches utilize heat pipes—evacuated tubes containing a small amount of condensible fluid that can extract the heat from the tube. I believe that

all such approaches will be used in the future. The tube component by itself is extremely versatile and lends itself to many different applications and concepts.

Applications

A solar collector therefore consists of an array of tubes, perhaps 10 to 20. It can be regarded as a device for producing heat from the sun. What are the applications for such a device?

Heat is an essential component of our society and is used in many ways. Solar collectors have traditionally been used in applications where heat is required at fairly low temperatures. Flat plate collectors are commercially viable for heating swimming pools and providing domestic hot water. Evacuated collectors can operate in these temperature ranges and at higher temperature ranges as well. In these higher temperature ranges up to around 150°C heat can be used to produce air conditioning, water sterilization, washing, for industrial process heat, and desalination.

All of these applications are technically possible and have been demonstrated more than once for different sorts of evacuated collectors. Whether these applications constitute a market, i.e. whether they are economic, will be dealt with in the next section.

At the University of Sydney we have undertaken considerable research and development on heat extraction techniques from evacuated tubes, methods of connecting tubes together to form complete collectors, and use of these collectors in various applications. We have built several field trial installations most of which are still operating satisfactorily and generating data which is used for designing further systems and comparing the performance of one system concept with another.

All of our work is, of course, taking place with interaction with other organizations in Australia and overseas. The Sydney University evacuated collector tube is by no means the only device of its type in the world. There are at least 10 other evacuated solar collector tubes that depend on similar physical principles. In addition, many installations using evacuated collectors have been built and are operating. The results of performance of these installations are available in scientific literature and through personal contact with other workers in the field. Our own research program is undertaken with very great attention to related work by others.

COMMERCIALIZATION

Since its inception, this project has placed considerable emphasis on commercializing the developments that have been made. Indeed, the very fact that the University of Sydney became involved in research in solar energy is a reflection of the fact that the university was concerned to make a contribution in an area of practical significance. When the first grant was obtained from the New South Wales Government the university was discussing with a large Australian company, CSR Limited, the possibility of licensing the selective surface. CSR was interested in local manufacture of collector tubes incorporating this surface.

In the event, CSR did not proceed with its interest.

This occurred for a number of reasons, not the least important of which was the way in which the university approached the licensing discussions. The University of Sydney has had very little experience in licensing the discoveries that it has made to commercial organizations.

Despite its withdrawal of interest, CSR passed on a lot of valuable information to the university, including copies of costing and feasibility studies that it commissioned and recommendations on countries in which patent protection should be sought. The university followed these recommendations very closely. As a result it has widespread coverage of the two basic patents on the selective surface.

From 1978 to 1980 the university continued to be interested in industrial interaction and licensing the technology that it had developed. However, very little progress in this direction was made. When I joined the university in July 1980, I placed considerably more emphasis on commercialization aspects of the work.

I take the point of view that, if it is to become commercial, a project such as this must proceed with the maximum of industrial interaction even if this causes significant problems in the way the work is carried out in the university. During the first two years at the university I talked to more than 50 industrial concerns and we had a large number of activities carried out either by industry or in close collaboration with industry. In particular, we attempted to transfer technology wherever possible into the industrial environment and to subcontract manufacturing operations to this sector.

Enter Agreement

In March 1981, the university signed a licensing agreement with a Japanese company, Nitto Kohki Co. Limited. This agreement gave Nitto Kohki the right to manufacture and sell evacuated tubes incorporating the Sydney University surface in specified territories. In return for these rights, Nitto Kohki made an upfront payment to the university and undertook to pay a royalty based on the tubes sales. The university for its part undertook to assist in the transfer of technology to Nitto Kohki and to provide supporting and continuing research and development in areas of relevance to the agreement.

Lest the wrong impression be given, it is worth recording here that the university did not find Nitto Kohki. Nitto Kohki sought out the university and pursued the licensing agreement most vigorously. The entire negotiating period took more than one year and the proposal to enter into an agreement met with considerable opposition from within the university and without.

Within the university serious doubts were expressed that the university could meet the type of commitments necessary to support a licensing agreement of this type. It was stated that there would undoubtedly be a conflict of interest between the academic requirements of the university and the highly commercial requirements of a manufacturing organization.

Outside the university it was argued that an Australian development such as this should be commercialized first in Australia. It has, in fact, always been

the aim of the university to achieve commercialization in Australia, and considerable efforts had been made to achieve this without success. The university argued very strongly that commercialization overseas would, if anything, enhance local commercialization. The agreement was specifically written with this in mind.

In retrospect, it seems that our arguments were correct. The commercialization activities of Nitto Kohki quantified the investment necessary to set up a tube manufacturing facility and it demonstrated that large-volume manufacture was possible. It is a tribute to that organization that they, with no vested interest in this development initially, assumed many of the major risks in the first steps of the commercialization program.

Successful Effort

Nitto Kohki's commercialization efforts have been highly successful. Technology was transferred through a series of visits from Japan to Australia and back. Within less than eight months Nitto Kohki had the tube coating technology established in Japan at a significantly larger production rate than in the university. Shortly afterward it had all other aspects of prototype tube manufacturing technology developed. This company is now undertaking an aggressive program aimed at building up the markets for the product that they are producing.

As mentioned above a substantial amount of funding for the Sydney University program has come from His Royal Highness Prince Nawaf of Saudi Arabia. In return for this funding the university granted selling and manufacturing rights to His Royal Highness in many countries. Prince Nawaf has established a Spanish-based company, Solar Science Corporation, which is charged with responsibility of commercializing the development.

The university is interacting closely with Solar Science Corporation in order to assist this to take place. Solar Science Corporation is developing a marketing and production strategy that is compatible with its resources and goals.

The commercialization of our developments in Japan and the work of Solar Science Corporation means that the project has succeeded, at least in part, in its efforts to become commercial. The primary goal of our work, however, has always been to achieve commercialization in Australia. This is an Australian development which has received a large amount of Australian funding and the university feels a very strong commitment to achieve commercialization locally.

This feeling is shared by the New South Wales Government through the Industrial Investment Unit and the Energy Authority of New South Wales. In addition, our colleagues in Japan, Nitto Kohki Co. Limited, understand and respect our desires in this area. As a result we have continued our efforts to seek a local organization which would undertake commercialization in Australia.

To this end, in April 1982 the Energy Authorization of New South Wales and the university jointly sponsored a seminar to industry aimed at encouraging local commercial involvement. This seminar was very well attended with representatives from about 40 organiza-

tions. It resulted in expressions of interest from six companies. None, however, proceeded with a firm proposal for commercialization.

Scarce Application

In retrospect it is not difficult to see why Australian industry has been less than enthusiastic in commercializing our developments. Until recently a large market for these devices had not been identified. It was always thought that solar collectors with the characteristics of the ones we had developed would find application in the high-temperature area.

Indeed, these collectors are capable of producing heat at temperatures greatly in excess of those possible with flat-plate collectors. In addition, a substantial amount of energy is used in the temperature range just above that at which flat plate collectors can operate. However, when one examines specific applications in this temperature range, it is difficult to find situations where the collectors can be used economically at the present energy costs.

The realization of this lack of a defined market prompted the university to concentrate in areas where significant markets did exist. There is one particular application of solar collectors which is large and commercially viable at this stage—domestic hot water. The Sydney University evacuated collectors, and all evacuated collectors, have traditionally been regarded as being too expensive for the domestic hot-water application. Nevertheless we have performed research specifically aimed at degrading collector performance slightly while reducing cost significantly with the aim of producing collector designs which might be cost-competitive in this application. We believe we have succeeded in doing this.

Recently, a large Australian company, Rheem Australia Limited, has become interested in these developments. Rheem has obtained a grant from the National Energy Research Development and Demonstration Council to engineer solar collectors incorporating evacuated tubes for domestic hot-water applications. In addition, Rheem and the university are trying to reach agreement on licensing the technology and inventions that have been developed at the university for manufacture and sale in Australia and other territories.

Joint Effort

It will be some time before we know if this approach is successful. It will only succeed if evacuated collectors can capture a large fraction of the domestic hot-water market. With its moderate climate and high levels of sunshine, Australia is a natural place in which to develop such a marketing concept. Rheem is approaching this work in a highly professional way and I believe that the university is behaving similarly. If the project can succeed, together we will certainly make it do so.

There are now several different companies that are interested or involved in commercialization of these developments. This raises the possibility of conflict of interest between the different parties and potential difficulties for the university in confidentiality. Indeed,

doubts have been expressed along these lines, although to date no conflicts have emerged.

I take the point of view that, given reasonable attitudes on behalf of the people involved and a spirit of mutual cooperation, most such potential difficulties can be foreseen and avoided. If they do occur, I believe that with similar attitudes they can be resolved satisfactorily.

The agreements that the university has made have been specifically framed to minimize the possibility of such conflicts of interests. However, as in practically every human endeavor, the thing that counts are the attitudes of the individuals involved. Given that these are reasonable, practically anything can be achieved. If they are unreasonable, any project can be made to fail.

LESSONS TO BE LEARNED

Finally, I would like to review some of the things that we have learned in this long and stimulating project. In the first place, it is over 10 years since planning started for research on solar energy at Sydney University and over eight years since the start of technical work. The selective surface is now over six years old. The major development on which our commercialization depends can no longer be called new. Those of you involved in technology development will realize that such long times are not atypical in this type of work.

There is no doubt that the university has done excellent technical work and research of the highest caliber. I can say this quite modestly since almost all the technical and research achievements have been made by people other than myself. I venture to say, however, that without additional input this technical work would have had no commercial significance. The additional inputs came from many areas.

My Head of School, Professor Harry Messel, provided the necessary enthusiasm and entrepreneurial skill to interest people outside the university in the development. Our two major sources of funding, the New South Wales Government through the Premier Mr. Neville Wran, and His Royal Highness Prince Nawaf Bin Abdul Aziz of Saudi Arabia demonstrated an extraordinary degree of confidence and, in retrospect, foresight in providing a large amount of funding to support the work.

The Japanese company, Nitto Kohki Co. Limited, with its highly entrepreneurial approach has made a major contribution to commercialization. In my own small way I believe that my efforts to involve industry in Australia and elsewhere have been helpful in achieving the success that we have seen. Finally, industry itself, particularly in Australia, through its willingness to become involved at whatever level is possible, has been extremely helpful in our work. We have great hopes that our collaboration with Rheem will become an important success story in Australian technological development.

When these various inputs are examined it becomes clear that the success of the project has really depended on two things. The first was the personal commitment and initiative of a number of individuals. I cannot stress this point too strongly. Large organizations

can develop policies for interaction and commercialization that are extremely important in directing the thoughts of individuals within these organizations along appropriate lines.

Success in such endeavors will not occur unless the individuals involved are highly motivated and prepared to work extremely hard. Our project has been very fortunate in having a number of such individuals who have had very strong personal commitment. These have been involved at all levels ranging from technical through entrepreneurial to management and commercial.

The interaction between these individuals has not been without its problems. With talented people this will always be the case. Nevertheless, all who are involved have regarded it as extremely important to see the project succeed. I believe that ultimately this commitment has caused them to modify their own strong feelings enough to enable the project to progress successfully.

The second major factor that is common to all successful development initiatives is the degree of interaction between widely diverse sections. We have had input from people within the university, both academics and administration, from government, from entrepreneurs and industry. All have been important and indeed necessary for the success of the project. Any one sector working alone would not have achieved success.

Again, the diverse interests and ways of thinking of people in the different sectors involved have caused problems that have been and continue to be overcome given reasonableness of the individuals involved. I cannot stress too much the importance of interaction between sectors at all levels in seeing that good scientific research in relevant areas is ultimately transformed into commercial products of economic significance.

CONCLUSION

The last chapter in this story cannot yet be written. Indeed, this will be possible only when (not if) our development is finally made obsolete by some other advance, as yet unknown. We are quietly confident that, before this happens, we will see the growth of a large and profitable industry based on our work. We are working very hard to help this to happen.

I believe that this is a most appropriate thing for a university to do, and that we can do it without compromising our academic work.

At the same time, I would be most disturbed if universities devoted most of their resources to this type of work. As in all things, a balance is required. A proportion of highly interactive work, such as this, located in a university dedicated to excellence and scholarship, is highly beneficial, both to the university and to the community in which it is located.

I would go further and say that we in the universities have a responsibility to maintain such a balance—highly interactive, mission oriented work for the direct benefit of the community, and fundamental research, for the development of knowledge that is, after all, the greatest resource of mankind.