UKERC

UKERC ENERGY RESEARCH LANDSCAPE: SOLAR ENERGY

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Last Updated: 23 February 2013

1. Overview

Return to Top

Characterisation of the field

Photovoltaic (PV) Solar Energy is now a well established renewable energy technology, continuing to rise year on year with worldwide new installations in 2012 of 32 GW_p, an increase over the 2011 figure of 28 GW_p. However, there are some significant shifts occurring in the industry with prices of PV modules continuing to fall and the market becoming more global. In 2010 more than 80% of the new installations were in Europe, falling to 53% in 2012. Crystalline silicon PV modules continues to dominate the market with thin film PV struggling to keep pace with falling prices and production scale. The UK has become a significant global market with an accumulated PV installation of 1.6 GW_p and an established PV installation industry thanks to the Feed in Tariff. Most notably the rapid increase in production from China accounts for over half the world production and has led the drive to reduce the price of crystalline silicon modules to an average price now less than $\$1/W_p$ and the lowest module prices dipping below $\$0.7/W_p$. This has made it tougher for the newer technologies to break into the market except for First Solar which exceeded $2GW_p$ production of cadmium telluride thin film PV and some notable CIGS manufacturers such as Solar Frontier which now has a capacity above 1 GW_p. First Solar led the way in getting module prices below the magic $\$1/W_p$ and shows the potential for innovation in PV combined with very large scale manufacture. Continuing price reduction depends on running at close to capacity on the production lines and progressing improvement in PV module efficiency which climbed in 2012 to 12.7%.

There are three classes of thin film PV materials, amorphous silicon (a-Si), cadmium telluride (CdTe) and copper indium di-selenide (CIS). The front runner was the a-Si but over the past two years CdTe has now gone to the number one slot for thin film PV. In addition to the terrestrial electricity generation PV market there is a substantial consumer market for powering a range of consumer products and an established market for powering satellites. An exciting development in the consumer sector is the Cardiff based company G24i which is manufacturing dye sensitized solar cells (DSSC) onto plastic sheet in a very low cost role to role process. This points the way to future, very low cost PV power using either DSSC or organic PV (OPV).

At the other end of the price scale space market is dominated by high performance crystalline silicon and increasingly the triple junction cells based on gallium arsenide (GaAs) that have now achieved a record laboratory concentrator efficiency of 43.5%. The latter is increasingly looking attractive for terrestrial applications through concentrator PV (CPV) where the relatively expensive solar cell covers only approximately 1/500 of the solar collection area. This would be a low cost solution for utility scale installations in regions with a high proportion of direct sunlight. The UK has excellent technology strengths in CPV and potential for strong export market.

PV solar electric power can be provided either as a standalone system where battery storage would be used, or integrated into the grid via an inverter. The former is important in regions of the world where no grid electricity exists and the latter in regions such as the UK that has a good grid infrastructure. The PV modules account for approximately half the cost of a grid connected array with the power electronics for power tracking and inversion along with metering and installation, collectively referred as the balance of systems (BOS) accounting for the remainder. Developments in the power electronics are equally as important as the modules, requiring high power extraction from the module under different illumination and high reliability for low maintenance. A PV array is expected to last for at least 25 years (minimum of 80% of the design output) but with energy payback time of less than three years.

Research Challenges

The cost of PV solar energy has continued to fall and this has been reflected in the fall in Feed-in-Tariffs in the UK and elsewhere. Grid parity is already approaching in countries with high solar insolations such as Spain and it likely to follow across most parts of Europe, including the UK. In the DECC UK Renewable Energy Roadmap Update 2012, PV Solar Energy has been included for the first time as a key technology in the Renewable Energy mix in the UK.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/68637/7382-uk-renewable-energy-roadmap-update.pdf

The reduction in specific cost per Watt peak (£/W_p) remains the main driver for R&D with the aim of making the cost per kWh generated competitive with fossil fuels. The latter provides a direct comparison with the cost of other energy sources but is specific to the location of the PV array. This also depends on amortising the initial cost of purchase and installation over a 25 year period. However, R&D provides a route to continuously drive down the cost of the modules and BOS such that the economic payback time could be much shorter. The research challenges extend across the range of PV materials and technologies, mentioned above, and are articulated in the UKERC Road Map

http://ukerc.rl.ac.uk/Roadmaps/Solar/A_Road_Map_for_Photovoltaics_Research_in_the_UK.pdf

and in the Materials UK Strategic Research Agenda (SRA).

http://www.matuk.co.uk/docs/4_Alternative%20Energy%20FINAL.pdf

The challenges relate to increasing conversion efficiency of PV modules and reducing the cost in manufacture. Improving efficiency ranges from fundamental improvements in the materials through to increased light capture. Long term reliability is also essential, particularly when considering new materials and is also an issue with inverters. Integration into the built environment is also increasingly recognised as a fertile research area where innovation can lead to wider implementation and reduced system costs. As PV module production volumes increase it has become even more important to consider materials supply and issues relating to sustainability of materials and finding replacements to high cost materials such as indium. The research challenges also extend to manufacturing methods, including process monitoring and materials characterisation. High volume and low cost production will move more towards in-line processes, preferably at atmospheric pressure and for thin film to use a wider range of substrates including steel sheet and plastics.

Other important resources for the UK researcher in PV solar are the European Strategic Energy Technology (SET) plan and the EPIA/EU Solar Europe Industry Initiative.

2. Capabilities Assessment

Return to Top

The UK is active over all aspects of PV solar energy technology but capabilities vary widely. The UK also has good strengths across the supply chain from materials supply through to system integration. A common characteristic is the degree of innovation and the number of small as well as large businesses. The research landscape follows the range of PV industrial activity but is much stronger in areas such as materials science and weaker in manufacturing technology and process monitoring. This relates to the nature of start-up businesses in the UK which tend to be small, innovation led, whereas larger scale manufacture is typically as a result of inward investment. The UK is strong in architecture and design and probably reflects the sensitive nature to aesthetics in the UK market. However, integrating systems is somewhat weaker, reflecting both the nature of research funding and the low base of PV installation in the UK but the past year has seen a considerable growth of the PV installation industry. The UK Feed In Tariff (FiT) and growth in the installation industry will stimulate more applied R&D in PV installation, driving down system costs and extracting the maximum power under variable light conditions. The UK market has been predominantly export led and is therefore globally competitive but price pressures from China are causing the manufacturing sector to struggle. It is interesting that of the newer technologies, such as Dye Sensitised Solar Cells (DSSC), the UK is in a very strong position for early manufacture. However, in the main stay of PV production, crystalline silicon modules, the main UK manufacturer is Sharp Solar, other more specialist module manufacturers, such as Romag and GB Sol have managed to make headway against strong competition. Other notable gaps in manufacturing capability exist with thin film PV module production which has not kept pace with global developments. Hopefully, this will change as the base of thin film PV research continues to expand in the UK. There are numerous supply chain companies who have taken advantage in the rapid growth of PV manufacture and include NSG Pilkington, Dupont, SAFC Hitech, IQE and Crystalox.

Overall the diversity of R&D strengths in the UK has made it difficult in the past to achieve critical mass in any one area. However, the trend towards collaborative projects, which is strongly reflected in this data base, is making the UK more globally competitive and starting to make some of the links both within supply chains and between PV technologies.

Table 2.1 UK Capabilities

UK Capability	Area	Market potential
High	• PV Materials science • Emerging technologies (organic solar cells) • PV System and components testing and installation • PV module manufacture • Architectural design • CPV	Global market potential Global market potential Global specialist market potential European market Global market Global market
Medium	• PV integrating system • PV System and components performance monitoring • Equipment manufacture	UK installer application UK specialist market potential Global
Low	• PV cell design • Power electronics • Process monitoring	UK specialist industry application European market Global market

3. Basic and applied strategic research
Return to Top

In the past decade the UK University PV research has increased significantly and the current Research Council portfolio is worth in the region of £100M including underpinning research, much of which is for collaborative projects. This contrasts with the previously fragmented research landscape with relatively few significant collaborations. The SUPERGEN programme has taken the lead with this trend but is now by no means alone. There were originally two SUPERGEN PV programmes, "PV Materials for the 21st Century" covering inorganic thin film research and "Excitonic Solar Cells" covering organic PV research. These programmes have created critical mass of research effort and stability in the research teams. In the past year a new phase of the SUPERGEN programme started with the award of a SUPERGEN Hub grant to a consortium led by Loughborough University which will combined both the inorganic and the organic programmes. This is intended to be more inclusive of research teams across the UK through SUPERGEN Challenge calls. However, the SUPERGEN funding is now only a small fraction of the total funding with other collaborative initiatives such as the UK-India programme and Science Bridge with the USA. The approach in the UK contrasts with that in the US, Japan and Germany where there is more emphasis on central research facilities for PV. The strengths in the UK in materials science lends itself to our collaborative approach but makes it more difficult to offer larger facilities for testing and going to larger scale in materials synthesis and devices. This also reflects a lack of research activity at the module level in universities where the view is that this is left to industry. The growing strengths in materials research offers the opportunity for exploitation of this technology and this will require larger facilities such as the Tata Colors/ Dyesol Accelerator project for low cost fabrication of dye sensitised solar cells on sheet steel for commercial roofing.

We have seen some strong emerging themes in the UK R&D landscape that offer the potential for exploitation by UK industry. This includes the application of nano-materials in hybrid organic and inorganic solar cells, photonic down conversion to improve utilisation of the solar spectrum and concentrator PV using epitaxial III-V semiconductors. There is also a growing activity in solar harvesting where photocatalysis is used to split water for hydrogen production. All these themes are based on world leading materials research and this base in the UK has been strengthening.

Research in the built environment towards zero carbon homes has stimulated more research in the incorporation of PV into buildings and testing of PV systems. At the applied end of the scale this is now looking at social housing programmes and housing renewal. Larger scale integration of PV solar energy into the renewable energy mix will require more research on integration of PV with energy management systems at the domestic level and development of micro-grids, energy storage and all linked to efficient use of energy. The architectural challenge for greater PV integration into the building fabric will encourage research in new PV materials and in particular in flexible PV. This is not necessarily because we need the flexibility at the point of use but provides versatility to be combined with more traditional building materials.

Table 3.1: Research Funding

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
Solar fuels via engineering innovation	EPSRC	The quest for sustainable resources to meet the demands of a rising global population is one of the main challenges for humanity this century, with global energy needs set to double by 2050. This is set against the backdrop of increasing CO_2 emissions and associated climate change, and the ambitious target set out in the recent UK Fourth Carbon Budget of a 50% cut in CO_2 emissions by 2025. Solar energy can be used to drive the conversion of CO_2 into fuels via a process called photocatalytic reduction. The utilisation of CO_2 as an alternative fuel represents an attractive strategy to address both the consumption of non-renewable fossil fuels and global warming, while offering sustainable, safe and useful carbon capture. This research is being carried out by Heriot-Watt University.	£1,179,790	2013 - 2018	
SUPERSOLAR Solar Energy Hub	EPSRC	The SUPERSOLAR Hub of Universities has been set up to co-ordinate research activities, establish a network of academic and industrial researchers, conduct cross-technology research and provide a focus for international co-operation. SUPERSOLAR is led by CREST at Lough-borough University and supported by the Universities of Bath, Liverpool, Oxford, Sheffield and Southampton. This group is active in all of the PV technologies including new materials, thin film chalcopyrite, c-Si, thin film a-Si, dye sensitised solar cells, organic PV, concentrator PV, PV systems performance and testing. SUPERSOLAR will set up a solar cell efficiency measurement facility for the benefit of the PV community in the UK. The consortium contains a deliberate balance of expertise, with no bias towards any one technology.	£4,088,360	2012 - 2017	
High Performance Vacuum Flat Plate Solar Thermal Collectors for Hot Water and Process Heat	EPSRC	The aim of the proposed research by the University of Warwick is to provide the necessary knowledge to allow the development of a pre-prototype High Performance Vacuum Flat Plate Solar Thermal Collector with minimal materials content. The development of a thin evacuated solar collector offers new and exciting prospects for integrating solar collectors into building designs and for their use in medium temperature (100-200 Celsius) applications such as air	£302,411	2013 - 2016	

		conditioning or low temperature process heat. The research planned will develop technology for the effective utilisation of the solar energy resource and fits within EPSRC's Energy theme. Solar thermal energy is predicted to be a significant growth market with the potential to make a significant contribution to reducing fossil fuel use in the building energy sector. The research is targeted at providing new knowledge and techniques that will enable the advances in technology necessary for a step change in solar thermal collector performance to be realised and a range of new products and application areas developed. Such new products will encourage inward investment and lead to the creation of new companies that can contribute significantly to the transition to a low carbon society whilst maintaining and improving quality of life.			
Rational design of solid-state semiconductor-sensitized solar cells: from materials modelling to device fabrication	EPSRC	In this project we take the first step along this direction by focussing primarily on the electronic energy-level alignment at the sensitizer/oxide interface. The interfacial energy level alignment is directly related to the open-circuit voltage of sensitized solar cells and is a key design parameter for improving cell efficiencies. Our proposed rational design will consist of the following steps: (i) identify promising sensitizers via computational modelling, (ii) synthesize and characterize the selected materials, (iii) fabricate and optimise the solar cells, and (iv) perform advanced spectroscopy to understand the fundamental operation and limiting factors to performance in complete solar cells. This synergistic use of first-principles modelling and experiment has not been attempted so far in nano-photovoltaics research and has the potential of revolutionizing the field. Owing to our complementary skills, our research team is unique in the UK and EU arenas and this project holds the promise for revolutionizing our understanding of sensitized solar cells at the nano- scale, and introducing and developing paradigm-shifting technology. In this project we will focus specifically on solid-state semiconductor-sensitized solar cells. These devices are an evolution of the concept of dye-sensitized solar cells whereby the dye sensitizer is replaced by a semiconductor quantum dot or a nano-scale semiconducting	£989,490	2012 - 2016	

		film. This choice has three advantages: (I) the expensive transition-metal based dye sensitizer is replaced by a inexpensive light-absorber obtained by colloidal synthesis (ii) the optical properties of the sensitizer can be tuned by exploiting quantum size effects, and (iii) in comparison to conventional thin film photovoltaics, there is a much broader library of materials which may work effectively as semiconductor sensitizers. This research is being carried out by the University of Oxford.			
Sustainable Product Engineering Centre for Innovative Functional Industrial Coatings - SPECIFIC	EPSRC	The shared vision for SPECIFIC is to develop affordable large area solar collectors which can replace standard roofs and generate over one third of the UK's total target renewable energy by 2020 (10.8 GW peak and 19 TWh) reducing CO_2 output by 6 million tonnes per year. This will be achieved with an annual production of 20 million m^2 by 2020 equating to less than 0.5% of the available roof and wall area. SPECIFIC will realise this by quickly developing practical functional coated materials on metals and glass that can be manufactured by industry in large volumes to produce, store and release energy at point of use. These products will be suitable for fitting on both new and existing buildings which is important since 50% of the UKs current CO_2 emissions come from the built environment. The key focus for SPECIFIC will be to accelerate the commercialisation of IP, knowledge and expertise held between the University partners (Swansea, ICL, Bath, Glyndŵr, and Bangor) and UK based industry in three key areas of electricity generation from solar energy (photovoltaics), heat generation (solar thermal) and storage/controlled release	£5,012,105	2011 - 2016	
Efficiency Enhancement of Silicon Photovoltaic Solar Cells by Passivation	EPSRC	The aim of this proposal is to develop methodologies which are able to bring the efficiency of cells made from cheap forms of silicon close to the efficiencies achieved from the higher cost electronic grade material. This could increase the efficiency of multi-crystalline solar grade silicon by around 5% absolute and even more in the case of upgraded metallurgical silicon. Current silicon cell structures work well because hydrogen (usually from the silicon nitride antireflection layer) passivates surfaces and bulk defects. In electronic grade single crystal this reduces recombination to	£516,973	2012 - 2015	

		insignificant levels. It doesn't work as well in solar grade multi-crystalline silicon or upgraded metallurgical silicon because there are regions, sometimes entire crystal grains, which are not passivated by the hydrogen. However other regions are of very high quality often as good as electronic grade silicon. We associate the resistance to passivation with specific types of defect observed in lifetime maps of slices. In this project we plan to identify the defects which show resistance to hydrogen passivation by using electronic and chemical techniques (carrier lifetime, Laplace deep level transient spectroscopy, SIMS, Raman spectroscopy and defect modelling). The key part of the proposal is to use our knowledge of defect reactions in silicon to develop alternative passivation chemistries which can be applied, during slice or cell production, to those defect species resistant to hydrogen passivation. In this way we would expect to make a very important improvement to the efficiency of the dominant solar PV technology. This research is carried out by the University of Manchester, Elkem ASA, National Renewable Energy Laboratory, Fraunhofer, University of Aveiro, University of Oxford, MEMC Electronic Materials SpA.			
Development and Integration of Biomass and Concentrating Photovoltaic System for Rural and Urban Energy Bridge: BioCPV	EPSRC	This project addresses the issues related to integrated solar photovoltaic system - converting incoming solar energy into electricity and biomass power technologies - generation of electrical power from waste materials, for rural electrification. This project seeks to develop a new class of solar photovoltaic technologies - Concentrating Photovoltaic (CPV) to integrate with Biomass and waste power generation as a backup source and develop high efficiency hydrogen generation and storage from the integrated systems. The integrated system will be installed at Uttar Sehalai Tribal Hamlet, located in a remote village, 200km west of Calcutta for rural electrification with key focuses on satellite based remote monitoring technologies. The project will brings together Biomass, Concentrating Photovoltaic, and Hydrogen Generation and Storage expertise from University of Leeds, Heriot-Watt University, University of Nottingham in the UK and Visva-Bharati University, Santiniketan, Indian Institute of Technology Madras, PSG College of Technology in India with	£1,401,637	2011 - 2013	

		the goal of developing a low cost autonomous power generating system for rural electrification.			
Photovoltaics for Future Societies	EPSRC	Globally, humanity faces profound challenges in meeting increasing energy demand in the face of climate change and peak oil. The development and application of small-scale technologies for energy conversion and energy efficiency is an essential component amongst the collection of strategies that will be necessary to confront these challenges. Technological progress in this field is swift with new development promising leaps in cost reduction, efficiency and in flexibility of application. However, regardless of technical efficiency, new technologies will only make a difference as long as they are successfully integrated into people's living environments. First generation PV is well established as part of low carbon energy strategies, most notably in highly developed states like Germany and Japan. Its application is now extending rapidly as efficiencies improve and costs come down as a result of government support. Nevertheless, PV has vast unrealised potential, as a relatively efficient means of generating electricity which can be utilised in a far wider range of situations than competing technologies like wind, water or biomass. PV is therefore uniquely disruptive in its potential to eventually enable most consumers of energy to become producers of energy. The realisation of this potential will require significant further reductions in cost along with a massive increase manufacturing volumes. This research is being carried out by the University of Sheffield.	£1,366,123	2011 - 2015	
New Materials and Devices for Photovoltaic Applications	EPSRC	With the advent of global warming, rapidly increasing demand for energy, and concerns over the security of supply of traditional carbon based fuels the requirement for alternative, sustainable energy sources is recognised throughout the world. Photovoltaics (PVs) harvest electrical energy directly from sunlight, delivering power at the point of use and are potentially a major component of the long term solution to this growing challenge. There is a rapidly growing worldwide focus on the development of new third generation PV technologies which offer the prospect of significantly improved performance and/or low cost manufacture, thus helping to accelerate commercial exploitation and large-scale	£1.3m	2010 – 2015	

		deployment. New PV technologies will require innovations in materials, concepts and devices and the unique and flexible nature of Platform Grant funding will help the group at the University of Warwick tackle this important strategic challenge.			
Energy Futures DTC	EPSRC	We propose an Energy Futures Doctoral Training Centre that provides depth and breadth in PhD training in energy and its role in climate change mitigation. This will integrate with other energy DTCs recently awarded by EPSRC, but will not offer the full 12 month training programme associated with other fully funded DTCs. Our DTC will focus on future energy generation and distribution, aimed in particular on the role of the energy sector in achieving the UK's ambitious mitigation goals required to meet the challenge of climate change. It will accept 10 of the very best science and engineering graduates annually, funded by a strategic investment from Imperial College, and supported by industry. Breadth will be provided by our existing energy-wide training experience at MSc level, and established links between the Energy Futures Lab and the Grantham Institute for Climate Change at Imperial College, and by the inter-department and inter-faculty research linkages forged through existing and future interdisciplinary research projects. Depth is provided by our energy research networks and the research teams behind them, which we link by collectively addressing critical and cross-cutting research questions, such as how can we improve the energy efficiency of cities of the future , and how can we decarbonise energy generation . We will further develop this integrating approach within our Energy Futures DTC to link students across our energy themes, and ensure that students are given exposure to the broad energy, climate change and sustainability context.	£443,507	2010 - 2015	
Boronic Acids for Dye Sensitised Solar Cells	EPSRC	An excellent class of solar cell (dye sensitised solar cell DSSC) operates in a similar manner to photosynthesis. Whilst current technology is good there is still much room for improvement. The dyes used in DSSCs can themselves have detrimental environmental impacts as well as be costly and have a short operating lifetime. This project will provide new dyes that offer significant improvements relating to all these	£87,254	2012 - 2014	

		points taking a giant leap forwards to realising solar electricity generation as a cheap reliable technology for all. This research is being carried out by the University of Birmingham.			
Microstructural evolution of CdTe-based solar cells during chlorine activation	EPSRC	The purpose of the programme carried out by Durham University is to identify the dominant mechanism(s) underpinning chlorine activation as well as rapid screening of potential processing routes designed to optimise solar cell efficiency. The latter is a paradigm shift in solar cell fabrication methodology, moving away from methods based on trial and error, which are time consuming and costly.	£102,124	2012 - 2014	
Solar cells based on InGaN nano-structures	EPSRC	One requirement in reducing greenhouse gases is for high efficiency multijunction solar cells (MJSCs) to extract power from concentrated solar power (CSP) plants, which are expected to become central to the delivery of solar power to national and super-grid systems. At present such MJSCs must combine different materials systems, and are usually limited by the requirement to lattice-match the individual cells to avoid efficiency losses due to defects. In this proposal we aim to circumvent these problems by investigating solar cells based on InxGa1-xN, which has a direct band gap of 0.7-3.4 eV, spanning most of the visible spectrum, thus promising MJSCs from a single materials system. To avoid the problems of lattice mismatch and of material quality, which limit prototype solar cells based on InxGa1-xN epilayers to low x (x<0.3), we will grow the InxGa1-xN in nano-rod form, merging the nano-rods using methods we have already developed to provide a solar cell template. This research is being carried out by the University of Bristol, University of Nottingham and the Arizona State University.	£429,592	2011 - 2014	
Luminescent Lanthanide Layers for Enhanced Photovoltaic Performance (LEAP)	EPSRC	It is now widely accepted that the world's increasing reliance on fossil fuels over recent centuries is causing drastic changes in the Earth's climate. Renewable energy technologies - such as solar, wind and wave energy - offer a pathway for the generation of clean energy. This project concerns photovoltaic (PV) technology - the conversion of sunlight to electricity - and, in particular, involves the application of luminescent materials to PV modules. Shipments of PV modules have been increasing at a steady	£631,430	2011 - 2014	

		rate of >40% per annum since 1994 and continued strong growth of 20-30% predicted for the next few years. However, efficiency and price are still the main barriers to reducing the cost of solar electricity. This project seeks to develop a new class of PV devices and modules, based on today's semiconducting technology however utilising luminescent materials to alter the wavelengths contained in the sunlight before the photons interact with the solar cell. Via two techniques known as down-conversion (DC) and up-conversion (UC), we are able to greatly address two of the main loss mechanisms that limit the theoretical performance of a single junction solar cell to about 30%. With DC, we are able to use luminescent materials to absorb photons in the range of 300-500nm (UV through to blue-green light) and for each of these emit TWO photons at about 1000nm, where silicon solar cells respond very efficiently. Preliminary modelling has indicated that such a DC layer applied to the front of a silicon solar cell could increase its absolute energy conversion efficiency (sunlight to electricity) from 16% for a typical production device to 19%. Thus, a huge step change in performance is possible. UC layers are able to collect near-infrared (NIR) light that passes straight through the silicon, and for each of these NIR photons we can emit a single higher-energy photon that can be harvested by the silicon solar cell. The performance of UC layers depends on the intensity of sunlight though, and hence we will design and test these systems under 500-times concentrated sunlight. This project brings together spectral conversion and PV expertise from Heriot-Watt University (HWU) in the UK and matches this with luminescent materials expertise from the Fujian Institute of Research on the Structure of Matter (FJIRSM), one of the Chinese Academy of Sciences (CAS), with the goal of establishing a new class of PV devices that are able to promise a step-change in performance for both c-Si and thin film (e.g. a-Si:H) PV technologies.			
Enhanced solar energy harvesting in dye sensitized solar cells using	EPSRC & TSB	On a recently completed TSB programme, CONVERT (TSB ref. AE100D), two of the partners of the present consortium (the Wolfson Centre at Brunel University and Intrinsiq Materials Ltd.) developed long-life down-converting	£390,996	2011 - 2014	

nano-phosphors and nano-structured optics		phosphors that, once proven by scaling up in demonstrators, will be used worldwide in coatings and on cells to transfer more of the sun's energy into preferred PV frequencies. In this project we will scale up DSSCs to show the effect of augmenting the natural energy available and hence enhance energy output. In addition, we will harvest the light from a third of G24i's current cell's surface that is wasted and redirect the light to the active regions of the cell, thereby aiming to achieve performance gains of ca. 25%. This research is being carried out by Brunel University.			
Amorphous and crystalline GaNAs alloys for solar energy conversion devices	EPSRC	The choice of material for the photoelectrochemical, (PEC) photoanode (photocathode) is crucial for efficient hydrogen production, with a need for corrosion-resistance for prolonged operation. The band gap of semiconductor materials used for photoanodes must be at least 2.0eV, but small enough to absorb most sunlight. In addition to choosing the correct band gap, the conduction and valence band edges must straddle the H^+/H_2 and O_2/H_2O redox potentials so that spontaneous water splitting can occur. Currently there is no material that fully satisfies these requirements. Gallium nitride (GaN) is an excellent candidate for this application since it has a band gap ~3.4eV, high mechanical hardness and high chemical stability. The band gap of GaN can be adjusted and decreased due to strong negative bowing in the GaN-based solid solutions with group V elements. The group from Berkeley have theoretically predicted that GaNAs alloy with a band gap ~2eV could be the ideal photoelectrode material. The Nottingham, Strathclyde and Berkeley groups have jointly investigated the growth and properties of GaN1-xAsx alloys at the N-rich end of the phase diagram during recent years. Our collaboration was strengthened by a 1 year EPSRC feasibility grant (EP/G007160/1), which showed that it is indeed possible to grow such structures by molecular beam epitaxy (MBE). We have succeeded in achieving GaN1-xAsx alloys over a large composition range by growing the films much below the normal GaN growth temperatures. We discovered that alloys with a high Arsenic (As) content, above 17%, are amorphous, but despite this fact the GaNAs energy gap decreases monotonically with increasing As content.	£416,206	2011 - 2014	

		Optical absorption measurements reveal a continuous gradual decrease of band gap from ~3.4eV to ~1.4eV with increasing As. Soft x-ray absorption spectroscopy (XAS) and soft x-ray emission spectroscopy (SXE) studies have shown that the conduction band moves down and valence band moves up as the As composition increases in amorphous GaNAs alloys. Our results indicate that the amorphous GaN1-xAsx alloys have short-range ordering that resembles random crystalline GaN1-xAsx alloys. These GaN1-xAsx alloys cover the whole composition range and can be used not only for photoanode applications in PEC cells for hydrogen production, but also have technological potential for many optical devices operating from the ultraviolet to the infra-red.			
Interconnect Manufacturing Process for Thin Film Solar Cells (IMP)	TSB and EPSRC	This TSB/ EPSRC funded project "Interconnect Manufacturing Processes for thin film solar cells", brings together a powerful consortium with the aim of developing a simplified interconnect technology for thin film PV involving laser scribing and fast inkjet backfill with the dielectric and conductive materials. This high value manufacturing process will substitute one system for the six separate machines currently used. This single step approach will dramatically change the way PV modules are manufactured reducing complexity and cost of production. The programme takes advantage of existing thin film PV deposition technology at Powervision Ltd and world class solar cell characterisation and testing facilities at CREST (Loughborough University). M-Solv, the lead partner, has expertise in advanced laser micromachining and inkjet applications and also has good routes to market, particularly in the Far East.	Not available	2011 - 2014	
Development of Prototype High Efficiency Multi-Junction Organic Solar Cells	EPSRC and TSB	In this collaborative R&D project a consortia of industry and university groups will develop prototype Organic photovoltaics (OPV) cells using our patented multi-junction cell technology. Nano-structured organic and inorganic materials will be incorporated into multi-junction cells which will then be optimised to demonstrate high performance characteristics (efficiency and stability) as well as compatibility with low cost, large area fabrication. A key objective of this project will be to incorporate new transparent conducting electrodes into the multi-junction cell	£1,088,162	2011 - 2014	

		technology, thus eliminating the requirement for indium tin oxide (ITO) and enabling the new technology to overcome one of the key obstacles to low cost manufacture. This research is being carried out by the University of Warwick.			
Scalable low-cost organic photovoltaic devices	EPSRC	This project carried out by The University of Bath focuses on three key challenges for the translation of these lab-scale efficiencies into, low cost, scalable photovoltaic device technologies. Specifically, the three aims of this project are: (i) development of indium and PEDOT -free transparent conducting electrodes which are compatible with high device-module efficiencies and cost effective scale up and (ii) development of new synthetic methods for the scale-up of high-performance organic semiconductors and (iii) the implementation of these materials into OPV modules fabricated employing processing methodologies compatible with high through put, low cost manufacture. To address these aims we have assembled a highly multidisciplinary team comprising academics and industries with world-leading expertise in inorganic oxide electrode film deposition, polymer synthesis, processing, thin-film printing, functional characterization, nano-morphology, device physics and manufacturing. This proposal builds directly on the substantial advances made in our Stage 1 Grand Challenge in nano-technology and Energy program funded by EPSRC, targeting the demonstration of a commercially viable production process for OPV devices with enhanced stability and reduced cost.	£272,003	2011 - 2014	
Scalable, low-cost organic photovoltaic devices (SCALLOPS)	TSB and EPSRC	This project focuses on the key challenges for the translation of these lab-scale efficiencies into, low cost, scalable photovoltaic device technologies. Specifically, the three aims of this project are: (i) development of indium and PEDOT free transparent conducting electrodes which are compatible with high device-module efficiencies and cost effective scale up and (ii) development of new synthetic methods for the scale-up of high-performance organic semiconductors and (iii) the implementation of these materials into OPV modules fabricated employing processing methodologies compatible with high through put, low cost manufacture. Partners: NPL, Pilkington Technology, Imperial College London, University of	£2.4m TSB £803,541 EPSRC	2011 - 2014	

		Bath, Solvay Interox, RK Print Coat Instruments, and Flexink Ltd.			
Semiconductor nano-crystals for solar cells: Tuning shape, size and interface effects	EPSRC	This project at UCL will be built on one of the major challenges in contemporary physical sciences, that is the efficient conversion of the Sun's light into electricity in solar cells. By combining the experiences of two leading material simulation groups in the UK and China, we will provide an atomistic understanding of the processes that occur under the influence of light in technologically important semiconducting materials, especially the II-VI chalcogenide semiconductors. Our approach will be to exploit our complementary expertise in modelling the electronic properties of nano-structured and defective crystalline systems, which we will apply to novel solar cell architectures using inorganic nano-particles to absorb light - a highly topical area of interdisciplinary sciences at the heart of the stated research priorities of EPSRC. The primary focus of this project is on the simulation of real materials at length scales relevant to experimental analysis and photovoltaic device physics: bridging the gap between theory and experiment as well as the geographical divide between the UK and China. The project partners are Prof. Jingbo Li and Prof. Jian-Bai Xia from the Institute of Semiconductors, Chinese Academy of Sciences in Beijing, who are two world-leading experts in the simulation of semiconductor quantum dots. Together, we will address the fundamental physical processes occurring in a new class of nano-structure solar cells, where new electronic states introduced by the nano-structured materials can facilitate the utilisation of photons of sunlight that lie outside the range of traditional bulk heterojunction solar cells. In addition to providing the methodological advances required to describe these systems, we will address the optimal material combinations to enhance light to electricity conversion efficiencies in future solar cell devices. This project will utilise existing high performance computing infrastructures at both institutions, and all results will be directed into ongoing experimental work in both host countries. The successful outcome of the project promises substantial general impact in a key and highly relevant area of physical sciences, and the	£408,699	2011 - 2014	

		establishment of a strong material simulation collaboration between the UK and China in the fields of solar cells and computational materials science.			
Nano-crystalline Water Splitting Photodiodes II: Device Engineering, Integration and Scale-up	TSB and EPSRC	In this collaborative R&D project at the University of Warwick, a consortium of industry and university groups will develop prototype OPV cells using our patented multi-junction cell technology. Nano-structured organic and inorganic materials will be incorporated into multi-junction cells which will then be optimised to demonstrate high performance characteristics (efficiency and stability) as well as compatibility with low cost, large area fabrication. A key objective of this project will be to incorporate new transparent conducting electrodes into the multi-junction cell technology, thus eliminating the requirement for indium tin oxide (ITO) and enabling the new technology to overcome one of the key obstacles to low cost manufacture. Prototype cells will be developed that demonstrate certified power conversion efficiencies of 8%, accelerated lifetimes equivalent to 3 years in the field, and active cell areas of 10 cm x 10 cm.	£291,848 (EPSRC funding)	2011 - 2014	
Heterointerface control of organic semiconductor devices	EPSRC	Organic electronic materials are widely used in LEDs, transistors and, though less advanced, in solar cells. Organic semiconductor devices are generally divided into two classes: those made by vacuum deposition of so-called 'small molecules' and those made by solution-processing of film-forming materials (typically polymers). The UK community, following some of the early work at Cambridge has tended to concentrate on the latter class of materials. The rationale for this is two-fold. Firstly, in terms of translation to large-scale manufacture, direct low-temperature solution processing of active semiconductors is very attractive for low-cost processing, particularly where patterning can be carried out by direct printing (ink-jet printing has been developed, for example, for deposition of red-, green- and blue-emitting materials in full colour displays). Secondly, solution processing presents challenges and opportunities for the formation of useful device structures. In some respects it is awkward - it is generally difficult to assemble multiple layers of organic semiconductor to make conventional laminar hetero-structures because solvents are typically not	£6,693,636	2009 - 2014	

		sufficiently specific to allow successive layer depositions without disturbing lower layers - but in other respects, there are real opportunities to generate architectures that would be very difficult to make conventionally.			
Carrier lifetime measurement at grain boundaries in thin-film solar cells	EPSRC	In this project we will use state-of-the-art measurements of carrier lifetimes at individual grain boundaries to explore the fundamental mechanism(s) behind chlorine activation. The carrier lifetime is an important parameter specifying the electrical activity of a given grain boundary and its effect on device operation. In order to carry out such measurements a high spatial resolution (few nano-metres) must be combined with excellent temporal resolution (a few picoseconds) the technical demands for which have only recently been overcome. We will carry out the very first measurements of grain boundary carrier lifetimes in CdTe thin-film solar cells using the new Attolight scanning electron microscope recently installed at EPFL, Switzerland. This is the only scientific instrument of its kind in the world capable of carrying out such analyses. We will also explore the relative effectiveness of different chlorine activation routes (i.e. standard activation using solid $CdCl_2$ and gas activation methods) for passivating grain boundaries. This has important long term commercial benefits such as the production of efficient CdTe thin-film solar cells as well as reducing the environmental impact of the chlorine activation process. This research is being carried out by the University of Liverpool.	£25,425	2012 - 2013	
Engineered bulk heterojunction inorganic:organic hybrid photovoltaics	EPSRC	Inorganic-organic hybrid photovoltaic (h-PV) devices are a realistic prospect for the long-term development of entirely solution processable, scalable devices on rigid and flexible substrates. The pairing of a metal oxide (TiO_2, ZnO) with a conjugated polymer to form a hybrid device is an attractive combination of materials. For example, ZnO provides efficient electron mobility, effective light-scattering, is of low cost and can be formed in a wide variety of (nano-) structures from aqueous solution. The absorbing, hole-transporting conjugated polymers, such as poly(3-hexylthiphene)(P3HT), support a wide variety of processing routes and exhibit some of the best charge transport of all organic semiconductors. However progress made towards realising such h-PV	£99,908	2012 - 2013	

		technologies has been slow. Reported power conversion efficiency (PCE) values are typically < 1%, with some more recent publications reporting 2%. This compares with reported efficiencies of >8% for commercial organic-PVs. The nano-structured devices that will be prepared in this program will provide controlled bicontinuous networks for charge, and importantly will allow control of the polymer morphology - a parameter that has received little attention in h-PVs - although it is known to strongly influence exciton generation, free carrier transport and light absorption. This unique combination of materials and processing strategies presents an exciting opportunity for the development of h-PV devices that can overcome the current performance limitations by allowing control of the structural and morphological properties of the device not possible with other material combinations or processing techniques. This research is being carried out by the Imperial College, London.			
Stability and Performance of Photovoltaics	EPSRC	Definition of the performance of photovoltaics is normally reduced to the efficiency alone. However, this number contains no indication of key issues such as system component reliability, module stability or appropriate balance of system design, all of which play a crucial role in determining the performance in terms of usability. This UK-India collaboration will tackle some of the main challenges in developing cost-effective, efficient and stable solar systems. This project is being carried out by Loughborough University.	£2.4m	2010 – 2013	
Cheap Solar Electricity – The Essential Fuel of the 21st Century	EPSRC	Through this project, our team of scientists at Edinburgh University and beyond will collaborate with a number of public engagement experts to enable school students and the public of all ages and backgrounds to explore, discuss and reflect upon the issues related to innovation in low-cost solar energy technologies and its pressing need for the future of our planet. This proposal brings together the expertise and scientific entrepreneurship provided by the scientists within the innovative EPSRC Supergen consortium on Excitonic Solar Cells, with the public engagement expertise of The UK Association for Science and Discovery Centres, The Scottish Schools Equipment Research Centre (SSERC), The science media centre, CLEAPSS and the National STEM centre.	£152,343	2010 - 2013	

Probing and enhancing charge generation and transport in solid-state dye-sensitized solar cells	EPSRC	Photovoltaic devices that harvest the energy provided by the sun have great potential as clean, renewable sources of electricity. Despite this, uptake of photovoltaic energy generation has not been strong, largely because devices based on many current technologies are still too expensive. One promising alternative is given by organic-inorganic hybrid cells based on dye-sensitised metal oxide mesoporous electrodes, which are cheaper to produce and have reached power conversion efficiencies of over 11%. However, there remain concerns about the incorporated redox active liquid electrolyte, presenting the possibility of toxic, corrosive chemicals leakage. Recent research into replacing the liquid electrolyte with a solid-state hole-transporter has yielded cells with up to 5% power conversion efficiency. The University of Oxford propose a structured research programme that will lead to increases in the power conversion efficiencies of all-solid-state dye-sensitized solar cells (SDSCs) towards that of their electrolyte-containing counterparts. In particular, we will use a new approach in order to establish criteria for optimization of essential parameters such as the nano-scale morphology of the electrodes, the charge-mobility for the hole-transporter and the energetic level arrangement at the interface. The study will combine device measurements with a range of time-resolved spectroscopic investigations to deduce how each change to the system affects individual photophysical processes (such as photo-excited electron transfer) in the material, and how this translates into efficiency of device operation. Work will be based on a careful selection of material components that allow tuning of only one particular property at a time. This combined new approach will not only allow significant improvements to be made to specific SDSC designs, but also deliver a more general framework for the exact requirements of successful optimization approaches.	£739,361	2010 - 2013	

Artificial Photosynthesis: Solar Fuels	EPSRC	The development of scalable, efficient and low intensity-tolerant solar energy harvesting systems represents one of the greatest scientific challenges today. In this research proposal we propose to explore a bold and innovative approach that uses solar energy to both generate energy and fix carbon dioxide in one step, to produce a type of solar fuel cell which would yield methanol or similar feedstock (this is the long term ~10 year aim). This is an extremely challenging problem and in this study we will bring to together researchers in Chemistry and Electrical Engineering in Glasgow, with those in existing Bio-energy research (Bacterial Photosynthesis, Plant Molecular Biology) along with the key international groups in this area from the USA, Japan, and Germany, to explore the idea of transferring concepts from natural photosynthesis to solid state devices. In this research we will learn from Photosynthesis how to arrange light harvesting/reaction centre units on a surface in an immobilised environment to assemble highly efficient and broad spectrum light harvesting devices using inorganic/organic chemistry approaches. Therefore by combining research from Chemistry (Model systems, supramolecular chemistry, and photoactive units and metalloenzyme models) with Electrical Engineering (Surface patterning, lithography, and surface structure manipulation) and Molecular Biology (Structural biology, biological electron transfer, and membrane bound proteins) we will develop a major and long term interdisciplinary research program with this grand aim. This research is being carried out by the University of Glasgow.	£1,559,914	2009 - 2013	
Combinatorial CVD	EPSRC	This is an application for a Platform for baseline funding to support the joint Carmalt/Parkin research group. Parkin and Carmalt have collaborated extensively in the area of Chemical Vapour Deposition (CVD). Carmalt has focussed on the synthesis of molecular precursors for use in CVD, whereas Parkin has concentrated on the CVD growth and functional characterisation of thin films from these and other precursors. In the course of this research by UCL, they have, unusually for CVD, discovered a wide number of new phases especially metal nitride, oxide, sulfide and selenide materials	£814,511	2009 - 2013	

		that had proven due to kinetic reasons and precursor design, unobtainable by conventional solid-state synthesis. They have also determined how to control preferred growth and orientation of crystallites grown by CVD. This has enabled them to grow materials with improved functional properties for a variety of applications from gas-sensors, through ultraphobic, super-hydrophilic surfaces to thermochromic and self-cleaning films. The pinnacle of this work, especially for new phase determination has been their use of combinatorial CVD for the synthesis of new materials. Combinatorial CVD is currently the major focus of the Carmalt and Parkin joint group and is a significant component of all of their current EPSRC funding.			
Advanced Bio-Photovoltaic Devices for Solar Energy Conversion	EPSRC	Harvesting a large proportion of solar energy, in a cheap, efficient manner, poses many difficult technical challenges. At present, silicon based solar PV cells are the method of choice, but these devices tend to be very expensive to manufacture, since they contain highly purified, semi-conductive materials. In this application we propose to harness the photochemical reactions associated with photosynthesis, a fundamental biological process, to convert sunlight into a usable form of energy by means of a biological photovoltaic panel. Using a multidisciplinary consortium of groups based in Plant Science, Biochemistry, Genetics, Engineering and Chemistry we intend to develop, test and optimise biological photovoltaics for the production of hydrogen and/or electricity. In this application, we propose to separate the processes of oxygen evolution and hydrogen production in a semi-biological photovoltaic device using intact photosynthetic cells, in which protein complexes are intrinsically more stable, and which furthermore have mechanisms for self-repair. The device will be composed of two chambers, or half-cells, with oxygen evolution confined to one chamber and hydrogen production to the other. In addition, the approach can be used to produce a DC electrical current, in a manner analogous to standard silicon based photovoltaic panels. This research is being carried out by the University of Cambridge.	£1,137,893	2009 - 2013	

Femtosecond Optical Probes of Mesoscopic Materials for Photovoltaics	EPSRC	There is growing evidence that our increasing consumption of fossil fuels is leading to a change in climate. Such predictions have brought new urgency to the development of clean, renewable sources of energy that will permit the current level of world economic growth to continue without damage to our ecosystem. Photovoltaic cells based on organic or organic/inorganic hybrid materials have shown rapid improvements over the past decade, comparing favourably with existing inorganic semiconductor technology on energy, scalability and cost associated with manufacture. The most promising materials for organic or hybrid photovoltaics are based on blends of two components at whose interface light-generated excitations dissociate into charges contributing to a photocurrent. Blend morphology on the meso-scale plays a crucial role in these systems, with efficient photovoltaic operation requiring both large interfacial area and existence of carrier percolation paths to the electrodes. The proposed work will establish how both aims can be achieved, using a powerful new combination of non-contact femtosecond time-resolved techniques to examine a range of novel mesoscopic blends. This methodology will allow the simultaneous examination of exciton diffusion and dissociation, charge-carrier generation, recombination and conductivity, providing direct clues to the optimisation of materials for photovoltaics. Collaborations with researchers working on making photovoltaic devices will ensure that knowledge gained from these non-contact material probes will directly feed into enhancing device performance. This combined approach will allow the UK's exceptionally high expertise in the area of organic electronics to contribute effectively to its current goal of reducing harmful greenhouse gas emission. This research is being carried out by the University of Oxford.	£800,425	2009 - 2013	
Materials World Network: Nano-structured materials from nano-particle- and block copolymer	EPSRC	The proposed research includes synthesis of all necessary organic/polymer and inorganic components, characterization of assembly structures using various scattering, optical and electron microscopy techniques, as well as thorough investigations of their optical properties including simulation and modelling efforts, and work towards major novel optics	£530,211	2009 - 2013	

assemblies for nano-photonics and optoelectronics		in the form of sub-wavelength imaging, highly sensitive hot-spot arrays over macroscopic dimensions for sensing, and sub-wavelength waveguiding. While the main focus of our proposed work lies on non-magnetic materials and the assessment of linear optical properties of the fabricated compounds, a crucial point is that we are aiming at synthesis approaches that can be generalized over a wider class of materials systems. A final thrust of the program addresses a particularly topical exploitation area, where we will integrate specific plasmonic structures into hybrid solar cells and characterize and optimize plasmon enhanced photo-generation of charges and subsequent solar cell efficiency. If successful this will lead to a new generation, or class of photovolatics, namely plasmonic solar cells. This research is being carried out by Imperial College London.			
SUPERGEN Excitonic Solar Cell Consortium - MAIN CORE	EPSRC	Excitonic Solar Cells (ESCs) are a class of non-conventional solar cells, based on organic and nano-structured materials, in which the charge carriers are generated and simultaneously separated across a heterointerface. They include dye-sensitized nano-crystalline cells, organic cells and hybrid organic-inorganic cells, and in all cases cell fabrication can be achieved using low cost, large area deposition methods on both rigid and flexible substrates. Consequently, ESCs offer genuine medium to long term prospects for reducing the cost of PV below the commercially important threshold of $1 per watt peak. To date work on all types of ESC has been largely restricted to basic studies in academic and national research laboratories, with particular emphasis on improving device understanding and cell efficiency, which are 11% for state of the art dye cells, and much lower for the less well developed organic (4-5%) and hybrid cells (2-3%). However, progress in all types of ESC has undoubtedly been impressive in recent years, with research activity growing rapidly throughout the world. Major improvements in performance have been demonstrated in all cell types with the SUPERGEN Consortium at the forefront of much of this progress. This consortium is led by Warwick University with partners, Imperial College London, University of Cambridge, University of Bristol, University of Edinburgh, University of	£3,314,933	2009 - 2013	

		Bath, University of Oxford, Loughborough University and Heriot-Watt University.			
Theory of dye sensitized solar cells	EPSRC	Only a small fraction of the world energy usage (less than 0.05% in 2004) derives from solar cells because of the high cost of the current technology based on crystalline silicon. Dye Sensitized Solar Cells (DSSC or Gratzel cells) are one of the major alternatives to silicon photovoltaics and the subject of the proposed investigation. DSSC are relatively complex systems including a nano-crystalline titanium dioxide (TiO_2) semiconductor, a dye adsorbed on it, a solution containing an electrolyte that can be reduced and oxidized and a transparent electrode. The efficiency in the conversion of light into electricity achievable in mass produced DSSC is around 7%, while a desirable target efficiency of 15% (or larger) would make this technology suitable for large scale electricity production. Current improvements of the DSSC rely on the development of new dyes and new electrolytes. There are currently no predictive theories that allow the systematic improvement of DSSC and the efficiency improvement is largely based on chemical intuition and systematic search. The aim of the proposed research is to develop a methodology to compute and predict the elementary rates of all microscopic (charge transfer) processes taking place in DSSC. The control and understanding of these elementary processes are the basis for the rational improvement of cell efficiency. The theoretical description of DSSC requires a cross-disciplinary approach involving elements of solid state physics, electrochemistry and quantum dynamics. This research is being carried out by the University of Warwick.	£330,219	2009 - 2013	
Nano-structured metafilms: a new paradigm for photonics	EPSRC	The proposed research at the University of Southampton introduces a special type of metamaterials, namely planar metamaterials (or metafilms), for practical photonic applications. As a result, a whole new class of extremely compact (low-dimensional) photonic devices that replace the existing bulk optical components (such as spectral filters, polarizers, waveplates, beam splitters etc.) is envisaged. But more importantly artificial planar media allows achieving exotic photonic functionalities (e.g. optical superconductor,	£826,439	2008 - 2013	

		asymmetric transmission) that are hardly possible with the use of conventional bulk optical materials. Moreover, the research aims to add a new dimension to the concept of planar metamaterials, and therefore dramatically expand the range of available photonic functionalities, by combining electronic/molecular response of media and metamaterial resonances due to structuring.			
Nitride Photovoltaic Materials for Full Spectrum Utilization	EPSRC	Solar energy has to be converted into a useable form at reasonably low cost. Indeed, in the UK, recent increases in renewable energy generation have mostly relied upon increased use of wind power due to the relatively high cost of solar power. One of the most promising approaches to reducing the cost of solar power, is to use small-area high efficiency cells with light concentrated on them by low cost, large-area plastic lenses. The highest efficiency solar cells to date consist of three junction III-V semiconductor devices containing both arsenides and phosphides. The failure of the band gaps of these materials to match the wavelength range of the solar spectrum limits the maximum efficiency obtainable. This research is being carried out at the University of Liverpool.	£491,436	2012 – 2014	
Ageing of Printable polymer Cells	EPSRC	In this proposal we address the most important remaining issue, namely understanding and enhancing the lifetime of polymer solar cells. To do this we will combine advanced photophysical, morphological and chemical analysis of solar cells before, during and after operation to gain new insight into the factors controlling degradation of such cells. This will provide a solid foundation for developing strategies for extending the solar cell lifetime in the later part of the project.The operation of polymer solar cells depends critically on the nano-metre scale arrangement of the materials, so we will use sophisticated electron tomography techniques to study the nano-scale morphology and how it changes with device operation. This will be complemented by optical and electronic measurements performed in-situ on operating solar cells. A further innovation will be to make nano-scale perforation of an encapsulation layer and combine it with electron beam techniques to study local degradation with nano-metre resolution. This research is being carried out by	£589,517	2011 - 2013	

		the University of St Andrews.			
EXPLORER; Excitonic Polymer Organic Devices for Energy	EPSRC	Durham University propose three adventurous, cross-disciplinary projects within the area of energy research. The past decade has seen an upsurge in interest in the field of organic electronics. Devices such as light-emitting displays and chemical and physical sensors are already on the market - and probably in your home and in your pocket - while others, such as solar cells are developing fast. The motivation is the reduced cost, ease of manufacture, large-area capability and the enhanced efficiency which is possible using these new technologies. However, a lot more research is still needed. This study will unite: (i) the synthesis of new materials, (ii) detailed spectroscopic characterisation (iii) device fabrication and measurements of performance, and (iv) theoretical calculations.	£201,616	2011 - 2012	
Elimination of Efficiency Degradation Mechanisms in Silicon Photovoltaic Solar Cells	EPSRC	This research proposal aims to eliminate the degradation process by removing the reaction path from the silicon prior to the formation of the recombination centre. An essential pre-requisite to this is to achieve a detailed understanding of the defect centres and their formation. We have previously studied the oxygen dimers which are currently thought to be the precursors of the recombination centre. These can be detected using optical absorption measurements, ideally at low temperatures (~10K). Preliminary work indicates that it should be possible to develop treatments of the silicon material which reduce the concentration of the dimers to a negligible level in the finished cell and, because the dimers do not form at normal operating temperatures, so eliminate the formation of the defect. It would be quite feasible using this approach to maintain the concentration of interstitial oxygen which provides mechanical strength to the silicon with consequent yield and cost benefits. In this work the recombination centre will be studied using minority carrier Laplace Deep Level Spectroscopy and its structure determined by the application of uniaxial stress. The reaction of the oxygen dimer will be studied as the recombination centre forms, in real time, using optical absorption techniques. The work will be done in collaboration with MEMC who are one of the leading manufacturer of solar silicon, the	£268,035	2010 - 2012	

		Institut für Solarenergieforschung Hameln/Emmerthal (ISFH) in Germany who have undertaken much experimental work recently on solar cell degradation and the University of Aveiro in Portugal who will collaborate on theoretical calculations to support the Manchester work.			
Materials World Network: Hybrid photoconductors for high-efficiency photovoltaic cells	EPSRC	The research carried out by Imperial College London is highly multidisciplinary and combines experimental and theoretical approaches. The fundamental science and engineering questions we are going to study in this program include: (i) the development of automated microfluidic reactors for the synthesis of various II-VI and III-V nano-particles that emit in the visible or NIR; (ii) the influence of conjugated surfactants, including conjugated self assembled monolayers (SAMs), on energy and/or charge transfer processes from the host semiconductor; (iii) the effects of nano-particle surface traps and chemical bonding interactions introduced by the surfactant capping layers on the operation of hybrid organic/inorganic nano-particle solar cells and their stability. Our research plan is comprised of the following main tasks: i) Synthesis of high quality defect-free nano-particles of controllable size and chemical composition by the use of microfluidic reactors, including in-line and off-line characterization of the nano-particle quality; ii) Capping of the nano-particles and characterization of the capping layer and its effect on the charge and/or energy transfer from the host; iii) Modeling, fabrication, and characterization of bulk heterojunction hybrid organic/inorganic nano-particle semiconductor thin-film photovoltaic devices. Tasks i) and ii) will be lead by Imperial College while task iii) will be lead by Georgia Tech.	Not available	2009 - 2012	
A novel Design and analysis of 3D Building Integrated Concentrating Enhanced Photovoltaic Thermal System: BICEPT	EPSRC	This project will develop a non-tracking concentrating photovoltaic/thermal (CPV/T) system with optimised performance, which will be suitable for building facade/roof integration. As no tracking is required it is possible the cost of this system to reduce by two-fold, which makes more attractive for building integration. This will be undertaken through a new three dimensional design of a compound elliptical-hyperboloid concentrator of concentration ratios of 6.25 through a set of computation simulations together with	£178,444	2009 - 2012	

		controlled and outdoor tests. This design will enhance the optical efficiency of the concentrator unit and hence improve the overall electrical and thermal efficiency of the concentrating PV/T system. A prototype system will be made and indoor controlled characterisation will be undertaken at the HWU. Based on the process refinement one kW_p system will be manufactured to characterise at outdoors test conditions. In addition, an integrated Optical, Heat transfer and Electrical (OHE) model will examine the PV/T system to optimise its performance.			
Science Bridge Award USA: Harnessing Materials for Energy	EPSRC	This Science Bridge proposal builds upon the existing collaboration between the University of Cambridge and the University of California at Santa Barbara to perform the research required to bring existing research through to prototype products and devices in the field of energy-related materials. The proposal has five key themes: organic and inorganic solar cells; light emitting diodes (LEDs) based on gallium nitride (GaN); phosphors for solid-state lighting; organic LEDs (OLEDs); the low-cost integration of LEDs and OLEDs onto printed circuit boards; and ultralight materials and structures. We propose two approaches to make solar energy more viable. First, we propose to develop moderate-efficiency (about 15%) organic solar cells at extremely low-cost. UCSB will concentrate on developing more efficient cells and Cambridge will address low-cost manufacturing methods. This requires significant advances in printing methods for organic film deposition. The other approach to solar cells we will pursue is high-efficiency inorganic multilayer solar cells. The basic idea is that by stacking layers in the order of their bandgap, with the layer with the largest bandgap at the top, light is converted into electricity in the most efficient way.	£1,447,635	2009 - 2012	
Dilute Nitride Type II Quantum Dot Materials for Solar Cells based on GaAs - Collaborative Research in Energy with South Africa	EPSRC	The development of efficient, affordable solar cells for clean energy production is a major global challenge and in this proposal we are seeking to achieve a breakthrough in the fabrication of novel quantum dot materials capable of substantially improving the performance of III-V solar cells based on GaAs. Lancaster University propose a close collaborative project with Nelson Mandela Metropolitan University in South Africa, who have complementary	£401,156	2009 - 2012	

		expertise in photovoltaic cells, to develop and characterize hitherto unexplored GaSbN/GaNAs type-II quantum dot materials. These strain-compensated, dilute-nitride quantum dots will be implemented within the active region of prototype GaAs based solar cells to significantly extend the spectral response and improve the efficiency. This would lead to a new generation of solar cells for clean electricity generation. Feedback from device studies will provide valuable insight into the photovoltaic properties of these unique nano-structures, further aiding material optimization. The quantum dot materials that we shall develop here could either be used to increase efficiency in single junction cells, or could be incorporated into existing multi-junction cells to replace expensive Ge substrates, reduce cost and significantly increase performance. There are clear opportunities for uptake of the technology both within South Africa and the UK.			
Structure-Property-Performance Relationships for Organic Bulk Heterojunction Solar Cells	EPSRC	Organic semiconductors combine the semiconductor properties traditionally associated with inorganic materials with the more desirable properties of plastics such as low cost, flexibility and ease of processing and patterning. Moreover, the organic syntheses of these materials allow for great flexibility in the tuning of their electronic and optical properties. By combining these properties, organic semiconductors such as conjugated polymers and small molecules have been demonstrated as the active layer in a wide range of optical and electronic devices including photovoltaic solar cells. The leading design of organic solar cells is based on the bulk heterojunction, in which organic blends comprising an electron donating component (usually a conjugated polymer) and an electron accepting component (such as a fullerene derivative or a conjugated polymer) that are dissolved in the same solvent and then spin-coated from the solution to form a thin film, sandwiched between two different electrodes. Recent developments in materials and device fabrication processes are leading to rapid improvements in performance of these devices. For example, solar conversion efficiencies up to 5-6 % were reported for solution-processed organic solar cells. Despite their	£288,685	2009 - 2012	

		significantly improved device performance, a number of scientific challenges remain to more fully understand, quantify, and predict the behaviour of the organic bulk heterojunction solar cells. This research is being carried out by the Imperial College London.			
Enhanced solar light harvesting and charge transport in dye-sensitized solar cells	EPSRC	Dye-sensitized solar cells are moderately efficient with verified solar-to-electrical power conversion efficiencies of over 12% reported. However, even in the state-of-the-art systems only a fraction of the incident sun light is absorbed, implying substantial scope for improvement. Here we develop both state-of-the-art liquid electrolyte based DSCs and contemporary solid-state hybrid DSCs with the target being to considerably enhance the light capture and adsorption in these devices and also significantly improve the charge transport characteristics. Routes to both improve the photonic structure of the solar cells, create improved semiconducting oxide electrodes for enhanced charge transport and collection and develop and optimise new sensitizers for these systems shall be undertaken. This research is being carried out by the University of Oxford.	£101,895	2009 - 2012	
Low cost integrated PV in double glazed windows using CdTe bifacial solar cells	EPSRC and TSB	The aim of this project is to apply a thin film photovoltaic layer on to the inside face of a double glazed unit with the potential to supply up to 50W of power from the average window. Initial studies show that this is possible using highly efficient CdTe absorber along with TCO contacts. Further design work involving all the partners is required to integrate this with coatings for infra-red reflection. The bifacial CdTe solar cell technology allows the opportunity for thin film based solar cells to be used in building integrated PV (BIPV). This research is being carried out by Loughborough University.	£245,638	2009 - 2012	
SUPERGEN - PV Materials for the 21st Century	EPSRC	PV-21 is the UK's inorganic solar photovoltaic (PV) research programme. This proposal is for a renewal for the second four year cycle. The Consortium has sharpened its focus on the science that will deliver our medium to long term goal of "making a major contribution to achieving competitive PV solar energy". They had put in place lab-scale facilities for making three main types of solar cells based on thin film absorbers - copper indium diselenide, cadmium telluride and	£6.2m plus £1.86m	2008 – 2012	

		ultra thin silicon. To reduce costs, they will concentrate on critical materials and PV device issues. The team comprises nine universities - Durham University, University of Edinburgh, Imperial College, Northumbria University, University of Southampton, Glyndŵr University, University of Bath, Southbank University and Cranfield University along with seven industrial partners. PV-21 is also plays an important role in skills development, with nine PhD students due to be trained in the first cohort.			
High stability and high efficiency printable photovoltaics (OPV) for large-scale energy production	EPSRC	The depletion of oil reserves, spiralling fuel costs, concerns about the security of global energy supplies, and belated worldwide recognition of fossil-fuel induced climate change have sparked an urgent and unprecedented demand for sustainable energy sources. Amongst all of these sources solar photovoltaic (PV) energy stands out as the only one with sufficient theoretical capacity to meet global electricity needs, but high costs of silicon based PV prohibit widespread take-up. In this programme, we focus on the development of organic photovoltaics (OPV) as a low cost technology with the potential to displace conventional power sources. The proposed programme links Imperial College London with four leading Chinese institutions, building on ICL's strengths in the physics and application of molecular electronic materials and devices and on our partners' strengths in speciality materials development and scale-up. A collaborative programme between the UK and China in this area is particularly timely, given the pressing need for alternative power sources that are capable of meeting the rapid development rate and large energy demand of China. Our proposal focuses on solution-processable organic molecules and polymers which share many of the chemical, structural and rheological properties of the inks used in conventional printing and which are amenable to large-scale production through the existing printing and coating industries. This research is being carried out by Imperial College, London.	£864,655	2008 - 2013	

Thermal Conductivity Enhancement of High-Temperature Thermal Energy Stores For Use with Solar Power Plants	EPSRC	Thermal energy storage is of critical importance in many engineering applications. The demand for CO_2 reduction to curb global warming considerably increases the interest in utilizing renewable energy sources, especially solar energy. Due to the discrepancy between solar energy supply and energy demand, a thermal energy storage device has to be used. Thermal energy storage (TES) plays a vital role in solar energy applications in areas such as energy efficient buildings and solar power plants, and therefore, it has received significant attention. Thermal energy storage techniques can be classified as sensible heat storage and latent heat storage. Latent heat storage is particularly attractive, since it provides a high energy storage density and can store the energy as the latent heat of fusion at a constant temperature (phase change temperature of the corresponding PCMs). Although extensive investigations on low temperature latent heat storages mainly used for buildings have been conducted, very limited investigations on high temperature latent heat storages have been carried out for solar power plants. This research is being carried out by the University of Warwick.	£690,060	2008 - 2013	
Self-organized nano-structures in hybrid solar cells	EPSRC	Traditional mainstream inorganic semiconductor technology has been remarkably successful. However, standard fabrication techniques of microelectronic devices and components rely on a layer-by-layer assembly process and fall short of delivering three dimensional control of device architecture. Naturally-occurring complex systems utilize self-organising three dimensional architectures to deliver functionality beyond the properties of the individual components. To generate highly structured inorganic materials nature usually employs organic templates. Coordinating between inorganic chemistry, organic chemistry, material science and semiconductor physics is one of the opportunities within nano-technology. This area of multidisciplinary research provides the tools to fabricate three dimensional architectures which promise to deliver novel functionality to material composites. This research is being carried out by the University of Oxford.	£446,685	2008 - 2012	
Carbon Dioxide and Alkanes as	EPSRC	The vision is to create a solar nano-device which will drive the coupled photo-conversion of methane and carbon dioxide	£363,179	2008 – 2012	

Electron- sink and Source in a Solar Nano-cell: towards Tandem Photosynthesis of Carbon Monoxide and Methanol		into methanol and carbon monoxide respectively. This challenging target differs fundamentally from the familiar one of splitting water into hydrogen and oxygen. Our target offers products both on the oxidation and the reduction sides that are significant fuels or feedstocks. The photocatalytic reduction of CO_2 and oxidation of alkanes represent long-standing goals of great complexity, but we base our concepts on well-established principles. The goals are broken down into individual components, each of which is highly challenging within its own right and delivery of each would constitute a major breakthrough. The challenges will be met by a team of scientists, integrated across the four centres of Manchester, Nottingham, York and Norwich, who lead teams with expertise in photophysics, nano-science, photochemistry, electrochemistry and synthesis.			
Plastic UV Radiation Protection Operating by Stokes Emission (PURPOSE PROJECT)	EPSRC	This project at Brunel University aims to develop novel energy harvesting products for a wide range of applications. This will be achieved by enhancing the properties of polymer composites; more efficient use of solar/thermal energy, longer life and recyclability. These improvements stem from the use of novel inorganic phosphor particles downconverting solar UV light to other parts of the electomagnetic spectrum. With the incorporation of low cost novel phosphors, the new composite materials will have more efficient UV protection (giving longer life and enhanced recyclability), provide innovative thermal heating for climate control (in both car and domestic interiors), and give enhanced plant growth (by converting light to increase the intensity of the wavelengths of light used in photosynthesis). In summary, this generic technology has the ability to deliver significant energy benefits across a wide range of applications.	£461,183	2008 - 2012	
New and Renewable Solar Routes to Hydrogen Energy	EPSRC	The UK, together with the international community, is acutely aware of the problems arising from the unsustainable use of fossil fuels, and is increasingly focusing on the development of zero-carbon emission fuels, particularly hydrogen, using renewable energy sources. Of the renewable energy sources under consideration, solar energy is the most abundant and, if harvested efficiently, is capable of meeting global energy needs for the foreseeable future. It is estimated that solar	£4,106,687	2007 - 2012	

		power incident on the earth is 178,000 TW, approximately 13,500 times greater than the total global power demand (or burn rate) in 2000 (13 TW) and 6400 times greater than recent forecasts of the power demand for 2020 (28 TW). Much solar energy research is focused on its direct conversion to electricity in photovoltaic devices, or on its direct conversion to heat in solar thermal devices. A major barrier to all these 'conventional' routes is their prohibitive cost. Here, we propose to exploit low temperature natural biological and photocatalytic processes to develop alternative, and cost effective, methods for harvesting solar energy to produce renewable hydrogen fuels directly, and to explore how these could be embedded within novel, integrated energy production systems, incorporating fuel cell and hydrogen storage technology. The successful scale-up of these solar energy-driven renewable hydrogen generation processes would transform the supply of carbon-less fuel and make an enormous impact on the viability of hydrogen as an energy carrier. It will convert the potential to produce hydrogen in a carbon-free, renewable way into a process reality, and is an essential step on the route to fully exploiting fuel cell technology. It will position the UK as a world leader in one of the very few solutions to a truly sustainable energy future. As such, the impact is wide ranging, scientifically, technologically and commercially. This research is being carried out by Imperial College.			
Three-dimensional nano-shere templating: A novel method for the preparation of nano-structured photovoltaics	EPSRC	More recently organic PVs which consist of organic semiconducting materials have been prepared, which typically are inefficient (<5% conversion efficiency) but are economically attractive. Light absorption in photovoltaic devices leads to the creation of electronically excited molecular states (excitons). Excitons can travel for a few tens of nano-metres and if an interface is reached they will dissociate into an electron and hole, creating current. If an interface is not reached the exciton and current will be lost. The short exciton diffusion length is the principle reason for poor conversion efficiency in organic PVs. The purpose of this project is to significantly increase the efficiency of photovoltaic devices by engineering and optimising	Not available	2007 - 2012	

		architectures and interfaces in PVs. A three-dimensional templating method will be used to produce nano-structured, interconnected structures, which will overcome material limitations and present a viable route for the formation of low cost and efficient PVs. In addition to being economically attractive the project will allow for the first time a fundamental study of the relationships between the structure, composition and conversion efficiency in these exciting materials to be conducted. This research is being carried out by Imperial College London.			
Advancing the efficiency and production potential of Excitonic Solar Cells (APEX)	EPSRC	This project is centred on the development of the materials, device structures, materials processing and PV-panel engineering of excitonic solar cells (ESCs). These have the potential to greatly reduce both materials and also manufacturing costs where the materials, such as organic semiconductors, dyes and metal oxides, can be processed onto low-cost flexible substrates at ambient temperature through direct printing techniques. A major cost reduction is expected to lie in much-reduced capital investment in large scale manufacturing plant in comparison with conventional high vacuum, high temperatures semiconductor processing. There are extensive research programs in the UK and India developing these devices with the objective of the increase in PV efficiency through improved understanding of the fundamental processes occurring in these optoelectronic composites. However, there has been less activity in the UK and India on establishing from this science base a scalable, commercially viable processing protocol for excitonic solar cells. The scope of this UK-India call enables research and development to be undertaken which can pull together the set of activities to enable manufacturing application, and this extends beyond the usual scope of funding schemes accessible to the investigators. This project tackles the challenge to create cost-effective excitonic solar cells through three components: new material synthesis of lower cost materials; processing and development of device (nano-)architectures compatible with low process costs; and the scale up towards prototypes which can replicate solar cell performance achieved in the research phase. This project was	£2,039,039	2011 - 2013	

		carried out by Loughborough University, Heriot-Watt University, Imperial College London, University of Oxford, and University of Cambridge.			
High efficiency silicon solar cells with PECVD dielectric rear surface passivation - HIGHPOINT	EPSRC	The project aim is to develop an industrial production process for a new design of monocrystalline silicon solar cells with an efficiency above 20% on a cell area of 150 cm^2 which can be manufactured cost effectively in high volume. The solar cell structure will comprise the high efficiency front contact laser grooved buried contact process together with state of the art plasma enhanced chemical vapour deposition (PECVD) of low temperature dielectric films in the amorphous silicon dioxide/carbide/nitride family producing a pacified rear surface. The metal contacts will be formed by a self-aligning plating process. The improvements will be demonstrated at an industrial scale and the potential for a 20% reduction in cost at the PV system level will be verified. This research was carried out by HWU.	£383,195	2008 - 2011	
Manufacturable nano-scale architectures for heterojunction solar cells	EPSRC	This project at the University of Cambridge will produce manufacturable nano-scale architectures for heterojunction solar cells. Though routed strongly within 'science', the objectives are to achieve engineering solutions to allow the breakthrough needed in this field (target efficiency 10%). Excitonic solar cells based on molecular semiconductors require the presence of a heterojunction between electron and hole-accepting semiconductors in order to separate charges from photogenerated excitons. Large heterojunction interfacial areas are required if all photogenerated excitons are to reach the heterojunction before decaying, and this requires a complex nano-scale architecture. Current methods to achieve this nano-structure and limited and solar cell performance of such devices has stalled. We propose therefore to develop generic routes to separate the control of the nano-scale morphology from the selection of the donor and acceptor semiconductors. This will represent a critical advance in allowing a stable process window, and should allow improved photovoltaic performance through better morphology control and the ability to use semiconductors better matched to the solar spectrum. These routes will be compatible with low temperature processing (this is critical	£1,320,959	2008 - 2011	

		for low-cost manufacturing). The general principle we will use is to separate the processes needed to form the desired nano-scale architecture from the subsequent formation of the active semiconductor-semiconductor heterojunctions at which charge separation is achieved. Central to our approach is the use of 'sacrificial' polymer structures that provide excellent control of nano-scale morphology, and their later replacement with active semiconductors. We will use the controlled nano-scale structures produced using di-block copolymers			
Engineered hierarchical nano-structures for optimised hybrid photovoltaic devices	EPSRC	The overall aim of this project is to generate hierarchical structures with defined architectures at both the meso and macro scale, in order to optimise the efficiency of organic-inorganic hybrid solar cells. In this Grand Challenge we intend to develop novel hybrid-cells consisting of cheap inorganic electron transport matrices and readily manufactured organic molecules that both absorb light and transport holes. The efficiency of the cells will be maximized by engineering the interface between the materials on the nano-scale. Our Grand Challenge is to develop inorganic-organic-hybrid-photovoltaic cells which through interface engineering at the nano-scale are significantly more cost effective than currently available devices. The programme will be a joint venture between the London Centre for Nano-technology at Imperial College London and Warwick University. Collaborations are in place with Colleagues from the McDiarmid Institute for Advanced Materials and Nano-technology in NZ and with Kodak, UK.	£631,171	2008 - 2011	
Optimising polymer photovoltaic devices through control of phase-separation	EPSRC	In this project, which is being carried out at the Universities of Cambridge, Sheffield and Cardiff, a comprehensive mechanistic understanding is developed of the self-assembly processes by which nano-scale structure arises within such PV applicable materials. In particular we propose to study the evolution of nano-scale phase-separation during film casting using X-ray scattering. We will also utilize a range of complementary microscopy techniques ranging from environmental scanning electron microscopy, to time-resolved near field microscopy. The combination of such techniques will permit us to develop a complete picture of	£1.1m	2008 – 2011	

		film structure from molecular to microscopic length-scales.			
Optimising polymer photovoltaic devices through control of phase-separation	EPSRC	In principle, photovoltaic devices could meet all our energy requirements in a sustainable way, but at the moment the capital expense of conventional photovoltaics is too great to be competitive, and the volume in which they can be produced is much too small to make a serious dent in our electricity generating needs. Their relatively high manufacturing cost and the difficulty of scaling the manufacturing process is an intrinsic feature of their energy-intensive fabrication process. In contrast, non-conventional PVs based on organic semiconductors can be processed from solution using high-volume roll-to-roll printing technologies, offering the possibility of large area devices being fabricated on flexible substrates at very low cost. Unfortunately at present, organic PV devices are characterized by prohibitively low external power efficiencies (< 6%). Closing the gap in efficiency between organic and inorganic PV devices is a significant challenge / one which will require a full microscopic understanding of the processes that currently limit organic PV efficiency. The most promising organic PV devices are currently based on solution-cast blends of conjugated polymers doped with fullerene derivatives. This research was carried out by Diamond Light Source Ltd and the University of Sheffield.	£69,564	2008 - 2011	
Self-organized nano-structures and transparent conducting electrodes for low cost scalable organic photovoltaic devices	EPSRC	The development of cheap renewable energy sources is required to reduce the environmental effects associated with the use of conventional fossil fuel based energy sources. Of all the renewable energy technologies, solar energy has the greatest potential as a world power source. For this reason, solar photovoltaic (PV), the direct conversion of sunlight to electricity, is expected to play a significant role in future electricity supply. This multidisciplinary project brings together chemists, physicists, materials scientists and engineers with world-leading expertise in metal oxide electrode design, polymer synthesis and manufacturing. This project being researched at the Imperial College, London also involves collaboration with Pilkington Glass, Merck Chemicals and University of Bath.	£1.8m	2008 – 2011	
High-efficiency	EPSRC	Widespread implementation of photovoltaic electricity to	£1.1m	2008 –	

Block Copolymer Solar Cells: A Scalable Prototype for Low Cost Energy Generation		meet changing energy demands requires a step-change in the cost of photovoltaic power. This proposal assembles a consortium of chemists, physicists and materials scientists from Imperial College London and the universities of Manchester, Sheffield and Durham to produce new prototype polymer solar cells that have high power conversion efficiencies and could be mass produced cost effectively. The project will establish strategies for scaling up the device designs which have the highest efficiencies. Our objective is to construct affordable and scalable polymer solar cells that have an energy conversion efficiency of at least 7%.		2011	
Lower-cost Concentrating Photovoltaic Systems Using III-V Cells (III-V CPV)	EPSRC & TSB	The objective of the project at Loughborough University as a whole is to generate a novel concentrating photovoltaic device which will deliver a step change in the cost per kWh over conventional technology. This does not only require an increase in the efficiency, which will be delivered by the other partners in this project, but also an increase in energy yield, which will be ensured and quantified by this research team.	£115,693	2008 - 2011	
Low-cost Extremely Thin layer Absorber (ETA) Solar Cell: A Novel approach to make the conformal ETA Layers	EPSRC	The Extremely Thin Absorber-layer (ETA) solar cell is a relatively new PV configuration. In materials viewpoint, there are a large number of semiconductor materials available that are suitable to employ in ETA cell configuration. Most of them are yet to be tested in ETA cell. The first part of the project will be aimed at screening semiconductor material combinations to find out novel material combinations (high band gap n-type semiconductor/low band gap light absorbing semiconductor/high band gap p-type semiconductor) for ETA cells. This will be done by aligning the band gap and band edges of semiconductors. The next part of the project is the construction of the integrated ALD and CVD deposition system. The main advantage of constructing this deposition system is that it will give us the capability of depositing conformal layers of light absorbing low band gap semiconductor materials on high aspect ratio of microstructures. The system will also be capable of deposition of pin-hole free compact layers and deposition of p-type high band gap semiconductors on high aspect ratio microstructures. This research is being carried out by Loughborough University.	£292,938	2008 - 2011	

Nano-crystalline Photodiodes: Novel Devices for Water Splitting	EPSRC	The fossil fuel reserves of the world are rapidly diminishing and are also the prime cause for global warming. Solar energy represents a major, largely untapped energy source which could easily satisfy current and future global energy demands. Any solar energy conversion device must be inexpensive per $m^{2,}$ efficient and long-lasting. In this programme, novel, inorganic water-splitting systems, called macro-photocatalytic diode cells, MPCDs, utilising a range of new and established visible-light absorbing photocatalyst materials, will be developed for splitting water using sunlight in separate compartments. The latter feature is important as it will minimise, if not eliminate, the various efficiency-lowering recombination reactions associated with mixed product generation. The work programme involves a number of novel aspects including: the preparation of new nano-particulate, crystalline photocatalyst materials, fabricating them into different novel photodiode formats and the synthesis and utilisation of new redox catalysts. The use of nano-particulate semiconductor photocatalysts, made via continuous hydrothermal flow synthesis, CHFS, in conjunction with gel casting for robust porous supports, is a particularly important and novel advance, as too is the proposed combinatorial approach to the preparation of photocatalyst films by CVD. The project at the University of Strathclyde will develop a significant amount of the underpinning science required for the fabrication of the final, optimised, efficient MPCDs and include a study of the underlying reaction mechanisms, using time-resolved transient absorption spectroscopy. The proposal offers a route to achieving a step change in efficiency for energy capture from the sun and aims to deliver efficient, scalable demonstrators of the MPCD technology, suitable for development into pilot plant systems in the second phase of funding.	£518,659	2008 - 2011	
High-efficiency Hybrid Solar Cells for Micro-generation	EPSRC	This proposal assembles a consortium of chemists, physicists, materials scientists and electrical engineers from The University of Manchester and Imperial College London to address this need through the development of new low-cost, high-efficiency, demonstration solar cells for micro-generation. We propose new designs for hybrid	£1,012,365	2007 – 2011	

		organic/inorganic devices which integrate flexibility and stability with inexpensive materials and solution based processing.			
Novel Inline Deposition System for High Performance CIGS Solar Cells	EPSRC & TSB	CIGS (copper indium gallium selenide) solar cell structures have been identified as technologically important for the next generation of solar power production. They offer the advantages of being substantially less expensive to produce than crystalline devices and offer higher efficiencies than other non-crystalline photovoltaic materials. Currently, CIGS solar cells are typically produced using three separate deposition systems - two for the electrical contacts and one for the CIGS layer. The project aims to eliminate the requirement for three separate systems by combining all the processes into one system. This offers two important advantages that will ultimately result in the improved competitiveness of the process; the initial capital equipment cost will be lower than for three individual vacuum deposition systems and the inline nature of the system will allow higher throughput than conventional batch systems. The system will also demonstrate the proof of concept for roll-to-roll coating and continuous throughput systems. This research is being carried out by Loughborough University.	£84,508	2007 - 2011	
Magnetic field- and pressure- optical effects in $CuInSe_2$, $CuGaSe_2$ and $CuInS_2$	EPSRC	The development of improved sources of renewable energy is of extreme importance in order to reduce dependence on fossil fuels. Solar energy leads the way as the most environmentally friendly and abundant of such resources since the Sun transmits to the earth surface an amount of energy 100,000 times greater than present world energy consumption. A range of materials are employed for solar cells and here we propose work on chalcopyrite semiconductors which offer particular advantages, namely (1) extremely high absorption coefficients, higher than any other known semiconductor (2) energy gaps close to the optimal values for terrestrial and space conditions (3) robustness and relative insensitivity to irradiation by both high energy protons and electrons as a result of efficient self-healing mechanisms at room temperature. The materials to be studied are $CuInSe_2$, $CuGaSe_2$ and $CuInS_2$ semiconductors as are currently used in the absorber layer of solar cells	£475,911	2007 - 2011	

		which hold record conversion efficiencies for thin-film photovoltaic devices (19% for Cu(InGa)Se_2- photovoltaic devices and 12% for $CuInS_2$-based ones) and demonstrate superior stability when compared to any other thin-film solar cell. The band-gap of $CuInS_2$ (Eg ~ 1.53 eV) almost ideally matches the solar spectrum whereas in CuInSe2-based cells the optimum efficiency is achieved by alloying $CuInSe_2$ (Eg ~ 1.05 eV) and $CuGaSe_2$ (Eg ~ 1.68 eV). Progress so far with Cu(InGa)$(SSe)_2$-based technologies has mostly been attained using scientific intuition rather than knowledge-based design. Here we propose to use optical spectroscopy, in the presence of magnetic fields and high pressure, to improve the understanding of these materials and apply this to the development of improved solar cells. This research is being carried out by the University of Strathclyde.			
Development of a Novel Tunnel-junction-free Concentrator Cell and its Evaluation for a Smart Windows Application	EPSRC	We propose to develop a novel type of solar cell that will generate electricity from sunlight with efficiency above 30%. This is at least twice the efficiency of the cells currently used to power roadside signs and comparable with the highest efficiency tandem cells which power satellites in space. However, our cell offers many advantages over the tandem, in particular the absence of a tunnel-junction. This means they can cope with the large variations in the intensity and spectral content of sunlight on buildings and in the light-concentrating systems which reduce the cost of solar electricity. This research is being carried out by Loughborough University.	£71,289	2009 - 2010	
Metal substrate mounted flexible dye sensitised semiconductor solar cells	EPSRC	Low cost photovoltaic (PV) coatings in the modern built environment promise great financial /environmental benefits, potentially competing with mainstream energy sources. The novel approach studied dye-sensitised titania photovoltaics in polymer coatings on strip steel, providing a large area solar collector. The aim was "breakthrough" low cost PV surfaces, using cost effective materials and rapid/continuous coil coating manufacturing. This research was carried out by Swansea, Bath and Bangor University and Imperial College.	£1.4m	2007 – 2010	
Growth and Electronic Properties of InN		This project will study the growth and characterisation of a new optoelectronic semiconductor material, namely indium nitride (InN). Starting from the deposition of the first few	£441,841	2007 - 2010	

and N-rich Alloys		atoms that make up a single atomic layer of the material, the growth will be observed using scanning tunnelling microscopy (STM), through to the development of complete monolayers, and all the way to the growth of thin films (i.e. several microns thick). This research is being carried out by the University of Warwick.			
Self-assembling conjugated macromolecules for organic field effect transistors and solar cells	EPSRC	The design and construction of an ideal material for organic semiconductor devices requires the careful consideration of a range of physical properties. In some cases, what would represent good materials characteristics for one type of device may be highly detrimental to the efficiency of another. Intermolecular pi-pi interactions symbolise one good example: in organic light emitting devices, photoluminescence is quenched by these attractions and the device efficiency is reduced dramatically; in organic field effect transistors (OFETs), it is desirable to promote pi-pi interactions throughout the bulk, so that charge mobility can be maximised. In this proposal, we aim to prepare materials for organic photovoltaic (OPV) devices and OFETs. The novelty in this work originates from very recent results, in which we demonstrate that highly soluble materials with conformational freedom in solution are able to self-assemble in the solid state to give highly planar and conjugated structures. Such levels of planarity, which maximise the possibility of pi-pi interactions, have only been achieved previously with ladder or ribbon type structures which possess inherent solubility problems. In our systems, long range planarity can be achieved through the use of weak, non-covalent interactions; to date, this approach has not been given significant consideration and is therefore waiting to be exploited. This research is being carried out by Imperial College London.	£116,852	2007 - 2010	
PLATFORM: Molecular Engineering Rules in Functional Nano-scale Assemblies	EPSRC	The organisation of molecular and biomolecular components on the 1-100 nano-meter scale to achieve a desired functionality is central to the current growth of interest in nano-materials and nano-technology. Such structural organisation is of course already fundamental to the function of many biological macromolecules; the emulation of such structural and functional control is now a central element of	£411,774	2005 - 2010	

		many chemical approaches to functional materials and devices. The applicants of this proposal all head internationally leading research programmes addressing the engineering principles of functional nano-scale assemblies. The rationale behind all of these studies is the determination of the underlying structure / function relationships which will allow the rational design of specific nano-scale assemblies to achieved a desired functionality. The nano-scale assemblies studied by the applicants all lie close to the chemistry/life sciences interface and include natural and synthetic redox proteins, the integration of such redox proteins with nano-structured inorganic materials, and biomimetric approaches to solar energy conversion and light driven water splitting. This research is being carried out by Imperial College London.			
A novel device architecture for high-performance organic solar cells	EPSRC	The project is a feasibility study carried out by the University of Cambridge which will establish whether by aligning the polymer chains along the direction of the electric field that is present in the device it is possible to reduce recombination losses significantly. We have got indirect evidence from measurements on other device structures that this is possible, and the present feasibility study will establish whether this effect can be exploited for improving the efficiency of state-of-the-art organic solar cell systems towards reaching power conversion efficiencies of 10%.	£133,811	2008 - 2009	
SUPERGEN - Excitonic Solar Cells Consortium	EPSRC	finished	£1.1m	2005 - 2009	
Modelling Thin Film and Dye-sensitised Solar Cells	EPSRC	Thin film and dye sensitised solar cells encompass different approaches to solar cell design. What they have in common is the existence of contoured interfaces either at grain boundaries (thin film cells) or between the layers transporting the charges (dye-sensitised cells). The finite element technique allows us to develop electrical and optical models that consider these interfaces. By predicting photocurrents and photovoltages and quantities that characterise the cells such as transient currents, our models will aid in understanding cell operation and identifying the key factors limiting solar cell performance. There will be close interaction with UK experimental colleagues who can give us	£213,493	2005 - 2008	

		information on fundamental mechanisms which can be imported into the models. Our models can then be used to help interpret experimental data, providing feedback on the device physics of the solar cells. This will be done through collaboration with the EPSRC's Supergen programmes and via the EPSRC funded network PVNET. Our work will thus provide a nucleus for photovoltaic device modelling in the UK. This research was carried out by Cranfield University.			

Table 3.2: Key Research Providers

Name	Description	Sub-topics covered	No of staff	Field
Building and Sustainable Technology Group, School of the Built Environment, University of Nottingham	The Institute of Sustainable Energy Technologies (ISET) at the School of the Built Environment (SBE), University of Nottingham has an excellent reputation for innovative research into sustainable energy technologies including integration of renewable energy systems into buildings.	• Integration of PV in naturally ventilated buildings focusing on the potential for heat removal to enhance electricity generation.	49 academic staff, 30 PhD students	Architecture and the Built Environment
Energy Academy, Solar Energy, Heriot-Watt University	The HWU Energy Academy has two principal objectives. Firstly, to consolidate energy research activities and facilitate interdisciplinary programmes, both within the university and with other HEIs. Secondly to ensure external parties can easily gain an appreciation of our vision, skills-base and active research projects.	• Building integrated Photovoltaic	7 academic staff	Architecture and the Built Environment
Environmental Change Institute, University of Oxford	The ECI is actively researching technical, social and policy aspects to promote best-practice installations and encourage the growth of a strong UK solar PV market.	• PV compare project – a comparative test of commercially available photovoltaic technologies. (duration 2003 – 2005) • Monitoring the performance of West Oxfordshire District Council's solar office building in Witney, as part of a larger field trial monitoring scheme by the DTI. (duration 2003 – 2005) • The Supergen project investigates how to coordinate the effective operation of small distributed energy resources across the national grid. (duration 2005 – 2008)	4 academic staff, 6 researchers	Architecture and the Built Environment

Name	Description	Sub-topics covered	No of staff	Field
		• In partnership with the Sindicatum Climate Change Foundation, ECI helped to install renewable energy systems in the remote African villages. (2009)		
The Energy Systems Research Unit (ESRU), Department of Mechanical Engineering, University of Strathclyde	The Energy Systems Research Unit (ESRU) was established in 1987 as a cross-discipline team concerned with new approaches to built environment energy demand reduction and the introduction of sustainable means of energy supply.	• Performance of building integrated PV components	1 academic staff, 2 PhD students research student	Architecture and the Built Environment
Energy Research Institute, School of Process, Environmental and Materials Engineering SPEME, University of Leeds	The Energy Research Institute (ERI) is a major pioneering force of international standing within the disciplines of energy and resources. Strongly interdisciplinary in nature, having strong collaborative links with other University of Leeds schools and departments, as well as with other academic institutions around the world, the Institute spans a diverse portfolio of research areas.	• The economic and engineering feasibility of combined photovoltaic and thermoelectric (PV/TED) power generation (EPSRC) and a packaging disassembly approach to reducing disposal to landfill (EPSRC/Biffa)	10 academic staff, 1 PHD student	Electrical and Electronic Engineering

Name	Description	Sub-topics covered	No of staff	Field
Renewable Energy, Built Environment Research Institute (BERI), University of Ulster	This group provides a focus for research and development in the areas of advanced fenestration and solar energy technologies, low energy buildings, river hydraulics and timber and sustainable building materials. Extensive collaboration with industry, research organisations and universities in Northern Ireland, Europe and more generally, ensures that research undertaken is timely, relevant and at the forefront of current thinking. Advanced computer based numerical models and extensive experimental test facilities have been developed to enable the thermal and optical performance of building components and cladding systems to be evaluated.	• Solar thermal and PV system application	2 academic staff	Mechanical, Aeronautical and Manufacturing Engineering
Centre for Solar Energy Research, Glyndŵr University	CSER is a Centre of Expertise within OpTIC (a business incubation and technology centre for opto-electronics) and is managed by Glyndŵr University. CSER is part of the Low Carbon Research Institute (LCRI) which collaborates on renewable energy R & D across Wales and has proven expertise and a world class reputation in researching photovoltaic materials and devices.	• To continue to develop technologies and materials that will, at the end of the PV supply chain, improve the efficiency of PV and therefore increase electricity generation from renewable sources • To assist businesses working on any aspect of the renewable energy supply chain, including collaborative research and development, and by offering analytical services and training. • Accelerating progress in solar energy technology through linking fundamental research to industrial application	13 academic staff, 2 technical staff 3 PhD students	Metallurgy and Materials

Name	Description	Sub-topics covered	No of staff	Field
		• Technology road mapping policy		
Electronic and Photonic Molecular Materials Group, Department of Physics and Astronomy, The University of Sheffield	In this group, a near-field scanning probe microscope is used to study localised photo-current generation from molecular thin-films (based on blends of conjugated polymers and fullerene derivatives) that have applications in organic solar cells.	• Fabrication and optimization of prototype solar cells	3 academic staff 4 post doctors, 10 PhD students	Metallurgy and Materials
Materials Chemistry, School of Chemistry, The University of Manchester	Thin film photovoltaics materials.	• Novel precursors for the CVD of selenides especially $CuInSe_2$. • Chemical bath deposition of CdS and ZnS • The use of Quantum Dot Concentrators in solar cells • Metal oxides for DSSC and organic PV – collaboration with Imperial College	7 academic staff, 8 postgraduate research students	Metallurgy and Materials
Nano-scale Systems Integration Group, School of Electronics and Computer Science, University of Southampton	The interests of the Nano-scale Systems Integration (NSI) group is focused on fabrication and engineering at the nano-metre-length scale to produce integrated systems on silicon. This includes the creation and characterization of new metamaterials and the study of biomimetics, which aims to borrow evolutionary solutions to optical and mechanical problems from the natural world. Current research topics encompass MEMS/NEMS devices, photonic crystal circuits, solar cells, new materials, atom chips, Lab-on-a-Chip, particle manipulators, nano-magnetic materials and devices, and nano-photonics, as well as continuing work on ultimate MOS devices.	• Improve the efficiency (or decrease the cost) of photovoltaics by anti-reflection and light-trapping technique, plasmonic nano-structures and thin film silicon deposition	11 Academic Staff, 14 Research staff	Metallurgy and Materials

Name	Description	Sub-topics covered	No of staff	Field
Organometallic And Inorganic Chemistry, Homogenous Catalysis, Materials Precursors Group, School of Chemistry, University of St Andrews	Professor David Cole-Hamilton has been researching in organometallic chemistry applied to problems in materials science for 20 years, with particular emphasis on the design and synthesis of new precursors for MOVPE. He has collaborated with Stuart Irvine on the development of solar cells using MOVPE and is researching the synthesis of semiconductor nano-particles, which may be important as photovoltaic materials.	• Development of precursors for MOVPE of solar cells and related devices • Synthesis of nano-particles for light absorption, light emission and energy transfer • Mechanisms of growth processes	6 academic staff , 12 postgraduate	Metallurgy and Materials
Materials and Engineering Research Institute (MERI), Sheffield Hallam University	The Solar Energy research focuses on the manufacturing and processing of semiconducting materials and multi layer structures using Electrochemical deposition technique, and the fabrication of device structures and their characterisation. The group is consistently investigating a broad range of materials and device structures.	• Growth by electrodeposition of CuInGaS for solar cells • Electrical properties of defects in solar cells	7 academic staff, 3 research staff, 4 research students	Metallurgy and Materials
Renewable Energy Group, Centre for Materials Science and Engineering, Cranfield Defence and Security, Cranfield University	The centre is focusing on thin film solar cells and fuel cells. These include CdS/CdTe, ZnS/$CuInS_2$ based devices grown by physical vapour deposition, chemical bath deposition, spray pyrolysis and close space sublimation. The work has provided valuable data on these materials, which has enabled to construct a detailed model for CdS/CdTe cells. The centre also studies $CuInS_2$ cells based on	• Thin film solar cells made from CdS/CdTe heterojunctions. • Extremely Thin Absorber (ETA) layer solar cells based on thin $CuInS_2$ layers. • $CuInS_2$ based solar cells grown by electrostatic spray pyrolysis. • Solar Cell modelling	3 academic staff	Metallurgy and Materials

Name	Description	Sub-topics covered	No of staff	Field
	'environmentally friendly' spray deposition processes and were the first UK group to examine novel "extremely thin absorber layer" (ETA) cells.			
Renewable Energy Mechanical Engineering, School of Engineering and Physical Sciences, Heriot-Watt University	The RE group is partly focus on the photovoltaic (PV) modules. The two main challenges for PV research are: i) to reduce the amount of silicon used to make a PV module, and ii) to increase the conversion efficiency of PV modules. Achieving either or both of these goals will result in a reduction in the cost of the PV module and solar electricity.	• High efficiency silicon solar cells • Luminescent down-shifting (LDS): • Luminescent solar concentrators (LSC): Concentrating Photovoltaics (CPV): • Flexible thin-film solar cells	5 academic staff, 5 research staff 9 PhD students	Metallurgy and Materials
School of Chemistry, The University of Edinburgh	Research is focusing on the synthesis and characterisation of dyes for dye-sensitised solar cells	• New dyes for use in dye-sensitised solar cells	2 academic staff, 3 research student	Metallurgy and Materials
Advanced Inorganic Materials Group, Centre for Materials Physics, Department of Physics, Durham University	Focus is on the thin film solar cell research. This includes thin film deposition, device fabrication, electron microscopy, optical and electrical characterisation.	• Thin film CdTe/CdS photovoltaic structures • Effects of impurities • Influence of post growth treatments • Doping mechanisms • Effect of contacts degradation and mechanisms • Photovoltaic materials for the 21st century	3 academic staff, 5 PhD students	Metallurgy and Materials
Solar Energy Materials Initiative, Department of Materials, University of Oxford	The PV materials research is based in the Department of Materials and Department of Physics. The purpose of Solar Energy Materials Initiative group is to draw together scientists and engineers with an interest in how light energy is absorbed, dissipated, transported and stored. Combining research programs in	• Fabrication and testing of organic photovoltaic devices • Materials characterization and microscopy	7 academic staff, 19 students	Metallurgy and Materials

Name	Description	Sub-topics covered	No of staff	Field
	experimental and theoretical solid state physics as well as material synthesis and characterization we aim to create and develop sources of sustainable energy driven by the power of the sun.			
The School of Physics and Astronomy, The University of Manchester	In the Photon Physics group the study is focused on the highly correlated oxides showing metal-to-non-metal transitions, superconductivity and GMR behaviour, and nano-crystalline oxides, particularly those of interest in the manufacture of dye-sensitised solar cells.	• Dye-sensitised solar cells	2 academic staff, 2 post doctors, 6 post graduates	Metallurgy and Materials
Centre for Electronic Materials & Devices, Imperial College	The Centre for Electronic Materials and Devices is a multi-disciplinary centre encompassing researchers in the Departments of Chemistry, Physics, Materials and Electrical Engineering and Electronics. It is a Virtual Centre that is responsible for coordinating and promoting interdisciplinary research in electronic materials and devices.	• Dye sensitised nano-porous titanium dioxide solar cell based upon the photo-induced charge separation at the dye-semiconductor interface. • Development of high efficiency organic thin films solar cells based on small molecular semiconductors and polymer	6 academic staff, 14 post doctors, 16 PhD students	Metallurgy and Materials; Electrical and Electronic Engineering
CREST - Centre For Renewable Energy Systems Technology, Loughborough University	CREST's remit is to advance renewable energy technology so as to provide substantial and benign energy options for present and future generations. PV researches involve the PV system group, PV material group and BIPV group. CREST's research is focused on electricity generation from wind and solar energy and its integration into	Applied Photovoltaic group research: • Measurement and modelling of PV devices, modules and systems • Development of PV-related measurement systems (laboratory tests as well as outdoor) • Energy yield of PV modules and systems, concentrating on the	8 academic staff, 4 researchers, 13 PhD students	Metallurgy and Materials; Electrical and Electronic Engineering; Architecture and the Built Environment

Name	Description	Sub-topics covered	No of staff	Field
	networks and systems.	effect of environment on energy production • Modelling of device structures • Measurement technology of PV devices, with emphasis on quality evaluation of such devices • Building-integrated photovoltaics (BIPV) PV materials and devices group: • Research with CdTe and CIGS thin film PV and silicon-based PV. • Crystalline silicon solar cells • TCO development.		
Faculty of Engineering, Science and the Built Environment, London South Bank University	The research is of Photovoltaic (PV) panel design which containing solar cells for the clean generation of electricity.	• Photovoltaic panel design	1 academic staff	Metallurgy and Materials; Electrical and Electronic Engineering
Electronics, Power and Energy Conversion Group, Department of Engineering, Cambridge University	Electronics, Power and Energy Conversion group has the core research activities including power electronic devices and integrated circuits, and their uses in various applications. The major research involves solar cells and their integration in power systems.	• novel organic photovoltaic cells • power conversion electronics for connecting solar cells to the distribution network • the power system planning and stability implications of having distributed micro-generation within the distribution system	2 academic staff, 3 post doctors, 5 research students	Metallurgy and Materials; Electrical and Electronic Engineering
Energy Technology Research (ETR) Group, School of Engineering Sciences, University of Southampton	Research in electronic materials focuses on various semi-conductors that are used in the fabrication of solar cells, infrared detectors and heterostructure bipolar transistors. Two particularly important areas are fundamental atomic diffusion studies and the role of defects in	• Diffusion modelling in silicon germanium alloys. • Solar cell modelling • New photovoltaic devices and mechanisms, photovoltaic systems and evaluation of architectural aspects	1 academic staff	Metallurgy and Materials; Electrical and Electronic Engineering

Name	Description	Sub-topics covered	No of staff	Field
	infrared detector materials.			
Experimental Solid State Physics, Department of Physics, Imperial College	The group research covers most aspects of modern experimental solid state physics including molecular electronic materials, soft condensed matter, quantum optics and photonics, magnetism, superconductivity and inorganic semiconductors. There is a strong emphasis on novel materials and structures and on applications in a wide range of devices. Selected examples of current interests include next generation thin film solar cells (using inorganic semiconductor quantum wells, nano-structured oxides and organic semiconductors)	• Dye sensitised solar cells • Organic solar cells • Quantum well solar cells • Novel semiconductor solar cell structures	2 academic staff, 6 post doctors, 6 PhD students and 1 academic staff 2.5 post doctors, 5 PhD students	Metallurgy and Materials; Electrical and Electronic Engineering
Northumbria Photovoltaics Applications Centre (NPAC), School of Computing, Engineering & Information Sciences, University of Northumbria	NPAC is in the Energy Systems Group of School of Computing, Engineering & Information Sciences which combines two main areas of strength, photovoltaic and power engineering. At present, the group has particular expertise in the renewable energy technologies of photovoltaic and wind. This is complemented by the expertise in grid connection and power electronics.	• Doxford Solar Office monitoring • Monitoring of Domestic PV Installations • Photocampa • PV Domestic Field Trial • PV Cell Characterisation	10 academic staff, 2 research associates, 11 students	Metallurgy and Materials; Electrical and Electronic Engineering

Name	Description	Sub-topics covered	No of staff	Field
Optoelectronics Group, Nano-science Centre, Cambridge University	The main activity in the Nano-science Centre is making individual devices or structures which are only a few nano-metres in size and then measuring how they work. The work includes: Polymer Light-Emitting Diodes, Thin-Film Field-Effect Transistors, Photovoltaic and Photoconductive diodes.	• Development of new semiconducting polymers: Conjugated polymer photovoltaic devices • Polymer/nano-crystal photovoltaic devices • Characterisation of properties in semiconductor device structures • Modelling of polymer chains and fundamental processes	2 academic staff 3 post doctors 5 PhD students	Metallurgy and Materials; Electrical and Electronic Engineering
Physical Group, Department of Chemistry, University of Bath	The Physical group has an established international reputation for its work in a range of fields, most notably semiconductor photoelectro-chemistry. The main focus of our current work is on light stimulated reactions taking place at solid/solution interfaces. Practical applications include the development of novel solar cells that mimic photosynthesis by using a layer of adsorbed dye to absorb light, resulting in the injection of electrons into a porous ceramic oxide. Recently this group have started a major project on inorganic thin film solar cells as part of the Supergen consortium funded by EPSRC. This work will involve the development of novel low cost electrodeposition routes to fabricate films of materials such as copper indium sulphide/selenide (CIS/CIGS). Some projects are collaborated with Dr Alison Walker who is in the	• Fabrication and characterisation of dye-sensitised liquid junction nano-crystalline solar cells. • Fabrication and characterisation of electrodeposited thin film inorganic solar cells (CIS, CIGS, CdTe). • Preparation and characterisation of semi-conductor quantum dots on nano-crystalline oxides. • Development of solid-state analogues of liquid junction dye sensitised solar cells. • Microwave reflectance studies of silicon photo-etching in fluoride solutions. • Spectroscopic and electrochemical studies of redox modified electrodes. • Studies of electrochromic electrodes based on ruthenium complexes. • Modelling of solar cell	6 academic staff, 3 post doctors 6 PhD students	Metallurgy and Materials; Electrical and Electronic Engineering

Name	Description	Sub-topics covered	No of staff	Field
	Department of Physics.			
Semiconductor Materials & Devices Research Group, Department of Electronic and Electrical Engineering, The University of Sheffield	The SMD Group has a long-standing reputation for international class work on semiconductor materials and electronic and opto-electronic devices. The presence of the EPSRC National Centre (NC) for III-V Technologies within the Department for the past 26 years has ensured a critical mass presence which has underpinned most of the Group's very extensive work. The NCOs role is to supply a wide range of well-characterised next-generation semiconductor epitaxial material and novel electronic devices to the UK academic community through EPSRC´s grant awarding structure.	• Fabrication service for GaAs/AlGaAs solar cells, MQW pin cells, multi-quantum well solar cells on behalf of K.Barnham at Imperial College	11 academic staff, 5 research associates 11 post doctors	Metallurgy and Materials; Electrical and Electronic Engineering
The Opto-electronic Devices Research Group, School of Engineering, The University of Hull	Research is focused on Thermophotovoltaic (TPV) cells.	• Thermophotovoltaic (TPV) cells. with III-V materials	2 academic staff, 2 research students	Metallurgy and Materials; Electrical and Electronic Engineering
Sustainable Energy Research Group, School of Civil Engineering and the Environment, University of Southampton	The Sustainable Energy Research Group within the School of Civil Engineering and the Environment undertakes research in core areas of energy, specifically in the built environment and in renewables. The Group's interests include building envelopes and their impact on energy and comfort, photovoltaics and marine current energy converters.	• Thin Film Solar Cell Development • Photovoltaic Roof Tile Development • Investigations on Reliable Photovoltaic Connectors • Photovoltaic Module Mismatch Studies • Solar Campus - University of Southampton • Photovoltaics in Residential Applications • Photovoltaics in Food Transport	4 academic staff 5 postgraduate researchers	Metallurgy and Materials; Electrical and Electronic Engineering; Architecture and the Built Environment

Name	Description	Sub-topics covered	No of staff	Field
Stephenson Institute for Renewable Energy, University of Liverpool	This Institute will bring together energy-related research activities from across the University to focus on developing clean and sustainable energy technologies including energy dissipation and friction, wind and marine energy, fusion technology, photovoltaics, carbon capture and storage, sustainable feedstocks, batteries, fuel cells, hydrogen generation and storage, solar harvesting, energy transport.	• High Efficiency thin film device fabrication • Advanced electrical characterisation • Transparent Conducting Oxides / Optical modelling • Thin film crystal growth • Nano-structure growth and core-shell PV devices • Structural Characterisation	5 academic staff 9 Research Students	Metallurgy and Materials; Electrical and Electronic Engineering
Building Research Establishment (BRE)	Developing low carbon buildings that meet both regulatory and customer needs shouldn't be onerous or costly. We can help you to plan, design and construct such buildings, improve existing buildings, solve specific problems or carry out post occupancy evaluations of performance.	• Building Energy Modelling • Energy Consultancy • Energy Policy Support • Building Materials • Building Services • Renewables • Training • Energy Assessor Accreditation Schemes • Innovation • Codes and Assessments		Architecture and the Built Environment
Centre for Plastic Electronics, Imperial College	Plastic electronics is widely recognised as a vital and rapidly growing platform technology with the potential to impact on multiple application sectors, including those that closely address our priority themes in energy, environment and healthcare.	• Materials design, synthesis and processing • Advances multi-parameter structural, electrical and optical characterisation • Nano-strucure and interface control • Multiscale materials and device modelling • Device fabrication and optimisation		Architecture and the Built Environment, Metallurgy and Materials

Name	Description	Sub-topics covered	No of staff	Field
Durham Energy Institute, University of Durham	Durham Energy Institute is a leading UK energy research institute. Based-upon our success at winning research funding we are one of the UK's leading university research communities in at least five energy disciplines. We also have strong capabilities in technologies for fusion energy and biofuels.	• Biofuels • Photovoltaics • Electricity Conversion, Transmission and distribution • Geo-Energy • Society and Energy • Technologies and Fusion Energy	16 academic staff	Metallurgy and Materials; Electrical and Electronic Engineering
Low Carbon Research Institute (LCRI)	The Institute was set up to unite and promote energy research in Wales, UK to help deliver a low carbon future. The multidisciplinary LCRI aims to support the energy sector, UK and globally, to develop low carbon generation, storage, distribution and end use technologies, and to offer policy advice.	• Solar photovoltaic • Built environment • Hydrogen energy • Biofuels • Large energy generation • Marine energy	Over 120 researchers	Energy demand and supply

4. Applied Research and Development

Return to the Top

The UK has seen growth in industrial based R&D from small spin-out businesses to large businesses such as Tata and Pilkington. The Tata Colors Accelerator project funded by TSB and in collaboration with Dyesol has established a pilot plant for functionalised dye sensitised solar cells onto steel sheet. At the other end of the scale, Molecular Solar is a spin out from Warwick University and is exploiting the innovative single molecule tandem cell. The main sources of funding for applied R&D are the TSB and Carbon Trust. Other sources of funding are either through the EU Framework 7 programme or the regional assistance funds such as the Convergence funding. A significant amount of private investment is also evident from the G24i development of a roll to roll process. Materials supply continues to be a strength in the UK applied R&D with Crystalox being a global supplier of multi-crystalline silicon and Pilkington NSG becoming a major supplier of Transparent Conducting Oxides (TCO) on glass. IQE is the world's largest manufacturer of custom epitaxial wafers and the triple junction solar cells for CPV is one of their growing markets. We also have strong R&D activity in chemical supply with SAFC Hitech being a major supplier of high purity organometallics used in the manufacture of triple junction solar cells and Dupont supplying metallisation products. In fact the balance of applied R&D is very much towards the materials and probably weaker in moving towards modules and balance of systems, such as the inverters. The university sector play an important part in the applied R&D both through spin out of innovative businesses and partnering with industry in technology projects. With future growth of the PV market and more private investment, this trend is set to continue.

Table 4.1: Research Funding

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
PROPRESS - Productionising Printing Enhancements to Silicon Solar Cells (Generation)	TSB	This research is being carried out by Intrinsiq Materials Ltd.	£990,164		
Hi-grade waste heat recovery utilising III-V Thermo-photovoltaic materials	TSB	This research is being carried out by Compound Semiconductor Technologies (Lead), IQE, Lancaster University, Pilkington and Tata Steel.	£809,500		
Proof of Concept: Universal Photovoltaic Solar Roof Tile	TSB	This research is being carried out by Solar Century Holdings Ltd.	£165,581	2012	
Oxford Photovoltaics: Development of Product Prototype Solar-Power Glazing Modules for BIPV	TSB	This research is being carried out by Oxford Photovoltaics Ltd	£554,614	2012 - 2014	
Enhanced solar energy harvesting in dye sensitized solar cells using nano-phosphors and nano-structured optics	TSB	This research is being carried out by Brunel University of London, Excelis Ltd, G24i Ltd, Intrinsiq Materials Ltd (Lead)	£612,647	2011 - 2014	
Development of Prototype High Efficiency Multi-Junction Organic Solar Cells	TSB	This research is being carried out by Asylum Research UK Ltd, Imperial College London, Kurt J. Lesker Company Ltd (Lead), Molecular Solar Ltd, New World Solar Installations Ltd and the University of Warwick.	£1,001,588	2011 – 2014	
High performance Solar Cell Fabrication (SolarFAB)	TSB	Epitaxial semiconductor material specialist IQE will head up this project with Semefab and CST Global on high-performance solar cell fabrication,	£566,757	2011 – 2014	

Scalable, low-cost organic photovoltaic devices (SCALLOPS)	TSB and EPSRC	This project focuses on the key challenges for the translation of these lab-scale efficiencies into, low cost, scalable photovoltaic device technologies. Specifically, the three aims of this project are: (i) development of indium and PEDOT free transparent conducting electrodes which are compatible with high device-module efficiencies and cost effective scale up and (ii) development of new synthetic methods for the scale-up of high-performance organic semiconductors and (iii) the implementation of these materials into OPV modules fabricated employing processing methodologies compatible with high through put, low cost manufacture. Partners: NPL, Pilkington Technology, Imperial College London, University of Bath, Solvay Interox, RK Print Coat Instruments, and Flexink Ltd.	£2.4m TSB £803,541 EPSRC	2011 - 2014	
Development of Proof of Concept Modules for Concentrator Photovoltaic Receivers	TSB	This research is being carried out by Narec Solar Ltd.	£99,507	2012 - 2013	
Innovative Rear Contact Solar Cell	TSB	This research is being carried out by Silicon CPV Plc.	£168,889	2012 - 2013	
Interconnect Manufacturing Process for Thin Film Solar Cells (IMP)	TSB	This research is being carried out by Loughborough University, M-Solv Ltd (Lead), Power Vision Ltd.	£983,617	2011 - 2013	
High Performance Solar Electric & Thermal (SET) Energy Collector	TSB	This research is being carried out by Northern Technology Developments Ltd.	£145,186	2011-2012	
Polymer Photovoltaic Architectural Glass	TSB	This research is being carried out by Centre for Process Innovation Ltd (Lead), Linde Electronics Plc, Pilkington Technology Management, Polysolar Ltd, Sagentia Ltd and Solvay.	£1,061,591	2010 - 2012	

Development of Water-based DSSCs for printable Flexible Photovoltaic Power Sources	TSB	This research is being carried out by G24i Ltd (Lead) and Imperial college London.	£874,654	2010 - 2012	
SCOPE - Smooth high Conductivity Organic Photovoltaic Electrodes	TSB	This research is being carried out by Conductive Inkjet Technology Ltd and Eight 19 Ltd (Lead).	£945,342	2010 - 2012	
Plasma Enhanced Deposited ITO	TSB	This research is being carried out by Plasma Quest Ltd and TWI Ltd.	£600,000	2009 - 2010	
Development of low cost high-efficiency and long-life photovoltaic cells	TSB	This research is being carried out by the Centre for Integrated Photonics Ltd, University of Oxford and Wafer Technology Ltd.	£933,050	2008 - 2012	
Development of low cost high-efficiency and long-life photovoltaic cells	TSB	This research is being carried out by Teer Coatings Ltd (Lead), and University of Bolton.	£933,050	2008 - 2012	
Low Band-Gap Thermophotovoltaic Cells for Clean Energy Generation and Efficient Waste Heat Energy	TSB	This research is being carried out by Compound Semiconductor Technologies Global Ltd and Lancaster University, Pilkington, QinetiQ Group Plc, RWE Power and Wafer Technology Ltd (Lead).	£1,905,759	2008 - 2012	
Nano-coated Plastic Films for Low Cost, Efficient, Hydrogen Production	TSB	This research was carried out by Microsharp Corporation Ltd (Lead), Nano-force Technology Ltd and Stored Solar Ltd.	£503,090	2008 - 2010	
Novel Inline Deposition System for High Performance CIGS Solar Cells	TSB	This research is being carried out by Loughborough University, Oxford Applied Research and Scientific Vacuum Systems Ltd (Lead).	£771,078	2007 - 2012	
Solid State Dye Sensitized solar cells	TSB	This research is being carried out by Oxford Photovoltaics Ltd.	£100,000	2010 - 2011	

Low cost integrated PV in double glazed windows using CdTe bifacial solar cells	TSB	This research was carried out by Applied Multilayers Ltd, Loughborough University, OVE ARUP & Partners Ltd (Lead) and Pilkington Technology Management.	£1,529,285	2008 - 2011	
Lower-cost Concentrating Photovoltaic Systems using III-V cells (III-V CPV)	TSB	This research was carried out by Whitfield Solar Ltd (Lead), Aldwych 2011 Ltd, Loughborough University, National Renewable Energy Centre Ltd and The Kelvin Institute Ltd.	£723,647	2008 – 2011	
TSB Epitaxial silicon solar cells by new generation deposition equipment (EPISODE)	TSB	This research was carried out by Echerkon Technologies Ltd (Lead), Loughborough University, and University of Southampton.	£905,867	2008 – 2011	
TSB High Efficiency silicon solar cells with PECVD dielectric rear surface passivation (HIGHPOINT)	TSB	This research was carried out by National Renewable Energy Centre Ltd (Lead) and Heriot-WATT University.	£889,781	2008 - 2011	
CONVERT - Enhancing Photovoltaics	TSB	This research was carried out by Brunel University of London and Intrinsiq Materials Ltd (Lead).	£634,421	2008 - 2010	
Novel Transparent Conducting Films and Their Use As An Alternative to ITO	TSB	This research was carried out by Conductive Inkjet Technology Ltd, Epigem Ltd (Lead), University of Durham and Zytronic Displays Ltd.	£747,268	2007 - 2009	
Sputtered semi-conducting silicon for large area flexible solar cells	TSB	This research was carried out by Plasma Quest Ltd (Lead), Romag Ltd and University of Southampton.	£743,162	2006 - 2009	
Solar Concentrate: Affordable building integrated photovoltaic solar concentrator systems	TSB	This research was carried out by Optical Antenna Solutions Ltd, Optical Products Ltd (Lead), PERA Innovation Ltd, Persimmon Homes Ltd, Polyplas Extrusions Ltd, Solar Trade Association Ltd and SolarEmpower.	£417,993	2007 - 2008	
HISTORIC - Low Cost 110X PV Concentrator	TSB	This research was carried out by the University of Warwick.	£81,966	2006 - 2008	

Low Cost 100x PV Concentrator	TSB	This research was carried out by Whitfield Solar Ltd (Lead), National Renewable Energy Centre Ltd, University of Ulster and the University of Warwick.	£742,266	2005 - 2008	
HISTORIC - Low Cost 100x Pv Concentrator	TSB	This research was carried out by the National Renewable Energy Centre Ltd.	£393,836	2005 - 2008	
Polymer photovoltaics	TSB	This research was carried out by Merck Chemicals Ltd (Lead), BP Plc, DuPont Teijin Films UK Ltd and the Imperial College London.	£1,170,364	2005 - 2008	
High efficiency solar panels based on multilayer graded-bandgap CIGS	TSB	This research was carried out by IonoTec Ltd (Lead), Pilkington United Kingdom Ltd, and Sheffield Hallam University.	£637,410	2005 - 2008	
Power Electronics – Enabling a Resilient Energy System	TSB - Emerging Energy Technologies EPSRC	The Technology Strategy Board, Welsh Government and the Engineering and Physical Sciences Research Council (EPSRC) are to jointly invest up to £5.4 million in research & development and knowledge exchange projects to help stimulate innovation and develop UK supply chains between the power electronics and energy sectors.	£5.4M	2013	
Feasibility study PV coatings on steel, based on dye-sensitised titania	TSB - Emerging Energy Technologies	A research group has been formed by Corus to develop functional photovoltaic (PV) coatings, by integrating dye sensitised solar cell (DSSC) technology into coatings of strip steel. Advantages over current PV technology are lower materials cost and high speed, low cost manufacturing processes.	Project Cost: £455,493 TSB provided: £227,746	2007 - 2008	

		At Corus RD&T, novel continuous application processes of functional layers needed for DSSC PV will be investigated. At Beckers Industrial Coatings (BIC), the gel electrolyte system and its application process will be developed. Dyesol, a world leader in the DSSC field, will be involved as a sub-contractor, which will significantly accelerate the development because of Dyesol's technical knowledge and proven experience in DSSC industrialisation.			
Sputtered semiconducting silicon for large area flexible solar cells	TSB - Emerging Energy Technologies	This project aims to develop a viable, low cost commercial process for large area flexible solar cells, for applications such as building integrated photovoltaics (BiPV) and appropriate stand-alone systems. The process will be based on recent research successes in depositing semiconducting thin film silicon solar cells by a newly developed Plasma Quest Ltd (PQL) proprietary advanced plasma sputter deposition techniques. The process builds on other recent PQL demonstration of high throughput sputter deposition of high performance thin film metals, dielectrics and transparent conductors onto low temperature flexible plastics. The work will initially target PV products for the built environment, leading to related applications such as sensors and display technologies. Under this technology programme application, the project will aim to fabricate and test solar cell demonstrator products up to the A4 size recommended by the Panel.	Project Cost: £743,162.00 TSB provided: £511,678.00	2006 – 2009	

The development of advanced low cost InP based Photovoltaic Devices	TSB - Emerging Energy Technologies	Thermophotovoltaic (TPV) devices are photovoltaic cells which produce electricity from heat sources such as industrial combustion processes, with potentially 100-10,000 times the output of a Si solar cell. Potential applications include industrial waste heat recovery, domestic combined heat and power (CHP), embedded generation, military applications, hydrogen powered transport, and solar concentrator systems.TPV cells currently available use GaSb, an expensive material. This project aims to develop 3-terminal devices based on InGaAs/InP responding to both the 1-1.7 micron infrared region currently covered by GaSb and the shorter 0.5-1 micron region. These will exploit the advantages of cheaper InP substrates and higher efficiency from broader spectral coverage. In the longer term the project will assess potential for InP devices grown on Si substrates to address the solar concentrator market.	Project Cost: £668,558.00 TSB provided: £223,730.00	2005 - 2008	
Enhanced Display Performance through Smart Thin Film Optical Coatings	TSB - Emerging Energy Technologies	Smart display systems with sensing and actuating functions will be developed through the integration and feedback of optical functions using smart thin film coating materials and techniques. This methodology, combined with modelling, will be used to improve the overall performance and energy efficiency of a display that can be viewed in a wide range of ambient light conditions. The developed technology will also open up other applications in solar cells and photovoltaic devices.	Project Cost: £603,269.00 TSB provided: £387,183.00	2006 - 2008	

		The project consortium aims to demonstrate the technical and economic benefits of smart thin film optical coatings, firstly for displays in niche markets and exploitation of design tools, where sales of £3.5M per annum to the consortium has been estimated 5 years after project completion. The application of the techniques developed to mass display markets and optical systems is estimated to have an additional income to the partners of £3.6M per annum 8 years after project completion.			
Low Cost 100x PV Concentrator - LUCENT	Emerging Energy Technologies DTI (Collaborative R&D programme)	This project was to develop and optimise a design of solar concentrator and accompanying PV solar cell. The concentrator device uses lenses to focus sunlight onto the small cells increasing the energy density by up to 100 times thus saving substantially on cell costs. The design is based on a simple lightweight 2 axis tracking unit that will follow the sun during the day. The project emphasis is on reduced cost renewable energy.	£0.85m	2004 ~	
Engineering Porosity in Nano-structured Films for Hydrogen Generation	DTI (Collaborative R&D programme)	A Tandem Solar Cell generates high quality hydrogen from sunlight and water and is a carbon-free, renewable photovoltaic technology. At its heart is a porous, thin-film electrode that captures sunlight and, using an electrical voltage, decomposes water into hydrogen and oxygen. This project aims to improve the gas generation efficiency of this electrode by changing this thin electrode or nano-structure to increase its porosity, improve its electronic structure and lower its electrical resistance.	£120k	2004~	

SPARC / LCRI	LCRI (ERDF)	The overall aims of the project are to enable grid parity for PV solar energy in Wales by 2015, to enhance the adoption of PV solar electricity and help to meet the ambitious carbon neutral target for Wales by 2025.The SPARC Cymru project aims to accelerate academic research in new photovoltaic (PV) materials for solar energy conversion, leading to a new generation of low cost PV module products. We will explore both very low cost dye sensitised solar cells (DSSC) and thin film inorganic materials. A holistic approach to the development of new, low cost PV module technology will also address the power electronics used to extract the electrical power from the modules. The project is led by Glyndŵr University with project partners, Swansea University, Bangor University, Tata Colors, Pilkington NSG, OpTek Systems, Pure Wafer and Dulas.	£4.3m	2010 - 2013	
Advanced Photovoltaic Research Accelerator	Carbon Trust	In August 2008 Carbon Trust kicked off a partnership with Cambridge University and The Technology Partnership (TTP) that leverages world leading plastic electronic expertise to develop commercially competitive organic solar cells. The investment aims to accelerate the large-scale deployment of cost-effective photovoltaics by focusing on the in-line, roll-to-roll manufacturing processes required to fabricate organic solar cells. The aim is for these plastic solar cells to be delivering 1GW of power (equivalent to carbon dioxide savings of more than 1 million tons per year) within ten years.	£5m	2008	

		A core aim is to develop organic PV modules with these 3 characteristics in the near to medium term: • 8% efficiency • Lifetime of at least 5 years Manufactured on a roll-to-roll web up to one meter wide			

Table 4.2: Key Research Providers

Name	Description	Sub-topics covered	Scale of operation	Sector
ARUP	ARUP are an independent firm of designers, planners, engineers, consultants and technical specialists offering a broad range of professional services. Through our work, we make a positive difference in the world. We shape a better world.	• Engineering • Planning • Consultants • Sustainable		R&D Manufacturing
Building Research Establishment	BRE helps government, industry and business to meet the challenges of our built environment. Today's need to combat climate change, and the significant economic and social issues we now face, are no exceptions.	• Consultancy • Research • Testing • Innovation • Sustainability • Training	4 Executive Officers and 600 staff	R&D science and engineering
Cambridge Display Technology (CDT)	Cambridge Display Technology (CDT) is the leading developer of technologies based on polymer light emitting diodes (PLEDs). CDT has an active programme to develop efficient solar cells and light detectors using its polymer semiconductor know-how and experience, and has filed several patents in the area.	• Developing polymer solar cells	14 Executive Officers and Directors $18.1m turnover; 120 employees	R&D science and engineering
CVD Technologies Ltd	CVD Technologies are recognised leaders in the field of AP (atmospheric pressure) CVD.	• Product and process feasibility • Prototyping • Design and commissioning		Research and Development Manufacturing
Dulas Ltd	Dulas has over 20 years experience in the field of solar photovoltaic (PV) energy. They provide a complete service from resource assessment and system design, right through to manufacture and installation. The	• The fields of grid connected domestic PV systems, • Grid connected commercial and larger systems, and • Off-grid systems.	Turnover of the Solar Department £3mp/a 80+ UK staff	Manufacturing

Name	Description	Sub-topics covered	Scale of operation	Sector
	Dulas Solar department specialises in two distinct areas of solar power: UK solar and oversee solar.			
Dyesol (UK) Ltd	Dyesol is a global supplier of Dye Solar Cell (DSC)materials, technology and know-how.	• DSC Technology		Research and Development
Filsol Solar Ltd	Filsol specialise in providing cost effective, high quality solar water heating and solar photovoltaic (PV) solutions for domestic, commercial and public sector buildings throughout the UK.	• UK Manufacturing base in South Wales • In house system design and specification service • Nationwide installer network • Tailored supply and project support solutions • Maintenance and aftercare support	7 in Management team	Installers Manufacturing
G24i	G24i's Dyes Sensitised Solar manufactures a thin, extremely flexible and versatile nano-enabled photovoltaic (solar) material that converts light energy into electrical energy, even under low-light, indoor conditions.	• Incorporate DSC technology into a wide array of energy-saving products. • Radically extend the mobility and utility of mobile devices. • Generate electricity in remote locations. • Mitigate global climate change.		R&D and development manufacturing
Icax Ltd	ICAX™ is a cleantech company helping to meet the demand for on-site renewable energy and sustainable development by using inter-seasonal heat stores to achieve low carbon buildings.	• Design and Installation • Thermal Modeling • Initial Feasibility		Consulting Engineers

Name	Description	Sub-topics covered	Scale of operation	Sector
Innovative Materials Processing Technologies Ltd	Over the past decade IMPT has developed and refined an innovative method for coating thick and thin films of advanced materials for various high-tech applications	• Thermal barrier coatings • Flat panel displays • Photovoltaics • Specialist coatings		Research and Development
IT power	IT Power is a leading international energy consultancy which specializes in sustainable energy technologies and policy, and related economic, financial, commercial and environmental work	• Installation of stand-alone as well as grid-connected PV systems • Management of implementation and demonstration, • Technical assistance, • System simulation, • R&D and feasibility studies, • Product evaluation and testing, • Market development, etc.	23 staff in the UK A further 40 staff are at overseas	Consulting engineers
Mantis Deposition Ltd	Mantis Deposition manufactures a range of deposition components such as e-beam evaporators, magnetron sputter sources, gas crackers and atom plasma sources. All their sources are UHV capable.	• Nano-technology • Instrumentation • Thin Film Deposition	16 Staff	Manufacturing and Engineering
NaREC Photovoltaic Technology Centre (PVTC)	A well-equipped solar cell process line and characterisation laboratory operated by an internationally recognised research and development group with over 60 man-years experience. The facility is managed and operated by NaREC - a Centre of Excellence created in the North East of England to provide enablement, testing and development services to the energy	• Full process capability for high efficiency LGBC solar cells including phosphorus diffusion, silicon nitride deposition (LPCVD), laser patterning, wet chemical- and plasma-etching, metallization (plating and sputter deposition), controlled-atmosphere sintering • Thin film solar cell process capability including TCO deposition (RF	8 staff and the turnover is around £1m	R&D science and engineering

Name	Description	Sub-topics covered	Scale of operation	Sector
	sector.	sputtering),laser patterning and wet chemical etching • Solar cell interconnection and lamination • Solar cell, wafer and module characterization and testing capabilities including dark and light IV measurements (up to 40 x concentration), spectral response, minority carrier lifetime (microwave PCD), LBIC, wafer impurity analysis (FTIR), dielectric layer thickness and refractive index (ellipsometry), accelerated environmental testing of cells and modules.		
National Physical Laboratory	NPL is the UK's National Measurement Institute, and is a world-leading centre of excellence in developing and applying the most accurate measurement standards, science and technology available.	• Technical R&D • IP Exploitation • Consultancy	500 staff across every discipline	R&D science and engineering
Neo Performance Materials (Europe) Ltd	Manufactures other inorganic basic materials	• Manufacture other inorganic basic materials	4 Staff	Manufacturing

Name	Description	Sub-topics covered	Scale of operation	Sector
Oxford Instruments	Oxford Instruments is a leading provider of high technology tools and systems for research and industry.	• Design and Manufacture equipment that can fabricate, characterise, manipulate and analyse matter at the atomic and molecular level.		Manufacturing
Photovoltaic Accelerator Facility, Shotton	The project is a joint venture between Dyesol and Corus Colors, supported by the Welsh Assembly Government, with the aim to commercialise revolutionary low-cost solar generation material. The partnership is integrating Dye Solar Cell (DSC) technology into steel strip in a coil coating line, so that they can be brought to market as a fully integrated steel building product known as Building Integrated Photovoltaics (BIPV).	• Develop DSC for building integrated photovoltaic	30 Staff	R&D and development manufacturing
Pilkington NSG Group	The United Kingdom is one of the NSG Group's major manufacturing centres. Pilkington Group Limited is based in St Helens and has offices at the NSG Group's European Technical Centre situated at nearby Lathom, Lancashire. Pilkington employs around 3,000 people across the UK, in activities ranging from the manufacture of float, rolled and wired glass to glass processing and merchanting, automotive original equipment (OE) and automotive glass replacement (AGR) manufacture.	• Manufacturing • Processing	3000 people	R&D and development manufacturing

Name	Description	Sub-topics covered	Scale of operation	Sector
Plasma Quest Limited	Plasma Quest Ltd (PQL) is a problem solving research-based company whose core business is thin film deposition sputtering research, and systems development. PQL engages in all stages of Customers' thin film materials requirements, from bespoke sputtering trials through to complete thin film process development and production trials. PQL has developed a high-density plasma method of thin film sputtering that provides process and thin film deposition benefits not currently available from conventional systems - the patented technology, "High Density Plasma forming device" is operationally referred to as High Target Utilisation Sputtering (HiTUS).	• Using the HiTUS for a very wide range of materials system • Contract R&D and Process Development	6 Staff	R&D science and engineering
Plasma Technology Limited (PTL)	The mission of the company is to design and manufacture plasma-based equipment for research and commercial uses.	• Plasma and Materials Engineering • Equipment Design	50 staff	Research and Development
The Shadow Robot Company	Shadow's broad expertise in robotics allows our engineers to engage in unique projects, helping our clients solve difficult problems through bespoke systems.	• Bespoke Robotics • Electronic Engineering • Robot software engineering • Fabrication		Manufacturing and Engineering
Sharp Laboratories	Sharp Laboratories are focusing more of our effort on the emerging green areas of photovoltaic energy generation, energy storage, energy management, low energy lighting and healthcare. They are researching new areas, building new skills, recruiting	• Optoelectronics	100+	R&D Manufacturing

Name	Description	Sub-topics covered	Scale of operation	Sector
	more people, working with more Sharp businesses and developing a wider range of products. Transfer of technology to mass production in displays is a continuing part of SL activity.			
Sharp Manufacturing	Sharp is one of the world's leading innovative developers and manufacturers of LCD and solar technology as well as electro technical components in the areas of optoelectronics, infrared and flash memory electronics.	• Manufacturing Solar Modules	54,100 globally	R&D Manufacturing
Solarcentury	Solarcentury is the UK's largest, independent solar company. Solarcentury works directly with architects, housing developers and engineers. They also liaise with electricity suppliers to help sell back clean electricity.	• Photovoltaic systems for • Solar home • Commercial building • Public sector	100 staff	Manufacturing
STFC (Science and Technology Facilities Council)	The Science and Technology Facilities Council is keeping the UK at the forefront of international science and tackling some of the most significant challenges facing society such as meeting our future energy needs, monitoring and understanding climate change, and global security.	• Laser Science • Microelectronics, • Wafer Scale Manufacturing • Alternative Energy Production		R&D

Name	Description	Sub-topics covered	Scale of operation	Sector
Sustainable Engine Systems	Sustainable Engine Systems are a leading research and development company committed to the development of more efficient engines and heat exchangers.	• Micro-CHP		Research and Development
Tata Colors, TaTa Steel	Tata Steel Colors is an international business with nearly 50 years experience in the development and manufacture of pre-finished steels.	• Research, Development and Technology • Metals application • Integrated steel making • Functionalisation of steel products for energy generation and storage	80,000 globally	RD&T Manufacturing
Trackdale Ltd	Trackdale is a nano-technology materials company specializing in applications in the infrared.	• Thermal imaging • Gas analysis • Fibre optic applications		Research and Development
UK Material Technology Research Institute Ltd	MatRI readily adopts the process of 'shared innovation', pooling knowledge and skills from research organisations and industrial organisations and consortia of industrial companies to achieve shared goals. In doing this they have developed numerous partnerships with clients, industry, academia, trade bodies, professional bodies and other research institutions.	• Composites and Textiles • Polymer Science & Processing • Mechanical Engineering & Design • Finite Element Analysis • Microwave Engineering • Acoustics & Vibration	500+ staff	Research and Development
Xennia Technologies Ltd	Xennia is the world's leading industrial inkjet solution provider, revolutionising manufacturing by implementing inkjet technology as a reliable production process.	• Ceramics • Textiles • Packaging • Industrial decoration • Printed electronic • Biotechnology and Life Sciences		Research and Development

5. Demonstration Funding

Return to the Top

The Government's Solar Photovoltaics (PV) Major Demonstration Programme - which is administered on behalf of the Department of Trade and Industry (DTI) by the Energy Saving Trust - ended in March 2007, with the final round of funding for stream 2 (commercial) grants in February 2006. As demand for grants has been so high, the DTI announced a further £750,000 in November 2005 to support the programme through to completion. The scheme provides funding of between 40 and 50 per cent for the installation of solar electricity panels for both domestic (stream 1) and commercial (stream 2) applications. The aim of the programme has been to kick start the UK market for solar PV, by demonstrating the long-term potential of the technology and thereby encourage the use of more environmentally friendly and sustainable methods of generating electricity. Since 2002, the programme has provided £31 million of funding for 1,200 domestic and 180 commercial installations. As a result, it is estimated that 20,000 tonnes of carbon will be saved over the lifetime of the installations, thereby making an important contribution towards reaching the UK's climate change targets.

The PV programme was replaced by the DTI's Low Carbon Buildings Programme, which superseded the grant schemes for small-scale renewable energy technologies. The programme was then taken over by the Department of Energy and Climate Change (DECC). This programme was not exclusively for PV but provided up to 50% funding for domestic (stream 1) and commercial (stream 2) microgeneration technologies. The programme started in April 2006 and has come to an end in May 2010. The available funding was £500,000 per month and allocation was on a first come first served basis.

The incentive provided by these demonstration schemes has been superseded by the FiT introduced in April 2010, by Renewable Obligation Certificates (ROCs) for larger PV installations and solar thermal installation will be covered by the Renewable Heat Initiative (RHI).

The UK FiT has been responsible for over 400,000 new PV installations across the UK.

Table 5.1 Demonstration Funding Programmes

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
Major Photovoltaic Demonstration programme	DTI	The Government's Solar Photovoltaics (PV) Major Demonstration Programme has been to kick start the UK market for solar PV, by demonstrating the long-term potential of the technology and thereby encourage the use of more environmentally friendly and sustainable methods of generating electricity. Since 2002, the programme has provided £26 million of funding for 1,200 domestic and 180 commercial installations. The funding under the Major PV Demonstration Programme has been increased by £6 million, taking total funding to £31 million.	£31m	2002-2006	
Low Carbon Buildings Programme (LCBP) Phase 1	Department of Energy and Climate Change	Launched in April 2006, Low Carbon Buildings Programme Phase 1, was set up to demonstrate how energy efficiency and microgeneration can work hand in hand to create low carbon buildings. Grants were available for house holders, not for profit and commercial organisations streams. Applications could be made for Solar photovoltaics (PV), wind turbines, small scale hydro, solar thermal hot water, ground/water/air source heat pumps and wood fuelled heating (principally wood fuelled (biomass) boilers with or without CHP but not including wood fuelled by municipal solid waste or CHP fired using natural gas).	£35 million	2006-2010	

Table 5.2: Major Demonstration Projects

Name	Description	Sub-topics covered	Total Project Cost	Public Sector Funder	Public Sector Funding	Period
Sustainable Building Envelope Centre	Tata Colors, the Low Carbon Research Institute and Welsh Assembly Government are collaborating to form a Sustainable Building Envelope Centre in Shotton, Deeside. The aim of the centre is to accelerate the development of low and zero carbon solutions for the building environment using steel in combination with other materials and will be a showcase for sustainable products. The centre will be used to test and monitor new integrated heating, energy and ventilation systems on the fabric of the building.		£6m			2010 -

6. Research Facilities and Other Assets

Return to the Top

The UK does not have large research facilities dedicated to PV or where PV forms a substantial part of the mission. This inevitably leaves gaps in the capability of available open access facilities in the UK - for example, accredited testing facilities for new products and calibration purposes. The research facilities listed below provide a range of services largely directed towards development of materials and processes. Small scale materials development and testing is well served but larger scale facilities probably only exist at NaREC for silicon solar cell development. CREST have the capability to test modules but we do not have a source of calibration cells in the UK. The need for a national test facility was identified in the Photonics KTN Road Map, published in January 2009. This has now been realised through the newly established BRE National Solar Centre in St Austell.

The Centre for Solar Energy Research at OpTIC, Glyndŵr University's campus in St Asaph is dedicated to solar energy development and is expanding its range of test and process development facilities for a range of PV products. Commercial testing of PV modules is provided by a spin out from Loughborough, CREST, called Ipsol Energy.

Table 6.1: Research Facilities and Assets

Name	Description	Type of asset	Number of Supporting Staff	Annual Operating Budget
NaREC Photovoltaic Technology Centre (PVTC)	A well equipped solar cell process line and characterisation laboratory is managed and operated by NaREC – a Centre of Excellence created in the North East of England to provide enablement, testing and development services to the energy sector	Test facility	8 staff	
Optoelectronics Research Centre, Micro-electronics, Southampton University	In 2009, the Mountbatten building was reopened after it was destroyed in 2005 by a major fire. The clean room facilities and laboratories has the capacity to fabricate: • glass-based devices • thin film devices • solar cells • micro-fluidic devices • silicon-based devices • photonic devices	Fabrication facility	20 staff	
Centre for Solar Energy Research, Glyndŵr University	CSER is a Centre of Expertise at the Glyndŵr University campus at OpTIC in St Asaph. CSER is a member of the Low Carbon Research Institute (LCRI) which collaborates on	Research facility	12 staff	

	renewable energy R & D across Wales and has proven expertise and a world class reputation in researching novel photovoltaic materials and devices. The Centre provides: • State-of-the-art material and PV preparation facilities • Characterization and inspection equipment • Consultancy and project collaboration expertise • A network of business and academic contacts and expertise.			
EPSRC National Centre for III-V Technologies, Electronic and Electrical Engineering, The University of Sheffield	The centre supports the facilities of fabrication service for GaAs / AlGaAs solar cells, MQW pin cells, multi quantum well solar cells	Fabrication Facility	22	
CREST – Centre for Renewable Energy Systems Technology, Loughborough University	CREST supports facilities for PV cell fabrication, measurements and PV systems performance assessment including: • A fully instrumented outdoor measurement system for photovoltaic module performance • Large Area Laser Beam Induced Current Measurement System (LBIC) • Industrial class-A large area solar simulator (Spi-Sun 240A) • A large-scale solar simulator for testing photovoltaic roof / façade elements. CREST has the largest academic Photovoltaic Laboratory in the U.K for photovoltaic materials and devices. The facilities include: • A c-Si cell fabrication facility (including laser grooving) • Dye cell fabrication • Thin film deposition of TCOs and thin film cells.	Test and fabrication facilities	10 staff	
Low Carbon Research Institute (LCRI)	The Institute was set up to unite and promote energy research in Wales, UK to help deliver a low carbon future. The multidisciplinary LCRI aims to support the energy sector, UK and globally, to develop low carbon generation, storage, distribution and end use technologies, and to offer policy advice.	Research facility.	12 core plus research teams at Cardiff, Swansea, Glamorgan, Aberystwyth, Glyndŵr and Bangor	

BRE National Solar Centre	• Analysis, data collection and publications to create a full and authoritative knowledge base for the industry • An observatory for best practice, both in the UK and internationally • Support for the development of future standards to increase quality of PV installations • Support for UK solar industries in a worldwide market • Due diligence consultancy and testing for new build installations • Fault finding, verification and optimisation for existing systems • Product development for building-integrated PV and other integrated approaches • Direct support for Cornish small and medium enterprises • Encouragement for inward investment to create a cluster of solar PV companies on the site.	Test facility		

7. Networks

Return to the Top

There are a number of networks relevant to PV solar in the UK, each covering a different aspect of networking activity. The PV Net comprises of a network of UK research and industrial groups that are actively working in photovoltaic materials and device R&D. The PV Net provides events and information for the UK photovoltaic materials and device community. Student bursaries are provided for research students to attend conferences and PV NET is a sponsor of the UK annual conference on PV called PV SAT. This acts as a focal point for the PV R&D community covering basic materials research through to evaluation of field trials. This is organised by the UK Solar Energy Society (UK-ISES) http://uk-ises.org/ which is a non-profit organisation and is a forum for all those interested in the advancement of the utilisation of the sun's energy.

The British Photovoltaic Association (PV-UK) was the Trade Association for the PV industry of Great Britain. The Association was formed in 1991 to advance the development and use of photovoltaics (solar electricity), promoting the use of PV within the UK as well as other regions such as Africa, Asia and Latin America. The British Photovoltaic Association merged its membership with the Renewable Energy Association (REA) from the 1st April 2006 and was instrumental in lobbying for the introduction of the FiT in April 2010. In June 2010 the REA formed a Solar Power Portal http://www.solarpowerportal.co.uk/ to promote solar energy in the UK.

A number of the TSB funded Knowledge Transfer Networks KTNs have an interest in PV solar energy. The main KTN that has taken the lead with the UK PV Road Map is the Electronics, Sensors and Photonics KTN. Other KTNs play a role in different aspects of PV solar and are listed below.

The European Photovoltaic Industry Association (EPIA) is the world's largest industry association devoted to the solar electricity market. The association aims to promote photovoltaics at the national, European and worldwide levels and to assist its members in the development of their businesses in both the European Union and in export markets.

Table 7.1 Networks

Network	Date Established	Description	Membership Profile	Activities
PV NET	1999	PV Net is a network of UK research and industrial groups that are actively working in the field of photovoltaic devices.	70 members from 19 universities. 11 members from industry	• Encourage greater collaboration in research and implementation of photovoltaics. • Optimize UK resources through establishing shared facilities and greater awareness of UK research activity. • Act as a voice for the UK photovoltaic materials and device community • Encourage submission of high quality research proposals • Benchmark UK research against the best in the world and implement best practice in our own research projects.
Renewable Energy Association	2001	The Renewable Energy Association was established in 2001 to represent British renewable energy producers and promote the use of sustainable energy in the UK. The REA was called the Renewable Power Association until October 2005.	500+ Corporate Members	• Represent British renewable energy producers and promote the use of sustainable energy in the UK. • Undertake policy development and provide input to government departments, agencies, regulators, NGOs and others.
European Photovoltaic Industry Association (EPIA)		EPIA is the world's largest industry association devoted to	69 members from industry area in the Europe	• Observe continuously and in time the market situation

		the solar electricity market. The association aims to promote photovoltaics at the national, European and worldwide levels and to assist its members in the development of their businesses in both the European Union and in export markets.		• Understand trends and evolutions • Support decision-process • Provide internal and external accurate data and information • Develop a credible and reliable EPIA voice • Supply an efficient communication action
Electronics, Sensors, Photonics KTN	2010	ESP KTN groups all underpinning technologies together to make a single entity focused on knowledge sharing for growth.	1985 Members	• Support technology communities
Environmental Sustainability – KTN	2010	The Environmental Sustainability KTN wants to accelerate the UK's transition to a low carbon, resource and energy efficient economy by connecting businesses, universities, other research organisations and government agencies, and catalysing innovation across a wide range of environmental technologies	2154 Members	• Delivering improved industrial performance through innovation and new collaborations • Driving knowledge transfer between the supply and demand sides of technology-enabled markets • Providing UK businesses with the opportunity to meet and network with individuals and organizations, in the UK and internationally
Materials – KTN	2006	The Materials KTN is an overarching network of networks in Materials,	2642 Members	• Help to identify the challenges and opportunities which face

		set up to bring together the views of all in business, design, research and technology organisations, trade associations, the financial market, academia and others in the value network across the materials community		industry in chosen field of technology or business application • Link the best of business and academia to give companies large and small easier access to new markets, new technology and skills development • Support for R&D funding • Technology and design support to the materials community
Nano-technology – KTN	2009	The role of the Nano-KTN is to simplify the nano-technology Innovation landscape by providing a clear and focused vehicle for the rapid transfer of high-quality information on technologies, markets, funding and partnering opportunities.	1452 Members	• Improved supply-chains that make use of nano-technology and the creation of new supply chains to bring multi-disciplinary developments to market • An appreciable growth in the size of the UK's industry active in nano-technology, particularly in nano-enabled products in development and on the market • Increased flow of funds into national and regional nano-technology facilities including the Nano-Centres from sources such as EU FP7 and private finance
Energy Generation and Supply - KTN	2010	The mission of the Energy Generation and Supply Knowledge	1244 members	• Attract and optimize the various funding sources by use of roadmapping

		Transfer Network (EG&S KTN) is to create an integrated and dynamic network of business, technology, academic and policy stakeholders delivering strategic and effective knowledge exchange to advance the UK EG&S sector.		and market analysis • Enable effective knowledge transfer between all relevant people and organizations, in particular ensuring a match between utility and industrial needs, and supply-chain technology/research capabilities • To promote competitive markets in the UK and beyond
UK - ISES	1974	The Solar Energy Society has close links with other renewable energy organisations and government bodies, and is thus able to promote solar energy in all its aspects.		• Represents the UK national section of the International Solar Energy Society (ISES). • ISES has launched a world-wide information system for renewable energy, WIRE. This is a resource website for fast, comprehensive and up-to-date information on renewable energy

8. UK Participation in EU Activities

Return to the Top

In 2011 the Solar PV EERA (European Energy Research Alliance) was launched. The EERA is an alignment of the national research programmes of the EU member states and the focus for each member participation is normally through a national laboratory. With the more distributed research landscape in the UK the signature to the EERA agreements is EPSRC and acting through the UKERC. European research funding is through the EU Framework Programme. The focus has been put on the development and demonstration of integrated approaches for new PV system design options and concepts, with a strong emphasis on module manufacture and performance and of course cost reduction, as indicated below in more detail:

Short – Medium Term:

- Innovative production concepts for high efficiency PV cells/modules to be integrated into larger scale (multi-MW) photovoltaic production facilities in order to lower the W_p cost; and including low cost integrated components or devices for grid connected or stand alone PV generators;
- Support actions aimed at kick-starting Si-feedstock production by EU industries to secure a reliable and affordable supply for fostering PV cell cost reductions;
- Transfer to industrial scale of a new generation of PV technologies / products to facilitate the integration of innovative solutions at lower costs;
- Large area, low cost photovoltaic modules for building integrated PV (BIPV) and autonomous solar electricity generation systems in industrialized and developing countries;
- Integration of photovoltaic installations in generation schemes to feed local distribution grids, closer to the point of use and development of new devices and systems to manage these installations.

Medium – Long Term:

- Innovative concepts and fundamental materials research for the next generation of PV technologies (e.g. organic or hybrid solar cells);
- Thin film PV technology (development of cost-effective PV cells and modules based on new and improved technologies and materials);
- PV processing and automated manufacturing technologies (to reduce the costs and improve materials usage in the manufacture of PV cells and modules);
- PV components and systems - balance of systems (research into components and their integration into the overall system)
- Research for innovative applications of PV in buildings and the built environment (to develop integrated PV module systems which are configured for ease of mounting on building roofs and facades, hybrid PV/heating systems).

The table below lists EU Framework projects with UK participation. Both 6th Framework (FP6) and 7th Framework (FP7) projects are included.

Table 8.1: EU Framework Programmes

Project	Objectives	Action Line	Type of Action	UK Participants	Coordinator and Partners	Total Funding	EU Funding	Duration	Annual Spend
20 percent efficiency on less than 100 µm thick industrially feasible c-Si solar cells	The overall objective of the current project is a significant contribution to the dissemination of PV in order to improve the sustainability of the European energy supply and to strengthen the situation of the European PV industry. The approach to reach this overall objective is the development of solar cells which are substantially thinner than today.	FP7	Collaborative Project	National Renewable Energy Centre Ltd.	Universitat Konstanz, 11 Partners	€7,031,921	€4,879,986	2010-10-01 – 23-09-30	
All-carbon platforms for highly efficient molecular wire-coupled dye-sensitized solar cells	The proposed project comes with a visionary approach, aiming at development of highly efficient molecular-wire charge transfer platform to be used in a novel generation thin film dye-sensitized solar cells fabricated via organic chemistry routes. The proposed technology combines the assembled dye monolayers, linked with organic molecular wires to semiconducting thin film deposited on optically transparent substrates.	FP7	Collaborative Project	ICAX LTD	Stichting Energieonderzoek Centrum Nederlands 16 Partners	€11,660,114	€7,999,701	2010-12-01 – 2014-11-30	

Redox Materials-based Structured Reactors/Heat Exchangers for Thermo-Chemical Heat Storage Systems in Concentrated Solar Power Plants	ThermoChemical Storage (TCS) involves the exploitation of the heat effects of reversible chemical reactions for the storage of solar heat. Among gas-solid reactions proposed for such an approach the utilization of a pair of redox reactions involving multivalent solid oxides has several inherent advantages that make it attractive for large-scale deployment. The new concept introduced in the current proposal is instead of using packed or fluidized beds of the redox material as the heat storage medium, to employ monolithic structures like honeycombs or foams, made entirely or partially from the redox oxide materials.	FP7	Collaborative Project	Neo Performance Materials (Europe) Ltd.	Centre for Research and Technology Hellas 5 Partners	€3,068,330	€2,114,497	2011-11-01 – 2015-10-31	
Distributed CHP generation from Small Size Concentrated Solar Power	The DiGeSPo project concept is a modular 1-3 kWe, 3-9 kWth micro Combined Heat and Power (m-CHP) system based on innovative Concentrated Solar Power (CSP) and Stirling engine technology. This CSP m-CHP will provide electrical power, heating and cooling for single and multiple domestic dwellings and other	FP7	Collaborative Project	Sustainable Engine Systems Ltd.	Fondazione Bruno Kessler 6 Partners	€4,536,293	€3,278,174	2010-01-01 – 2012-12-31	

	small commercial, industrial and public buildings. It integrates small scale concentrator optics with moving and tracking components, solar absorbers in the form of evacuated tube collectors, a heat transfer fluid, a Stirling engine with generator, and heating and/or cooling systems; it incorporates them into buildings in an architecturally acceptable manner, with low visual impact.								
Thin Si film based hybrid solar cells on low-cost substrates	The ThinSi project will develop a solar cell processing chain for high throughput, cost-effective manufacturing of thin film silicon based solar cells on low-cost silicon substrates. The substrates will be made on the basis of an innovative powder-to-substrate concept. In line with the Workprogramme topic addressed, it will reduce the cost of solar cell modules compared to those made by the conventional wafer based approach. A set of innovative processes will be developed to realise the new low-cost concept and transfer the results into production.	FP7	Collaborative Programme	Oxford Instruments Plasma Technology Ltd.	Stiftelsen Sintef 10 Partners	€6,358,888	€4,416,582	2010-01-01 - 2012-12-31	

Efficient Solar Cells based on Organic and hybrid Technology	Widespread uptake of inorganic semiconductor solar cells has been limited, with current solar cell arrays only producing between 4 to 7 GW of the 15 TW (<0.04%) global energy demand, despite the terrestrial solar resource being 120,000 TW. The industry is growing at a cumulative rate of over 40% per annum, even with effects of the financial crisis. The challenge facing the photovoltaic industry is cost effectiveness through much lower embodied energy. Our objectives are to exploit the joint leadership of the top European and Indian academic and industrial Institutions to foster the wide-spread uptake of Dye-Sensitized Solar Cells technology, by improving over the current state of the art by innovative materials and processes.	FP7	Collaborative project	Dyesol UK Ltd,	Consiglio Nazionale delle Ricerche 3 Partners	€1,755,892	€1,341,166	2010-09-01 – 2014-08-31	
Novel Environmentally Friendly Solution Processed Nano-materials for Panchromatic Solar Cells	In this project we propose a disruptive approach; to replace titania with a novel electron accepting nano-porous semiconductor with a bandgap suitable for optimized solar harnessing and a very high absorption	FP7	Collaborative Project	Imperial College Of Science, Technology And Medicine, G24 Innovations Ltd	Fundacio Institut De Ciencies Fotoniques 4 Partners	€3 545 958	€2 722 101	2013-01-01 – 2015-12-31	

	coefficient to allow total light absorption within 2 um across its absorption spectrum. In addition the deposition of the nano-structured platform will employ processing below 200oC, compatible with plastic, flexible substrates and cost-effective roll-to-roll manufacturing.								
Active solar panel initiative	The Active Solar Initiative targets development of a fundamentally new, multi-disciplinary photovoltaic technology that will enable meeting and exceeding the year 2015 cost targets of the EU Photovoltaic Strategic Research Agenda, driving European consumer premises power generation to cost parity with grid electricity. The basis of Active Solar is a novel Parallactic Tracking technology concept that supports flat, fixed solar panels with internal concentration and dynamic sun-tracking. Active Solar panels will be a direct replacement of the ubiquitous photovoltaic solar modules. By means of a ten-fold reduction of amount of polycrystalline silicon, costs of the	FP7	Collaborative Project	Heriot-Watt University, National Renewable Energy Centre Limited	Fraunhofer 7 Partners	€3,915,227	€2,884,334	2009-01-01 – 2011-12-31	

	Active Solar panels will be reduced by up to 3 times compared to conventional PV modules.								
Nano-designed electrochemical converter of solar energy into hydrogen hosting natural enzymes or their mimics	The project involves a strong and partnership hosting highly ranked scientists (from the Imperial College London, the Politecnico di Torino and the GKSS research centre on polymers in Geesthacht) who have a significant past cooperation record and four high-tech SMEs (Solaronix, Biodiversity, Nano-cyl and Hysytech) to cover with expertise and no overlappings the key tasks of enzyme purification and enzyme mimics development, enzyme stabilisation on the electrodes, membrane development, design and manufacturing of the SOLHYDROMICS proof-of-concept prototype, market and technology implementation studies	FP7	Collaborative Project	Imperial College Of Science, Technology And Medicine	Politecnico Di Torino 6 Partners	€3,655,827	€2,779,679	2009-01-01 – 2012-06-30	
Innovative materials for future generation excitonic solar cells	INNOVASOL aims to develop radically new nano-structured materials for photovoltaic (PV) excitonic solar cells (XSCs) really competitive with traditional energy sources.	FP7	Collaborative Project	The University of Cambridge	Universita Degli Studi Del Piemonte Orientale Amedeo Avogadro 7 Partners	€4,002,760	€2,899,510	2009-04-01 – 2012-03-31	

	The main objective is to leapfrog current limitations of third-generation PV devices through a drastic improvement of the materials used for assembling XSCs.								
Accelerated development and prototyping of nano-technology-based high-efficiency thin-film silicon solar modules	This project focuses at bringing the next-generation technology to the market, using newly developed state-of-the art knowledge to solve the complex puzzle of achieving at the same time strong light in-coupling (high current) and good electrical properties (open-circuit voltage and fill factor). In a unique collaborative effort of the leading EU industries and research institutions in the field, the consortium will go beyond the current technology status by Introducing novel materials	FP7	Collaborative Project	CVD Technologies Limited	Forschungszent-rum Juelich GMBH 17 Partners	€14,365,711	€9,300,000	2012-03-01 - 2015-02-28	
Advanced Grating for Thin Films Solar Cell	The minority carrier diffusion lengths are small in polycrystalline or amorphous materials used in thin film solar cells, requiring thin layers to maximize charge collection. This is contradictory for the requirement to maximize solar energy absorption. The optical design consisting in increasing	FP7	Collaborative project	Mantis Deposition Ltd.	Commissariat a l Energie atomique et aux Energies alternatives 4 Partners	€2,426,887	€1,708,420	2010-09-01 - 2013-08-31	

	solar cell s light-trapping capability is of prime importance. In order to provide total internal reflection, both randomly textured surfaces and regularly patterned surfaces have been investigated. No one of these approaches provides optimal light trapping because no one is suitable for the broad solar spectrum. Recent approaches involving new TCO layers show that double textures provide improved scattering. The AGATHA project aims to realize an advanced light trapping design by combining micro-texturing of glass by hot embossing and nano-texturing of the top TCO layer by etching.								
Direct biological conversion of solar energy to volatile hydrocarbon fuels by engineered cyanobacteria	The objective of the DirectFuel project is to develop photosynthetic microorganisms that catalyze direct conversion of solar energy and carbon dioxide to engine-ready fuels. A key process target of the proposal is 'direct' in the sense that fuel production should not require destructive extraction and further chemical conversion to generate directly useable	FP7	Collaborative Project	The University of Manchester	Turun Yliopisto 8 Partners	€4,977,781	€3,729,519	2010-10-01 - 2014-09-30	

	transport fuels.								
Development and scale-up of nano-structured based materials and processes for low cost high efficiency chalcogenide based photovoltaics	This project will exploit the potential of chalcogenide based thin film photovoltaic technologies for the development and scale-up of new processes based on nano-structured materials for the production of high efficiency and low cost photovoltaic devices and modules compatible with mass production requirements	FP7	Large-scale integrating project	The University of Nottingham Innovative Materials Processing Technologies	Fundacio Institut de Recerca de Catalunya 12 Partners	€10,228,772	€7,541,468	2012-02-01 to 2015-07-31	
Concentrated Solar Power in Particles	In the frame of the project, a 100-150 kWh pilot loop will be designed, constructed and tested at the focus of the CNRS solar furnace in Odeillo, The main target for the innovative solar receiver is to deliver hot DSP in the temperature range 500°C-750°C for solid mass flow rate varying from 1 to 2 tons/h with a 70% thermal efficiency. Finally, the global system will be analyzed and scale-up will be proposed toward industrial CSP facilities (10-50 MWe). Economic assessment will allow comparing this new technology to the molten	FP7	Collaborative project	University of Surrey	Centre de la Recherche Scientifique 6 Partners	€3,138,274	€2,263,192	2011-12-01 to 2015-11-30	

	salt one.								
Multipurpose Applications By Thermodynamic Solar	The proposed MATS Project aims at promoting the exploitation of concentrated solar energy through small and middle scale facilities, suitable to fulfil local requirements of power and heat, and easily to back-up with the renewable fuels locally already available or that can be expressly produced. The implementation of the project will allow to test the CSP (Concentrating Solar Power) technology in a location very advantageous with regard to the solar radiation rate as an example for the diffusion of this technology in other Mediterranean Countries. Besides, it will represent the start-up for a development of specialized local industries.	FP7	Collaborative project	Cranfield University	AgenziaGENZIA Nazionale per Nuove Tecnologie, l'Energi a e Lo Sviluppo Economico Sostenibile 10 Partners	€20,457,085	€11,755,049	2011-07-19 to 2015-01-18	
Demonstration Of High Performance Processes And Equipments For Thin Film Silicon Photovoltaic Modules Produced With Lower Environmental Impact And	This project tackles major factors relating to micromorph module efficiency and production cost by assessing the influences of glass, TCO and silicon deposition (including in-situ cleaning). The project bridges the gap between research and industrial	FP7	Collaborative project	University of Northumbria	OerlikonSolar AG 6 Partners	€16,720,648	€9,383,967	2010-09-01 to 2013-08-31	

Reduced Cost And Material Use	application by executing new developments and improvements in the field of TCO and PECVD reactors and processes and transferring them to production plants where the full impact on module efficiency and costs can be evaluated.								
A new generation of concentrator photovoltaic cells, modules and systems	The Project, through a collaborative research between seven European and nine Japanese leading research centres in the field of concentration photovoltaic (CPV), pursues the improvement of present concentrator cell, module and system efficiency	FP7	Collaborative project	Imperial College of Science, Technology and Medicine	Universidad Politecnica De Madrid 6 Partners	€6,528,053	€4,999,998	2011-06-01 to 2014-11-30	
Adhesion and cohesion at interfaces in high performance glassy systems	The present project aims to establish a European Consortium bringing together leading experts in the fields of computational materials modelling, experimental materials research and industrial development of high-performance glass materials. The scientific and technological activities of the consortium shall be devoted to improving the efficiency, functionality and reliability of glass products for pharmaceutical and thin-layer optical and photovoltaic applications.	FP7-NMP	Small or medium-scale focused research project	King's College London	Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung E.V 6 Partners	€4,313,965	€2,999,622	2009-09-01 – 2013-02-28	

A micro-generation system using PV/heat-pipe roof modules	The proposed project aims to investigate a novel PV/hp (photovoltaic/heat-pipe) roof module able to work with a heat pump cycle to provide electricity and heat for buildings with enhanced efficiency	FP7-PEOPLE	International Incoming Fellowships (IIF)	The University Of Nottingham	The University Of Nottingham	0	€181,350	2009-06-11 – 2011-05-11	
Electrochemical silicon layers formation in fused salts	The goal of this project is to create new electrochemical methods of silicon layer formation in fused salt electrolytes in the range of thicknesses from nano-metres to micrometres. The research aims to achieve results of high technological significance formation of silicon thin films for photovoltaic applications.	FP7-PEOPLE	Intra-European Fellowships (IEF)	The University Of Cambridge	The University Of Cambridge	0	€246,983	2009-10-01 – 2011-09-30	
Computational modelling of electromagnetic control of melt flows and heat/mass transfer during manufacturing of bulk photovoltaic materials	This is a continuation of our experimental and numerical study of instabilities of melt flows in Czochralski growth of optical oxide crystals, which we plan to extend for bulk growth of photovoltaic materials. Our general target is a full-scale computational modelling of a bulk crystal growth technological process.	FP7-PEOPLE	Intra-European Fellowships (IEF)	The University Of Nottingham	The University Of Nottingham	0	€121,110	2009-08-01 – 2010-07-31	
Autonomous cleaning robot for large scale photovoltaic power plants in Europe resulting	The PV-Servitor project focuses on concepts for a fully autonomous cleaning robot for ground mounted large scale photovoltaic power	FP7-SME	Research for SMEs	The Shadow Robot Company Limited	Manu Systems Ag 12 Partners	€1500.222	€1,205,383	2009-09-01 – 2011-08-31	

in 5% cost reduction of electricity	plants consisting of several 100 kW units. The PV-Servitor shall be able to automatically clean glass surfaces of solar modules in several areas of up to 2,500 square meters in an unrestricted way. Its application will increase the electricity output of the PV plant by 8% at a service cost of only 3%, thus resulting in a 5% user-benefit by cost reduction of the electricity yield.								
Nano-materials for harvesting sub-band-gap photons via upconversion to increase solar cell efficiencies	To continue the path of cost reduction in photovoltaics the efficiency of silicon solar cells must be increased. With higher efficiencies more kWh can be produced from the same amount of silicon, which is the dominating cost factor at present	FP7-NMP	Small or medium-scale focused research project	Trackdale Ltd	Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung E.V 7 Partners	€4,166,766	€3,033,843	2010-06-01 - 2013-05-31	
Innovative materials for future generation excitonic solar cells	The project aims to develop radically new nano-structured materials for PV excitonic solar cells (XSCs) really competitive with traditional energy sources. The main objective is to leapfrog current limitations of third-generation PV devices through a drastic improvement of the materials used for assembling XSCs.	FP7-Energy	European Technology Platform	University Of Cambridge	Universita Degli Studi Del Piemonte Orientale Amedeo Avogadro 7 Partners	€4,002,760	€2,899,510	2009-04-01 - 2012-03-31	

Active solar panel initiative	The Active Solar Initiative targets development of a fundamentally new, multi-disciplinary photovoltaic technology that will enable meeting and exceeding the year 2015 cost targets of the EU photovoltaic Strategic Research Agenda, driving European consumer premises power generation to cost parity with grid electricity.	FP7-Energy	Collaborative project	Heriot-Watt University	Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung E.V 6 Partners	€3,762,476	€2,884,334	2009-01-01 - 2011-12-31	
Highly flexible printed ITO-free OPV modules	HIFLEX aims to develop a cost-effective Highly Flexible Printed ITO-free OPV module technology that matches the particular requirements of mobile and remote ICT applications in terms of efficiency under different light conditions, lifetime, cost structure, power to weight ratio and mechanical flexibility. The project intends to accelerate the exploitation of this OPV technology for a wide variety of ICT products in the mobile electronics market.	FP7-ICT	Collaborative project	The UK Materials Technology Research Institute Limited	Stichting Energieonderzoek Centrum Nederland 6 Partners	€4,993,874	€3,649,672	2010-01-01 - 2012-12-31	
Non-vacuum processes for deposition of CI(G)S active layer in PV cells	Current production methods for thin film photovoltaics typically rely on costly, difficult to control (over large surfaces) vacuum-based deposition processes that	FP7-NMP	Small or medium-scale focused research project	Xennia Technology Limited	Umicore Nv 7 Partners	€5,480,564	€3,474,727	2010-01-01 - 2013-06-30	

	are known for low material utilisation of 30-50%. NOVA-CI(G)S proposes alternative, non-vacuum ink-based simple and safe deposition processes for thin film CI(G)S photovoltaic cells.								
Ab-initio computational modelling of photovoltaic interfaces	Not given	FP7-IDEAS	ERC Starting Grant	The University Of Oxford	The University Of Oxford	€1,000,000	€1,000,000	2010-03-01 - 2015-02-28	
Plasmon resonance for improving the absorption of solar cells	The demand for affordable renewable energy is increasing steadily. Electricity generation by photovoltaic cells is one of the main players in this field, but is hampered by its still relatively high cost compared with other sources of energy. Within this project we investigate promising nano-technology - based strategies to enhance the performance and/or reduce the cost of different solar cell technologies.	FP7	Collaborative project	Quantasol Limited Imperial College	Interuniversitair Micro-Electronica Centrum Vzw 5 Partners	€3,396,658	€2,300,000	2010-01-01 - 2012-12-31	
All-inorganic nano-rod based thin-film solar cells on glass	The project aims are to synthesise Si nano-rods, to get densely packed rods at sufficiently large diameters (few 100 nm's) and lengths (>1µm for sufficient carrier absorption in indirect semiconductors)	FP7 - NMP	Collaborative project	The UK Materials Technology Research Institute Limited	Stichting Energieonderzoek Centrum Nederland 6 Partners	€4,993,874	€3,649,672	2010-01-01 - 2012-12-31	

	directly on cheap substrates like glass or flexible metal foils. The idea is to grow Si nano-rods from the gas phase that are inherently defect free, with a wrapped around pn-junction that bares the potential to decouple absorption of light from charge transport by allowing lateral diffusion of minority carriers to the pn-junction, which is at most a few hundred nm away, rather than a few µm as in conventional thin film solar cells.								

9. International Initiatives

Return to the Top

The Photovoltaic Power Systems Programme is a collaborative R&D Agreement, established within the International Energy Agency, and conducting projects on the application of solar photovoltaic electricity. IEA PVPS operates worldwide via a network of national teams in member countries. For the UK, participation in PVPS provides access to a wealth of practical international experiences on critical aspects of PV implementation, from network integration of systems to programmes and policies for promoting PV technology. Participation assists the UK to resolve the key issues that will help move the technology as rapidly as possible towards more cost-effective applications at home, and more reliable operation worldwide. The participation of all UK experts within PVPS is supported by the DECC. The Department for International Development (DfID) also supports experts' participation specifically under the PVPS activity 'Cooperation with Developing Countries'. UK participation in the EU/ EPIA Solar Energy Industry Initiative (SEII) is managed by DECC.

Table 9.1: International Activities

Name	Type	Description	UK Contact Point
PVPS	IEA-Technology Agreements	International Energy Agency's Photovoltaic Power Systems (PVPS) Programme provides a pool of international expertise and experience and a valuable mechanism with which to identify and overcome common problems in an efficient and cost-effective manner. In the UK, the R&D activities of PV under the IEA-PVPS include: • The EPSRC Sustainable Power Generation and Supply (Supergen) Project 'Photovoltaic Materials for the 21st Century': • The Domestic Field Trial (DFT); • Large-Scale Building-Integrated PV Field Trials (LSBIPV) provided funding for large building integrated PV projects; • The PV Major Demonstration Programme (MDP);	Mr Steve Martin, DECC steve.martin[at]decc.gsi.gov.uk
High stability and high efficiency printable photovoltaics(OPV)for large-scale energy production (EPSRC funded UK-China Energy Awards)	Collaborative projects	The Research Councils' Energy Programme wishes to develop collaborative projects in the fields of energy technologies, hydrogen and fuel cells as a key component of its strategy to foster closer scientific, technological and engineering links with China.	Prof DDC Bradley, Imperial College London
Thermal Conductivity	Collaborative	The Research Councils' Energy Programme wishes to develop	Dr CY Zhao, University of

Enhancement of High-temperature Thermal Energy Stores for Use with Solar Power Plants (EPSRC funded UK-China Energy Awards)	projects	collaborative projects in the fields of energy technologies, hydrogen and fuel cells as a key component of its strategy to foster closer scientific, technological and engineering links with China.	Warwick
Strategic Energy Technology (SET) Plan	Technology Agreements	We must make low-carbon technologies affordable and competitive – a market choice. This is the core idea behind the European Strategic Energy Technology Plan	Prof Nicola Pearsall, University of Northumbria
European Photovoltaic Industry Association (EPIA)		The European Photovoltaic Industry Association (EPIA) is the world's largest industry association devoted to the solar photovoltaic (PV) electricity market**.** The association aims to promote PV at national, European and worldwide levels and to assist its members in their business development in both the European Union and export markets.	
Solar Europe Industry Initiative (SEII)		The Solar Europe Industry Initiative (SEII) describes the strategic RD&D components of "SET For 2020", which are essential to enable rapid, large-scale deployment of PV at minimum cost and maximum benefit for society. Besides the efforts of the PV sector, the success of other Industry Initiatives under the SET-Plan (e.g. Electricity Grid Initiative) as well as the development of other technologies (electricity storage, electrical vehicles, demand side management, etc.) are essential for the success of the SEII.	Mr Steve Martin, DECC and Prof Nicola Pearsall , University of Northumbria
UK – China	Collaborative Projects	UK-China Joint Research Consortium on Sustainable Electric Power Supply is sponsored by the UK EPSRC. The Consortium includes researchers from 5 UK universities and 13 Chinese institutions to carry out collaborative research focusing on sustainable security of electric power supply system's considering renewable technologies. Two key objectives of the Consortium are: (1) To produce significant research advances in the field of sustainable security through joint research projects that combine complementary expertise's of researchers of the Consortium from both countries; (2) To provide a mechanism for early and efficient cross-dissemination of the results of the research carried out in both countries by linking SUPERGEN with the nationally funded "973" and "National Key Research Program" research programmes in China.	EPSRC
UK – India	Collaborative	This network aims to generate collaborative UK, India and Sri	EPSRC

	Projects	Lanka research and business development in low carbon technology. This project strand will provide opportunities and networking events to share ideas and to build capacity, competitions for the young low carbon scientist and the young low carbon entrepreneur of the year.	
EERA – European Energy Research Alliance	Collaborative Projects	EERA is an alliance of leading organizations in the field of energy research. EERA aims to strengthen, expand and optimize EU energy research capabilities through the sharing of world-class national facilities in Europe and the joint realization of pan-European research programmes (EERA Joint Programmes). The primary focus of EERA is to accelerate the development of energy technologies to the point where they can be embedded in industry driven research. In order to achieve this goal, EERA streamlines and coordinates national and European energy and R&D programmes.	Prof Ralph Gottschalg, CREST