The project title could not be more prosaic: plastic solar cells. But that is the name by which Kees Hummelen, senior lecturer at Groningen University, likes to refer to this most important application of his thoroughly fundamental research. “We are trying to develop ultra-smart materials which can then be knocked together in a low-tech manner to make a very cheap and reasonably efficient solar cell.”

A scientist’s quest for an ultra-simple solar cell

In fact he had always wanted to become an astronaut. A dream which other boys have had, perhaps, but one that Kees Hummelen nurtured for an exceptionally long time: from his infant school days right through until he embarked on his further education. A dream from which he was brusquely awakened when he attended an open day at the Aerospace Transport faculty of Delft University of Technology. “All I could see was complicated formulas with double integrals, and I realised I would have to choose something else,” Hummelen opted to do chemistry at Groningen University. After earning a doctorate (a thesis related to chemoluminescence) he was introduced by the Groningen physicist Sawatzky to fullerene chemistry, a young science concerned with exotic, perfectly spherical carbon molecules.

Networks
Polymer solar cells - to shun that mundane word ‘plastic’ - are based on the principle of the ‘bulk
heterojunction’. There are some words which non-initiates can make neither head nor tail of. Hummelen smiles. “Think of spaghetti with meatballs. So many meatballs that they are in multiple contact with one another. In effect you are making an organic composite material consisting of two interwoven networks. The spaghetti represents a network of molecules which can emit electrons - the donor - and the meatballs represent molecules which absorb electrons, the acceptor. Electrons are liberated in the donor material by light, which are absorbed by the acceptor material. Positive and negative charges are therefore created, and these then move through the separate networks to the cell’s electrodes.” But it cannot possibly be as simple as that? “True”, agrees Hummelen, “there are still various matters which need to be sorted out.”

Buckyballs
The analogy with balls is not entirely fortuitous. In 1993 Hummelen travelled to the celebrated Institute for Polymers and Organic Solids in Santa Barbara, California for a post-doctoral fellowship with the eminent scientists Heeger (winner of the Nobel Prize in Chemistry 2000) and Wudl. While there he got involved in the study of ‘buckyballs’. Large stable molecules consisting of 60 carbon atoms (C\textsubscript{60}, also known as buckminsterfullerene). Taking the form of pentahedra and hexahedra, buckyballs have precisely the same structure as a football. They were only discovered in 1985 and created quite a revolution in organic chemistry. Furthermore a method of making C\textsubscript{60} in large quantities was discovered in 1991.

“Buckminsterfullerene is extremely interesting for solar cell research because it absorbs electrons so easily. If you see a way of combining C\textsubscript{60} with a molecule that emits electrons you have a combination which looks very promising. It is a question of achieving the right balance: a donor which is too strong will simply lose its electron, and

“We envisage a kind of solar film that can be bought by the metre from a roll, from a builder’s merchant, for example”
then you will have a salt. And a donor which is too weak will not work. The best is to have something in-between: a donor which emits electrons under the influence of light. A number of conjugated polymers [long molecules with alternating double and single bonds along the polymer backbone - Ed.] is very suitable.” That is the basic principle of the polymer solar cell in a nutshell, as being developed by Serdar Sariciftci, presently working at Linz University and once one of Hummelen’s colleagues in Santa Barbara.

Feasibility
In California Hummelen set his mind to making C60 soluble in water and in greases by making small chemical changes to the football. In so doing he laid the basis for his present research in which it is vital that fullerene can be mixed with another polymer. He also met René Janssen, a chemist at Eindhoven University of Technology with whom he got on extremely well. Back in the Netherlands the Groningen researcher continued to be haunted by the potential of the buckyballs. Professor Bert Meijer of Eindhoven University of Technology put him in contact with Novem (Netherlands Energy and Environment Company), and later with the EET Programme Office. Hummelen formed a research team and applied for an EET subsidy, which was granted at the end of 1998. This led to the first phase of an extended research plan. The main focus of the first phase is on fundamental research. “We gave ourselves five years to develop a cell...
with an efficiency of some 5% and a significant lifespan. A 5% efficiency does not seem much, but given that we can only achieve 1% at present, that would be quite a step. Furthermore, if that 5% proves feasible there will be no turning back. Then will come the second phase, in which we shall aim for 10%, followed by the product commercialisation phase. So indeed we are planning for a development timetable of some 15 years."

**Arranging the structure**
The entire thrust of the research is to increase the conversion efficiency of the cell. Two parameters are important in this respect: the light absorption by the polymer and the conductivity of the mixture. Hummelen speaks about it with the infectious simplicity of someone completely at home with the subject matter. “At present we are concentrating mainly on conductivity. You see, the transfer of electrons from the donor to the acceptor is going very well. We have measured times of 40 femtoseconds using the fastest lasers in the world, and that is extremely fast. But it is just as important that the return of the electrons should be much slower. There is then time for the electrons to get to the cell electrodes. But this has to happen quickly. And this is where the bottleneck is; at the moment the efficiency of our cell is limited by its conductivity. What we are now trying is to arrange the meatballs and the spaghetti so as to ensure that the charge-bearers take as direct a route as possible. The trick lies in getting the material structure right.” Cell life is important as well as efficiency. At present this is not great because the material used tends to degenerate. Hummelen is optimistic about this. Philips Research saw the possibility of increasing the life of the polymer LED, which exhibits many similarities with the polymer solar cell, from a couple of seconds to several years over a period of ten years.

**Builder’s merchant**
However enthusiastic Hummelen is in talking about the chemical and physical processes of the solar cell, he really becomes animated about the significance of the cell for the future energy supply. The real trump for the polymer solar cell is its low cost. “We are looking for materials which are so smart that you could use them to knock up a solar cell on the kitchen table, as it were. Finding and fine-tuning the materials will require years of research, but if this succeeds then it will be possible to make solar cells using a dirt-cheap process. We envisage a kind of solar film that can be bought by the metre from a roll, from a builder’s merchant, for example. Perhaps ten years later it might even be sold as a kind of paint. Roofs, walls and windows: almost anything could then be used to generate electricity. If this is not a technological breakthrough then I’m a Chinaman!”

And we have not even yet spoken about the spin-offs of this research, the scope for using the newly-acquired knowledge in other fields. One of the partners in the EET project is Philips Research, which is monitoring the studies done by the other partners. Not because Philips would wish to get involved with solar cells but because there are clear parallels with the development of, for example, polymer LEDs.
Plans

“It might look as though plastic solar cells are our only goal, but that is not the case. If you just keep making new materials and use these to knock together a cell which turns out to work well without your knowing precisely why it works then you’ve in fact missed a step. We therefore collect all manner of information on the processes which take place in the material. This is a rather extreme example of fundamental research.”

At the moment the main thrust of this work is being done at Groningen and Eindhoven Universities. The research team now comprises six groups. Apart from Hummelen’s group there are groups led by Professor George Sawatzky (physics, Groningen), Dr. René Janssen (polymer chemistry and photophysics, Eindhoven) and Professor Bert Meijer (supramolecular chemistry, Eindhoven). The Energy Research Centre ECN (Dr. Jan Kroon) provides expertise in devices and characteristics and, as already mentioned, Philips Research (Professor Hans Hofstraat) is also involved in the project. Serdar Sariciftci’s group in Linz often acts as subcontractor to Groningen University.

“This is an incredibly multidisciplinary study”, says Hummelen, “In the present phase the emphasis of the project is on fundamental research. But we have agreed that we want to acquire experience from the outset with the technologies necessary to ultimately produce a solar cell. If at a certain point the cell begins to function well, you will see that new industrial partners will be invited to join the project. Shell Solar may perhaps be interested, or Akzo. And then we will continue with the fundamental work. Serdar, René and I have some great plans for the future.”