Bio solar **solutions**

A major collaboration between public and private institutions in The Netherlands is transforming solar energy technology. **Professors Joost Reek** and **Klaas J Hellingwerf**, and **Drs René Klein Lankhorst** and **Jeremy Harbinson** highlight the progress of the project to date and its promising future

To begin, can you briefly outline the major advantages of exploiting the Sun's energy?

In the long run, exploiting the Sun's energy is our only option! Fossil fuel will run out and nuclear is contested for its safety and the problem of waste storage. Novel sources of fossil fuels currently being explored – such as shale gas or methane from the bottom of the oceans – will not offer a durable solution due to the immense net increase of CO_2 production involved in burning fossil fuel. Alternatively, the Sun provides us with a plentiful supply of energy; in a single hour the Earth receives enough solar energy to run the entire world economy for a whole year, and with no net production of CO_2. Achieving a sustainable energy supply is therefore a matter of capturing just a small percentage of the available solar energy to allow a transition towards a global bio-based economy.

Could you outline the main objectives of the BioSolar Cells project?

Our main objectives are the development of optimised photosynthetic systems in plants, microorganisms and artificial leaves for the durable production of energy, chemicals, food and feed.

What is the Calvin cycle and to what extent is photosynthesis an efficient way of converting solar energy into chemical energy?

Photosynthesis is a complex process in which the energy from sunlight (photons) is used to convert carbon dioxide and water into sugars and oxygen. The photons are captured in the chlorophyll and then converted into chemical energy in a first step called the 'light reaction'. In a second conversion step, referred to as the 'dark reaction' or 'Calvin cycle', the chemical energy is used to convert carbon dioxide into sugars, a form of energy that can be stored in the organism.

The problem is that natural photosynthesis is not very efficient. Except for sugar cane, most crop plants convert no more than about 0.5 per cent of sunlight into chemical energy such as starch or sugar. For plants, this conversion rate is sufficient; however, if we want to exploit plants for our future food and fuel demands, than we need plants with higher photosynthetic conversion rates. Models have shown that the theoretical maximum efficiency of photosynthesis in plants comes close to 5 per cent and the main goal of BioSolar Cells' plant research is to ascertain how far we can push the current 0.5 per cent conversion rate towards the theoretical maximum.

To what extent can the use of algae and other photobiological solar cells help to improve sustainable energy supply?

At the moment, electricity accounts for 20 per cent of global energy consumption and the remaining 80 per cent is liquid or gaseous fuel. In future, this may shift to 50/50, with electricity that can be produced from solar energy using PV cells. The systems that BioSolar Cells are developing can be used to produce the remaining 50 per cent liquid/gaseous fuel from solar energy too and would thus be fully sustainable.

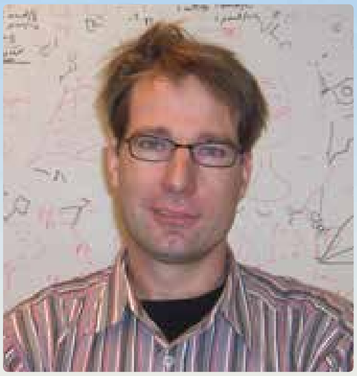
In the long run, artificial leaves (photobiological solar cells) should be capable of generating hydrogen from solar light with an efficiency of at least 40 per cent. This hydrogen can be stored and used, or can be chemically linked to carbon dioxide to form simple hydrocarbons like formic acid or methanol. These hydrocarbons can easily be converted into higher-molecular-mass hydrocarbons for jet fuel or diesel. When using cyanobacteria or algae, solar energy is directly converted into simple hydrocarbons or more complex compounds. Although the photosynthetic conversion in artificial leaves will be higher, the direct conversion of solar energy into hydrocarbons in algae and cyanobacteria will have many applications in energy production and also in producing building blocks for the chemical industry.

How is the BioSolar Cells initiative helping to tackle the EU's Grand Challenges?

One of the major global challenges is to supply a growing world population with sufficient energy, without causing devastating and irreversible effects on climate, the environment and biodiversity. BioSolar Cells is one of the initiatives that can help to transform our current fossil-based economy into a bio-based economy that is based on renewable and climate neutral sources such as sunlight, plants and algae. By increasing the productivity of plants and algae, BioSolar Cells will also contribute to the growing need for food and bio-based healthcare products and materials.

In what ways can The Netherlands specifically benefit from increasing its reliance on solar energy?

Our specific gain is in playing a major role in establishing the bio-based economy in Europe (and world). The Netherlands has a very strong agricultural industry and also an excellent chemical industry which are the two major components for setting up a bio-based economy. In addition, our



scientific infrastructure in chemistry and agriculture is first class, so we have the potential to build a very strong bio-based industry in The Netherlands.

Could you describe the 'artificial leaf' prototype which has been created by BioSolar Cells? How does this work relate to earlier prototypes developed by Massachusetts Institute of Technology (MIT)?

The work of Daniel Nocera and his co-workers is an important step in the development of artificial leaves. They have successfully demonstrated the solar-to-fuel concept. In BioSolar Cells we focus on developing novel building blocks that we use to construct different designs of artificial leaves. One such building block is a catalyst that very efficiently splits water into protons, electrons and oxygen and is superior to the MIT design. We have also built a prototype based on organic components instead of the inorganic chemistry used by Nocera. In a couple of years, we expect to have several different designs, one or two of which we will develop into industrial prototypes.

In 2011, Oxfam warned that average food prices are set to rise in future decades, and this has been linked to crops being over-produced for biofuel. What is your opinion on this important issue?

Long term, to 2050 and beyond, we will need all available arable land (plus parts of the oceans) to feed the world population. For BioSolar Cells, the main driving force behind our work on plants is the need to increase crop productivity, whereas our work on microorganisms and artificial leaves is geared towards production of chemicals and energy. So we endorse Oxfam's warning and are trying to do something about it!

How does the project employ training activities to improve education in this field?

We develop courses and training material for all levels of education, ranging from elementary school to postgraduate university level. On our public website we also refer to education activities that are related to BioSolar Cells and photosynthesis research.

How do your industry partners contribute to the achievement of your scientific objectives?

Most industry partners simply make funding available, while a small number actively participate in the research projects. However, all of them have a very keen interest in how our results can be applied.

With an eye on the future, where is the BioSolar Cells project hoping to focus its research efforts next?

BioSolar Cells has been designed as a 15-year research programme, of which the first five years are now currently funded and executed. The main output of this first period will be a number of lab prototypes and/or proof of concept. In the next phase of BioSolar Cells, research effort will be directed at further developing these concepts into real prototypes and processes at semi-industrial scale.

What overall impact do you think this work will have? What obstacles must be overcome to ensure the efficacy of this work?

This work may have major impact on the establishment of a bio-based economy in Europe and beyond. The major obstacle will be to leverage sufficient critical mass and funding in Europe to ensure that results from the first five years will indeed lead to further research into real applications for industry. This cannot be done by The Netherlands alone, but should be taken on at European level. Therefore, it is very encouraging to see the development of a European Public-Private Partnership on BioBased Economy (PPP Bio), where European industry and the European Commission have already expressed their intention to leverage close to €4 billion for bio-based research to be conducted within the next framework programme Horizon 2020.

How important is public outreach to your activities?

Public acceptance of all the novel technologies we are developing will be crucial to their successful introduction in society. We therefore put a lot of effort into our public website (www.biosolarcells.nl), research on life cycle analysis and public debate, and even in using art to educate and inform the public about our project.

The future of bio solar technology

Scientists working on the BioSolar Cells project are taking inspiration from Nature in their quest to harness the power of the Sun more efficiently than ever before. Their results may well shape the future of green energy

AS THE WORLD population continues to expand, and China's middle-class swells its ranks, global demand for food, goods and energy is soaring. With the emerging economies of India and Brazil set to follow in China and Russia's footsteps, pressure on the Earth's resources will only increase. However, not only have we found that oil, gas and coal reserves are finite and dwindling fast, but the carbon dioxide they emit is warming our climate with dramatic consequences. Alternative, sustainable sources of energy must be developed if we are ever to balance our demand for energy with the limitations of the planet's resources.

The BioSolar Cells research programme has ambitious goals for green energy development. This impressive collaboration of private and public sector institutions is pulling out all the stops to develop the next generation of biofuels and solar cells. The scale of the programme is huge. Initiated by six renowned Dutch research institutions, it has now grown to comprise 11 public research institutions and 35 corporations such as ExxonMobil, Total, Neste Oil, BASF, Synthetic Genomics Incorporated, DSM, Philips, Unilever and several SMEs. With a large budget of €42 million – 25 million of which was provided by the Dutch Government – this programme is the largest of its kind.

Researchers in The Netherlands are well placed to take on the challenge of harnessing the Sun's energy, as the country is a well-established hub of studies into photosynthesis. Plants use photosynthesis to convert energy from the Sun to the form of sugars they need for growth. BioSolar Cell researchers are hoping to build on their wealth of existing knowledge about this process and apply their discoveries in commercial and industrial settings. The focus of their work is divided into four main research clusters: plants; algae and cyanobacteria; artificial leaves; and social debate and education.

PLANT RESEARCH

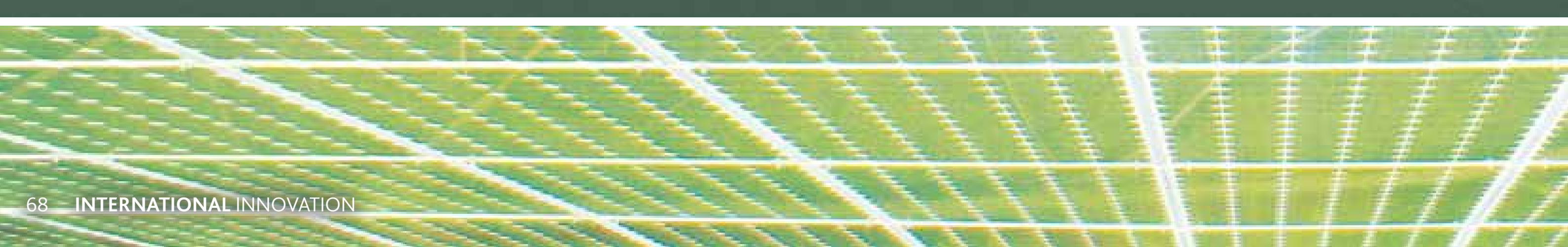
An important section of the programme explores the efficiency of photosynthesis in different plants under various conditions. It is estimated that the process is about 1 or 2 per cent efficient in most species. Professor Herbert van Amerongen and Dr Jeremy Harbinson of Wageningen jointly lead the plant research cluster. The work relies upon a multidisciplinary approach: "To better understand the operation and limitations of photosynthesis in plants we developed a comprehensive strategy in which modellers, biophysicists, physiologists and geneticists cooperate," Harbinson explains. "We also apply our fundamental understanding of photosynthesis to improving the energy use of greenhouses, in particular the efficiency of greenhouse lighting and management of the light environment."

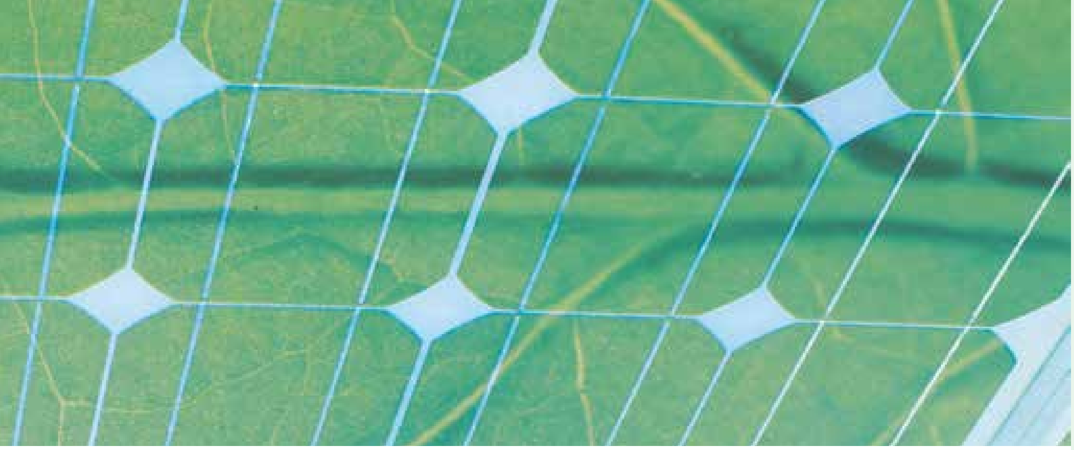
The cluster covers a wide range of investigations, from developing techniques for monitoring the parameters and limits of photosynthesis, to understanding which genes are key to the process. Novel methods are often used to carry out this work. For example, in one project, a new genome-association mapping technique is facilitating studies into how genomes for photosynthesis change under different stress conditions. This important work will enable the collaborators to determine which genes are candidates for selective breeding or genetic modification to make plants more efficient at producing energy and biomass.

ALGAE AND BACTERIA

The second research cluster concentrates on photosynthesis and biofuel production in algae and bacteria. Professor Klaas Hellingwerf from the University of Amsterdam, one of the leaders of this cluster, explains why algae make such a promising source of biodiesel: "Whereas plants are the preferred organisms for food production, for the bulk chemicals and liquid fuel, algae provide a platform with much higher versatility and efficiency," he reveals. "Moreover, algae can be cultivated in salt water, and therefore algae production does not necessarily compete with food production in terms of arable land and sweet water."

A strong argument against the development of biofuels is that it promotes competition for land that can otherwise be used for growing food to feed growing populations. The BioSolar Cells programme hopes to become part of the solution to the problem. By 2016





they aim to produce algae and bacteria capable of converting sunlight into liquid energy directly, at 5 per cent efficiency. As part of this cluster, the private sector partners are carrying out seven different investigations into potential industrial applications of the other byproducts and components of photosynthesis in algae. This work will make the production of algae-based biofuel more economically viable and competitive with traditional diesel.

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ARTIFICIAL LEAVES

Throughout the study, the collaborators are looking to Nature for answers to our energy problems. Plants naturally perform the remarkable process of converting sunlight into fuel and in seeking to mimic this, scientists have developed an exciting new technology. Professor Joost Reek from the University of Amsterdam is one of the cluster leaders of artificial systems. The team is working on improving and developing the design of artificial leaves: "The artificial leaf is a device that uses light to extract electrons and protons from water and produces hydrogen," Reek affirms "The aim of the BioSolar Cells programme is to build two different prototype devices: an inorganic prototype based on nanowires and an organic device based on rationally designed components."

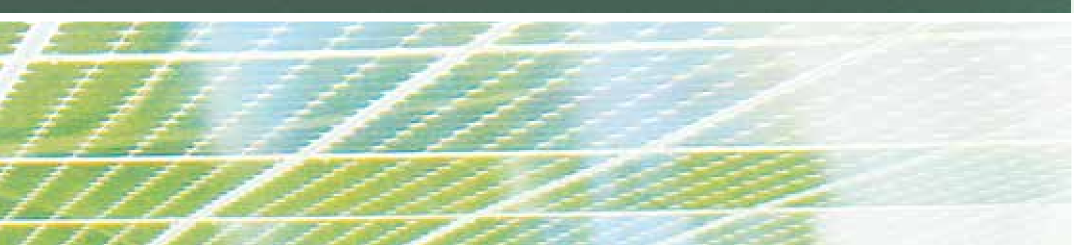
The goal of this innovative approach is to deliver a product by 2016 that can convert sunlight into energy at a foreseen 40 per cent efficiency. Three main components work together to achieve this. One part is designed to capture sunlight, the second converts photons into a liberated electrical charge, and the third, a catalytic system, uses the power of this charge to split water molecules into hydrogen and oxygen. The artificial leaf team is involved in a number of projects to develop and investigate the various materials and molecular components used to build these leaves.

SOCIAL DEBATE AND EDUCATION

The BioSolar Cells project represents a new frontier in the pursuit of sustainable energy. The team knows that there are numerous challenges to overcome, not only in terms of research and technological developments, but also in conflicting social attitudes towards their project. For their part, the participants in BioSolar Cells are dedicated to communicating their work to the public effectively and contributing constructively to the debate it provokes.

An impressive array of educational materials has been developed and is available to students and teachers, from secondary to tertiary education and beyond, on the project's user-friendly website. These materials are designed to encourage scientific investigation into photosynthesis and increase understanding and awareness of the problems we face in terms of energy production today. This also involves a number of intriguing artistic endeavours, or 'bio-art', aimed to change the way we think about the relationship between science and society.

BioSolar Cells is ambitious in its scope and the active collaboration between public and private bodies should lead to practical applications that may well change the landscape of the coming decades. As governments across the EU and beyond face stricter regulations and targets for lowering greenhouse gas emissions, programmes such as this are essential in the drive to phase out fossil fuels and develop sustainable and affordable alternatives.



INTELLIGENCE

BioSolar Cells

OBJECTIVES

To improve the system by which plants, algae and some bacteria capture energy from sunlight. In doing so, this research contributes to a more sustainable production of food, energy and green raw materials for industry.

PARTNERS

From The Netherlands:
Wageningen University and Research Centre
University of Groningen
Delft University of Technology
University of Amsterdam
Leiden University
University of Twente
VU University Amsterdam
Eindhoven University of Technology
HAS Den Bosch

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JOOST REEK received his PhD in 1996 from the University of Nijmegen. He is Coordinator of a successful European research training network, and is involved in other EU networks.

RENE KLEIN LANKHORST is Managing Director of the BioSolar Cells project, Senior Scientist at Plant Research International and Chairman of the International SOL Consortium.

KLAAS J HELLINGWERF received his PhD in Biochemistry from the University of Amsterdam in 1979. Since 1988 he has held the chair in General Microbiology at the University of Amsterdam, where he supervises the Molecular Microbial Physiology group of the Swammerdam Institute for Life Sciences.

JEREMY HARBINSON received his PhD in plant ecophysiology in 1984 from Cambridge University. In 2000 he took up his current position in the Horticultural Supply Chains group of Wageningen University. The thrust of his research has been understanding the operation, regulation and limitation of plant photosynthesis.

BioSolar Cells