European Commission

Forward looking workshop on

Materials for Emerging Energy Technologies

Research and Innovation

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REPORT ON

Forward Looking Workshop on Materials for Emerging Energy Technologies

Edited by

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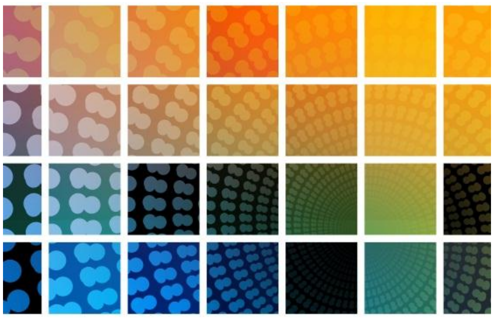

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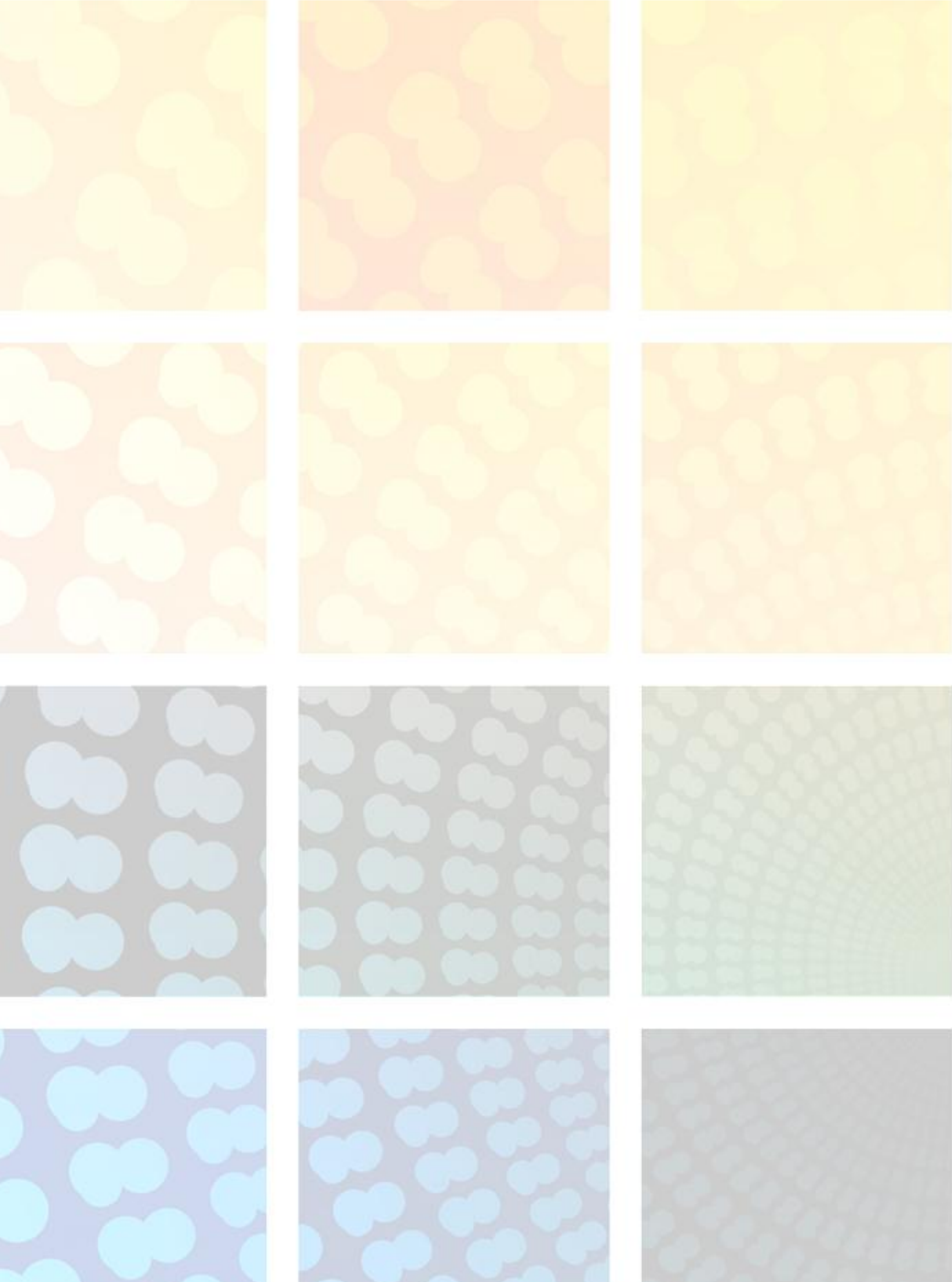

Chapter 1

Executive Summary

Materials are fundamental to economic, social and industrial development. They form the basis for the functionality of the built environment, products and technologies that are vital to modern society. This means that they can be the key innovative trigger in the development of many new products and technologies.

The intention is for this report to be an integral part of the European Commission's continuous assessment of developments of, and needs for, materials in energy technologies. The objective of this report is to identify possible material priorities for emerging energy technologies. Such solutions would have longer term (up to 2050) commercial prospects.

The Materials Unit of the European Commission (DG Research and Innovation, Directorate "Industrial Technologies") organised a workshop in Brussels on the 28th of October 2011 entitled "Forward Looking Workshop on Materials for Emerging Energy Technologies". The aim of the workshop was to identify research and development of new materials that support emerging low carbon energy technologies for market deployment by 2050. The objective was also to identify possible priorities, bottlenecks and synergies in the field of emerging energy technologies (with the potential for industrial development) and to gather ideas on how to progress on the successful deployment of materials with improved performance. Mindful of the importance to maintain the complementarities to previous workshops and technology assessments, 12 distinguished experts were invited from a variety of fields; artificial photosynthesis, thermoelectrics, piezoelectrics, salinity gradients, osmotic power, thermoacoustic power, structural power materials, materials based design, low energy nuclear reactions and high altitude wind power. The morning was devoted to short presentations of the materials and technologies. In the afternoon there were discussions and agreements on the technical & non-technical needs followed by synergies and common themes. The workshop closed with drawing up conclusions and recommendations.

The workshop provided a learning opportunity and a fruitful exchange of ideas among a highly qualified interdisciplinary group of people. This report contains summaries of the discussed technologies and materials. The report identifies many of the key issues related to research on, and development of, new materials in support of emerging low carbon energy technologies for market deployment by 2050. A conclusion of key issues and themes, gleaned from the presentations and discussions, is contained in this report.

The conclusions of the experts include that:

- No single technology would be a total solution in itself and that developing an energy mix will become even more important in the future.
- Europe must take the lead in development of energy technologies and associated technologies.
- An understanding of technology fundamentals, up-scaling and tech demonstrators are all very important in the development of new energy technologies.
- There is an opportunity to promote research that aims at finding synergies of a wide mix of energy technologies.

The experts' recommendations on actions identified needs for:

- Further research into the structure and properties of materials for energy.
- Further research into new materials or materials solutions.
- Sufficient funding to overcome the obstacles in the up-scaling of the emerging energy technologies.
- There is a need for much more multi-disciplinary activity to take place.
- Advanced computer based complexity modelling
- Recognition there are no simple fixes for power generation in the 2050 horizon.

Chapter 2

Introduction

Materials are fundamental to economic, social and industrial development. They form the basis for the functionality of the built environment, products and technologies that are vital to modern society. This means that they can be the key innovative trigger in the development of many new products and technologies. There can, however, be cases where the need for a very specific material, in a broad spectrum of applications, can lead to constraints in the diffusion of the technology. Enhanced research and development of new and improved materials, together with the associated diffusion impacts, could, in turn, alleviate, or even completely diminish, such constraints.

The intention is for this exercise to be an integral part of the European Commission's continuous assessment of developments of, and needs for, materials in energy technologies. This is a complementary alternative to the detailed roadmaps for materials or technologies. A recent example is the Materials Roadmap Enabling Low Carbon Energy Technologies[1]. Since 2007, the Strategic Energy Technology Plan[2] (SET-Plan) provides a framework for the development and innovation of more efficient, safe and reliable low carbon technologies, where materials play an important role. The objective of this report is to identify possible material priorities for emerging energy technologies that would have longer term (up to 2050) commercial prospects. In addition this work gathers ideas on how to progress the successful deployment of materials with improved performance characteristics. In addition to the main objective this report also seeks to pinpoint if materials will be one of the main bottlenecks for future low carbon energy technologies and if there is a call for research to boost progress in these emerging technologies. Keeping this in mind it is important to

1 http://ec.europa.eu/research/industrial_technologies/pdf/materials-roadmap-elcet-13122011_en.pdf SEC(2011) 1609 final

2 http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm

understand which current and prospective opportunities could be supported in order to promote the long term maturity of these and other emerging energy technologies.

Methodology

Taking the rationale outlined above, the Materials Unit of the European Commission (DG Research and Innovation, Directorate "Industrial Technologies") organised a workshop in Brussels (held on the 28th October 2011) entitled "Forward Looking Workshop on Materials for Emerging Energy Technologies". A panel of 12 distinguished experts were invited from of the following fields: *artificial photosynthesis, piezoelectrics, salinity gradients, osmotic power, thermoacoustic power, thermoelectrics, structural power materials, materials based design, low energy nuclear reactions and high altitude wind power*.

Before the workshop the experts, based on their respective field of expertise, were asked to write a short technical summary. The structure for this summary was as follows:

- The role of materials research in emerging energy technologies
- Technical and non-technical needs and bottlenecks
- Opportunities, synergies and common themes
- Recommendations on actions

The morning session was dedicated to presentations by the experts, with a focus on the technical explanation of each of the technologies and the role of materials in the development of future low carbon energy technology solutions. The afternoon was dedicated to discussions on the topic. One of the experts acted as rapporteur to aid in capturing all the feedback given by the experts, to record the commonalities between the technologies and compile those into this report. The experts were asked to revise their summaries based on the discussions at the workshop. Their summaries are presented in Section 3. The conclusions of this report are as agreed by all the experts and all the experts were given the opportunity to comment on and approve the final report.

Chapter 3

Summaries of the discussed materials and technologies

This section contains the individual submissions from each of the attending experts:

3.1 **Artificial photosynthesis** by Bo Albinsson

3.2 **Bamboo for wind power blades** by Mario Rosato

3.3 **High altitude wind on-ground energy generation** by Marcello Corongiu

3.4 **Low energy nuclear reactions** by Vittorio Violante

3.5 **Piezoelectric materials** by Dragan Damjanovic

3.6 **Salinity gradients & osmotic power** by Willem de Baak & Pedro M. Mayorga

3.7 **Thermoacoustics** by Mario Rosato & Kees de Blok

3.8 **Thermoelectrical materials** by Marisol Martin-Gonzalez & Xavier Crispin

3.9 **Structural power materials** by Emile Greenhalgh

3.10 **Materials and design** by David Peck (Rapporteur)

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3.1 Artificial Photosynthesis

The continued development of our society relies on sufficient energy supplies. It is now generally accepted that our present dependence on fossil fuels will not be an acceptable situation for future generations. Thus, new sources of energy that provide a large-scale, sustainable energy supply must be developed. Solar energy is one of the few alternative energy sources that could meet the increased future demands. Much more solar energy reaches the planet than is needed and if we only can find ways to harvest much less than one percent of the incoming solar energy we will have all our current and future demands fulfilled.

Solar cells, in spite of their high cost, will most certainly be developed into important providers of electrical energy. Many different approaches including silicon, thin film, dye sensitized and bulk hetero-junction solar cells have promising futures but they all share a common problem – energy storage. In our current energy system direct production of electrical energy contribute less than 20% of the total need and the vast majority of energy used is through fuels. In order to switch into a solar powered world we need to develop the production of solar fuels in parallel to solar cells.

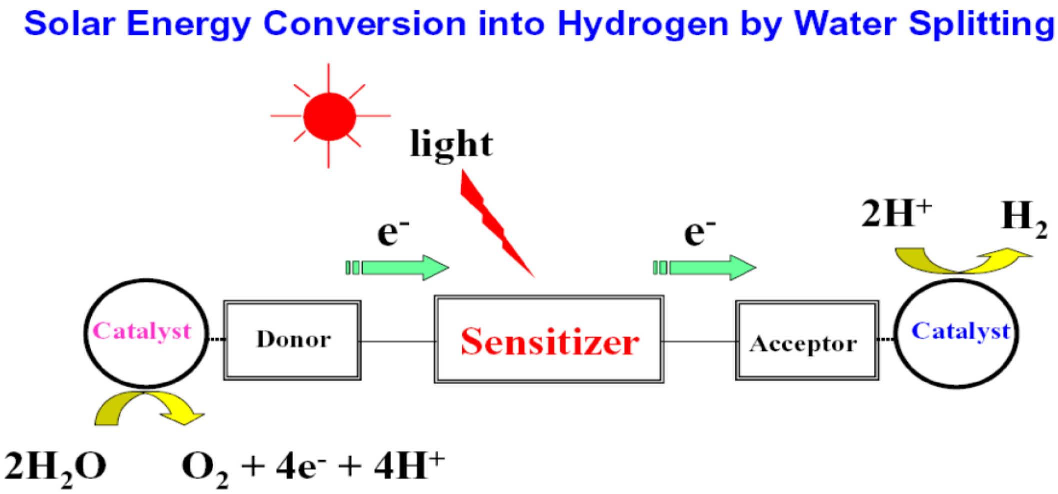

Figure 3.1.1

The role of materials research in artificial photosynthesis

Mimicking the natural photosynthesis by artificial man-made molecular systems has been a goal for the research community for several decades. All since the last (the first!) oil crisis, relatively small scale academic research efforts throughout the world have developed synthetic mimics of increasing complexity, encompassing both the antenna system and reaction centre of the natural photosynthetic machinery. Nevertheless, no functioning artificial photosynthetic device has yet reached the level of maturity needed to be useful outside laboratories. Fuels could also be indirectly produced from solar energy through conversion of biomass into biogas or hydrogen production by electrolysis of water using electricity from photovoltaics. The efficiency of the natural photosynthesis is, however, low and growing energy crops competes with the need to use agricultural land to produce food. In contrast, artificial photosynthesis is a direct way of producing solar fuels without the need of intermediate energy carriers.

Technical and non-technical needs and bottlenecks

One main scientific challenge for developing artificial photosynthesis is the use of water as a source of electrons in reductive fuel production. In Nature two water molecules are oxidized in a 4-electron process to form one molecule of oxygen. This process is efficient in the natural photosynthesis but has proven quite difficult to achieve in the artificial systems. In summary, many scientific challenges remains before artificial photosynthesis can be turned into a mature technology for producing fuels, but ramping up our efforts is necessary if we should meet the energy demands of a developing world without massive increase of carbon dioxide emissions to the atmosphere.

Opportunities, synergies and common themes

Below a number of opportunities, some remaining scientific challenges, and synergies with primarily photovoltaic research are listed. The list is not comprehensive and with the 2050 horizon in mind it should be realized that many, still unknown, opportunities are waiting to be discovered.

Solar energy is the only large scale alternative to fossil fuels. Only a fraction of a percent of the solar radiation impinging the surface of the earth is needed to be harvested to fill our energy need.

The identity of the final fuel (H_2, Methanol, other) is not important as long as it is carbon neutral.

Water is the only sensible raw material for artificial photosynthesis.

Any large scale solar energy technology must rely on earth abundant elements.

Organic molecular systems for artificial photosynthesis could be designed with high precision but are not expected to be photo-stabile enough for prolonged energy production. Hybrid inorganic/organic devices might be more reliable in this respect and more research should be done in this direction.

Self-organizing and self-repairing systems should be developed. Organic systems will be sensitive to photo damage and one possible solution to this problem is to utilize self-assembled systems in which damaged components are replaced through reversible equilibrium reactions.

One current challenge in artificial photosynthesis is the multi electron oxidation of water. In natural photosynthesis the 4-electron oxidation of water into molecular oxygen is carried out in a charge neutralized manganese cluster. Mimicry of this difficult redox reaction is still a great challenge that should be researched intensively.

Photon energy up- and down-conversion technologies should be developed. Water splitting is in principle easier with higher energy photons (UV) and if we could develop methods to up-convert the lower energy visible photons through e.g. triplet-triplet annihilation it should give access to more efficient photocatalysis. This technology is also of interest for the next generation of solar cells.

Research in artificial photosynthesis has large synergies with solar cell research. The quite detailed knowledge about light harvesting, energy migration and electron transfer reactions that has been developed within the artificial photosynthesis research community has already governed the development of photovoltaics. This is expected to become even more important in the future.

Recommendations on actions

In view of its potential to solve the future global need for energy, solar energy technologies should be given the highest priority. Research activities on solar cells and solar fuels are strongly related and developments of both fields are expected to run in parallel. Mastering the principles of light harvesting and charge separation is quite developed in molecular systems and it is now time to move into more complex, technical systems for energy production. Thus, large scale actions involving both scientists and engineers are expected to be successful. A few specific recommendations on actions are given below and combined with the scientific challenges listed in the previous paragraph these should constitute a road-map for solar energy research in Europe.

Research in artificial photosynthesis has given and will give crucial spin-off knowledge to other solar energy fields, i.e. combined actions are absolutely warranted.

Many different research directions with the common theme of developing solar fuels should be launched. In this report we have purposely used a broad definition of artificial photosynthesis. This is reasonable since, at this point, it is not known which of the different subfields (organic, biological, and inorganic) that will be developed most successfully. Most likely a combination of efforts will lead to a working device and increased knowledge in any of these subfields will govern the whole solar energy area.

3.2 Bamboo Composites for Wind Power

The role of bamboo in the development of environmentally friendly wind turbines.

The use of fibre glass reinforced resins for the construction of wind turbine blades has many drawbacks that can be solved by developing bamboo composites: harmful vapour emissions, high energy demand for the fabrication, problems to manage the destruction of the blade at the end of its life cycle. Furthermore, resins are derived form oil, hence they are a non renewable material. The wind turbine blade manufacture in EU is a market worth 2.3 bn €, while the whole wind turbine industry in EU generates 100 k jobs and 11.5 bn € turnover. The rotor represents 29% of the total cost of a turbine. Since China is already producing cheaper wind turbine blades made with bamboo, it is necessary to keep the pace and preserve the EU competitiveness in this strategic industry.

Photo 3.2.1: Example of 5-layered, vertical strips, bamboo plywood

Bamboo has many other advantages apart of the low cost and positive carbon sink.

- Fast renewable resource: max. 100 ton / ha.year, 100% usable.
- No need to plough the land , nor to replant.
- Recyclable material.
- Final use as clean biomass fuel with high thermal value.
- Big potential for jobs creation (0,5 to 1 job / ha planted).
- High capacity to absorb nitrates (2000 kg/ha.year).
- Grows on marginal or polluted lands.
- Versatile raw material for many industrial applications.
- Stabilization of slopes.
- Identification of needs (technical and non-technical).

Photo 3.2.2: Example of high density strand woven bamboo fibre composite.

Technical needs

Further research on identifying the optimum composite. The Universities of Riso and Cambridge have studied just one type of composite, while there is a wide range of materials that can be produced with this plant. Special attention should be given to researching composites made with bamboo and recycled thermoplastics. These have poorer mechanical properties, but are suitable for small power wind turbines.

Research on growing giant bamboo in Europe. Some species can resist up to -20ºC. It is an evergreen giant grass that grows continuously even in winter. It has a big potential for the nitrogen reduction in vulnerable zones, an aspect that has not been considered in the researches mentioned above.

Full genome sequencing of bamboo. The reproduction is asexual, though there is a certain genetic variability from cane to cane (they are not exact clones). Understanding how to select and improve species will lead to an increase in the biomass yield and improve the quality of the final product.

All the research has been focused on huge wind turbine blades. Research should be done on the manufacture of cheap and sustainable small wind turbines.

The machinery for processing bamboo is different from the one used in the wood industry. It is mainly low tech machinery produced in China and India. It is necessary to create an European industry of bamboo processing machinery.

Non technical needs

Funding the research.

Norms. Political intervention is necessary in three aspects.

The bamboo as denitrifying biological agent has not been considered in the EU Directive on Nitrates, leading to personal interpretations of local authorities and hampering the start up. The synergic effects of bamboo agriculture and derived industry must be supported.

There is also much ignorance and hype on the cultivation of bamboo, considered as an "alien invasive species", while Mischantum is also alien and more invasive, produces less biomass and of worse quality and in spite of that its cultivation is being promoted by many regional administrations.

Bamboo (and wood in a wider sense) is being paid more attention as a cheap biomass source than as a high quality renewable industrial material. Some kind of incentive to industrial activities that create jobs must be established, above the mere incentive to combustion of biomass. Wooden and bamboo products are the cheapest C sinks, burning biomass is not.

Synergies and complementarities with other energy technologies.

Bamboo composites can help reaching the 2050 goals for:

Automotive industry; Bamboo composites are lightweight, require little energy to be produced and present better tensile strength / cost and tensile strength / weight ratios than steel, and can potentially help to save fossil fuel imports and C emissions.

Energy saving in the construction; Bamboo composites can be used in a wide range of applications in construction, both as structural materials and as thermal and acoustic insulation.

Carbon emission savings in the construction; Buildings materials based on bamboo are carbon sinks, while bricks, concrete, plastics, tiles, glass and rock wool, aluminium and steel emit high amounts of C during their production.

Biomass energy industry; The leaves and scraps of the bamboo cane can be turned into chips or pellets for biomass boilers. The biomass productivity of giant bamboo is one of the highest of the vegetable Kingdom.

Biogas and waste-to-energy industry; The bamboo plantation is an optimum bioremediation system to treat leachates and digestates.

Recommendations to the Commission.

The dedicated expert would like to make the following recommendations on actions:

Incentives to the research and production of small wind turbines: Big turbines (P > 1 MW) are an important industrial sector, but the production of small power wind turbines can potentially create more jobs. Most of the micro-wind turbines are currently imported from China, just for the lower labour cost. So, some effort should be done in creating a separate industrial niche for small power wind turbines, which can be competitively produced in the EU with bamboo cultivated on site.

Specific economic support for start-ups that can cultivate bamboo for the nitrogen elimination in vulnerable zones and produce composites in EU and create jobs.

Funding the research of giant bamboo cultivation in Europe on large scale and measuring its growth, nitrate and carbon absorption rates in the different climates.

Removing legal voids and norm barriers that currently hamper the cultivation of giant bamboo in the EU. A clear position of the Directive on nitrates in the case of cultivation of plants that require more nitrogen that the limits established in the Directive (which was evidently written basing on the N requirements for traditional maize cultivation) is absolutely necessary.

China is producing wind turbine blades in bamboo composite. The CO2 emissions of the transport practically cancel the environmental benefits of the material

Defining the conditions of cultivation and fabrication in order to enable to consider wind turbine blades made in EU with European bamboo (and in more general sense, European bamboo made products) as a carbon sink, and hence qualify for the carbon stock exchange system.

A kind of incentive to bamboo or wooden based wind turbines blades produced with EU materials should be studied.

3.3 High Altitude Wind on-Ground Energy Generation

The Earth's atmosphere is a huge solar collector. Part of the heat released by the sun is transformed in a mechanical energy known as wind. While the solar radiation intercepted by planet Earth has been estimated in around 150,000 TW (power), tropospheric wind (wind up to 10 km of altitude) total dissipated power is estimated between 1,700 and 3,500 TeraWatt. By comparison, the whole mankind primary energy needs are estimated at approx. 16 TW (BP, Statistical Review of World Energy 2011). The problem is how to "catch" this energy and "bring it down" on the earth surface, in order to make it usable with a sufficiently high EROEI.

High altitude wind energy production technologies can be divided in two main categories: "flying" or "airborne" generation and "ground" generation. The first one collects technologies where the energy production device (alternators) are brought in altitude by an aircraft (usually a UAV) and the generated energy is brought down to the ground by mean of a cable which also works as a tether to maintain the aircraft linked to the ground. The main players adopting this layout are based in North America. In "Ground-gen" technologies energy generation is made on ground: mechanical energy is somehow collected in altitude (usually by aircrafts or "kites") and transferred through one or more lines to the on-ground alternators. The main players adopting this layout are based in Europe.

The mentioned layouts present different characteristics and consequently different needs in terms of material requirements. This report is focused on a specific "ground-gen" technology (www.kitegen.com). Other technology may have different needs: we can imagine that "flying-gen" technologies, for instance, may be particularly concerned by weight, resistance and conductivity of materials of the "cable" that transfers to the ground the energy generated on board, especially in an up-ward scale deployment. But we will limit this report on the outcomes about issues related to materials encountered within the deployment of the KiteGen project, with particular attentions to the Kitegen "Stem" 3MW generator.

The KiteGen concept is: in the air, to gather energy from the wind at an altitude of around 1,000 m, using a "kite", a semi-rigid automatically piloted high efficiency airfoil. On the ground there are heavy machinery for power generation. Connecting the two systems are high resistance lines transmitting the traction of the kite and controlling its trajectory. In the "Stem" configuration the wing pull the cables that, through a pulley system, activate the alternators on ground that produce electricity. When cables are entirely unwound, the wing is guided to a position where it looses its wind resistance and the cables are reeled in. Energy consumption of the winding phase is a minor fraction of the energy generated during the unwinding phase.

The role of materials research in emerging energy technologies

The first concept of high altitude wind energy production via the use of kites has been proposed about 30 years ago, but only some 20 years after that, material and technological developments made the concept deployable on a competitive cost based scale. After first pioneers started to work on the concept, in Europe and USA mainly, many other players started to investigate the issue. Nowadays hundreds of players are active on this field, every week somebody joining the group.

Technical and non-technical needs and bottlenecks

Alternators: Generation is made through permanent magnets torque motors. Performances are directly linked to alternator's characteristics. The use of neodymium allows alternators to reach high standards of efficiency, low weight, endurance, robustness, etc. but being a rare earth its availability may represent a bottle-neck in a development perspective. The main mining areas are China, United States, Brazil, India, Sri Lanka and Australia. Chinese government has recently imposed strategic materials controls on the element.

Drums : The drum has to be light, in order to lower the inertia of the machine but enough resistant to bear the high pressures due to the high tension line wrapped on it. In the past it has been manufactured in steel. On the present prototype it has been made in carbon fibre, but its cost is quite high and its manufacturing process (due also to the drum's dimensions of 600 x 1700 mm) does not allow to reach high levels of precision in layers and surface regularity, this can lead to vibrations (due to high speed rotational masses) and line wearing.

Take off mast (Stem) : Two masts around 20 m. length have been manufactured, one in carbon fibre, the other one in aluminium honeycomb. Like drums, masts have to be light, resistant, with a determined degree of rigidity.

Lines (ropes) : Lines represent a core element in the technology. KiteGen project could not have been developed without current HMPE fibres. Lines have to transfer kinetic power from the kite to the pulleys/drum in order to produce electricity. Friction is necessary but at the same time it has a direct impact on line's life cycle, which is directly linked to operational costs. HMPE fibres have a very high breaking strength, this allow its use for kite energy generation. High cost of HMPE lines is probably due mainly to the need of remunerate patents (which are in many cases owned by U.S. players), rather than to the cost of raw materials or manufacturing.

Moreover since the drag effect of lines reduce significantly the system's performances, developments in HMPE fibres may allow the production of lines with determined profiles without reducing breaking strength.

Another development is related to a solution (patented by Sequoia Automation) for decreasing the lines drag effect. The solution foresees a device to be added to an aerodynamically shaped line in order to maintain its orientation and inhibit fluttering. The material concern is given by the fact that during the production cycle of the generator the device may pass through pulleys and be wrapped upon drums. In order to maintain the device efficiency, its components must lose their shapes in the reeling phases and completely retaking them during "flying" phases.

Pulleys: Lines, before going onto the drums, pass first through two pulley directly linked to alternators and they have to transfer through the friction with the internal surface of the pulley's groove, the power that the alternators have to transform in electricity. The characteristics of this surface in terms of friction coefficient and durability have to be carefully trimmed in order to optimize the ratio friction/wearing that has a significant impact on system's performances.

Wing: Currently fabric/reinforced plastic kites, with inflatable struts, are used. Fabrics are mainly made in Nylon, Dacron or similar. The use of flexible materials reduces the aerodynamic performances of the wing. Recently a R&D activity has been started in order to study a semi-rigid wing, made by composite materials.

Power Electronics: The system has an energy «buffer» system based on ultracapacitors, with their fundamental advantages over electrochemical charge storage systems (up to 1 million charging cycles without significant loss of efficiency, rapid charge and discharge). Their main components are widely available materials like aluminium and carbon. Main manufacturers in USA, China, South Korea, Japan.

Opportunities, synergies and common themes

All the underneath issues represent a common theme with the other new emerging new energy production technologies. In particular as far as fibres, composite materials and power electronics, is concerned.

Recommendations on actions

From what said above the following developments in materials may be suggested:

- Alternative material based solution for high performances brushless alternators;
- Composite materials, taking in consideration their technical specs, availability, manufacturing proceedings and cost
- HMPE or equivalent high resistance / low weight fibres
- High resistance, shape-memory return attitude materials
- Electrode materials aimed to improve performances of ultracapacitors.

3.4 Low Energy Nuclear Reactions in Condensed Matter:

The study of the Fleischman & Pons Effect through Materials Science Development

The Fleischmann and Pons Effect (FPE) is the production of large amounts of heat, which could not be attributed to chemical reactions, during electrochemical loading of palladium cathodes with deuterium. Energy densities measured during excess of power are tens, hundreds, and even thousands times larger than the maximum energy associated to any known chemical process. On the basis of the present status of knowledge the large amount of energy may be ascribed to a nuclear process only. The effect takes place with deuterium and not with hydrogen; in this case the assumed mechanism is a nuclear reaction between deuterons into the palladium lattice.

The most intriguing feature of the phenomenon is the substantial lack of the expected nuclear emissions associated with the excess of power production ascribed to a deuterium-deuterium nuclear fusion process. A possible explanation is a modified nuclear decay channel, for the D-D reaction, into the condensed matter. ENEA, SRI and NRL have been involved within review programs in the US and in Italy. The main task was to demonstrate, on the basis of signals well above the measurement uncertainties and with a cross check, the existence of the excess of heat production during electrochemical loading of deuterium in palladium cathodes. The target was achieved and the existence of the effect is no longer in doubt. The complete reproducibility of the effect and the amplitude of the signals are not yet under control since this target will require the definition of the phenomenon. Recent data, in open literature, shows that, into the condensed matter (i.e. Pd, Ti, PdO), the cross section of the deuterium-deuterium fusion reaction, at low energy, is some orders of magnitude higher than the expected value. In this case the typical products of the reaction are observed but a new screening effect, in the order of several hundreds of eV, is observed.

Now in order to take into account the variety of phenomena, the discipline under investigation can be defined as Low Energy Nuclear Reactions in Condensed Matter (LENR) and Condensed Matter Nuclear Science (CMNS) .

The role of materials research in emerging energy technologies

The experimental evidence highlighted that material science is crucial for developing such an energy technology. A better control of the effect has been achieved by means of a material science approach. Material design, even if at a preliminary level, led to an improved control in the reproduction of the phenomena. The status of the material increasing the probability to observe the effect can be summarized in three points:

- The excess of power production is a D concentration threshold effect. For such a reason a proper metallurgy has been identified to enhance the deuterium mass transfer and solubility into the Pd lattice to achieve the threshold atomic ratio D/Pd = > 0.9.
- The crystal orientation (100) on the surface of the palladium cathodes was also correlated to the occurrence of the effect.
- The proper morphology, defined by means of the distribution of surface roughness is also correlated to the probability of having the effect.

These features have been identified as necessary conditions for observing the phenomenon. The evidence that identical observations of an excess of power have been conducted by different institutions by use of the palladium cathodes (belonging to the same lots of material) increased the level of attention for such an approach. Material science is the key for understanding since some material characteristics are supporting some processes and others are not. The main advantages of the LENR technology are:

- Energy source is unlimited and available everywhere.
- High power density.
- Absence of environmental impact.

Fig.3.4.1 is showing a 500 mW excess of power produced by a designed material. The plot of temperature evolution shows a bump in the increase of the electrolyte temperature correlated to the occurrence of the excess of heat production revealed by the calorimeter.

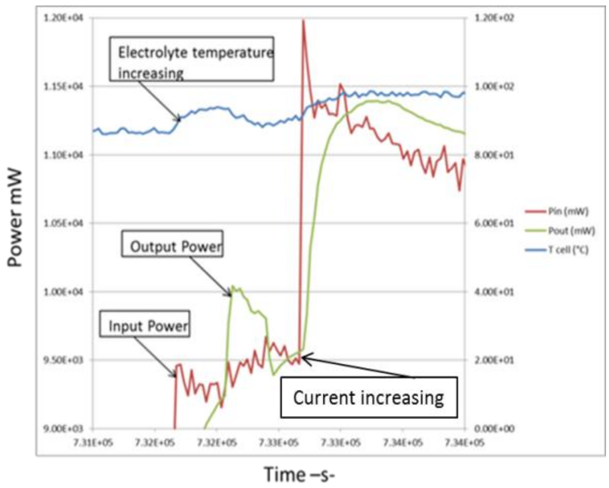

Fig. 3.4.1 500 mW excess of power given by a designed material

The delay between the excess of power burst and the electrolyte temperature increase is due to the calorimeter time constant.

Fig.3.4.2 shows the surface morphology, after etching, of a designed sample (mostly 100 oriented).

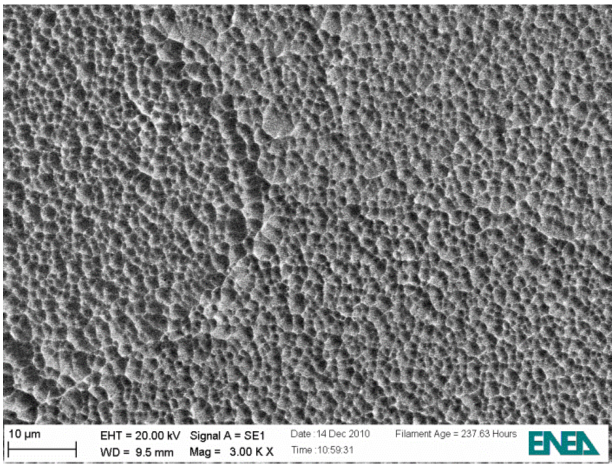

Fig. 3.4.2 Surface morphology of a designed sample

Technical and non-technical needs and bottlenecks

Technical needs:

- ENEA and NRL have identified some conditions characterizing the status of the material necessary to increase the probability for observing the effect. Further research on material science concerning the structure and the nano-structure of the materials should be carried out in order to define both the mechanism and the trigger.

- Materials characterization before, during and after the occurrence of the effect is crucial to achieve the full control of the phenomenon through its understanding. The definition of the phenomenon will open the research field to other metals or to specifically designed materials.

- Proper diagnostics and a systematic approach are required to study how the status of the material modifies both the mass transfer into the lattice and the electrochemical interface.

- X ray diffraction, SEM, TEM and AFM microscopy, XPS, Mass Spectrometry, are appropriate for investigating and characterizing the samples. Electrochemical spectroscopy is, instead, appropriate for identifying, "in situ", the status of the electrochemical interface to be correlated with both the material and the surface features able to produce the effect.

- The effect takes place only with D in Pd, therefore a search for ashes (mainly He and Tritium) have to be included into the research program as a further task in order to define the effect.

Non technical needs

The research is currently limited by economic and technical reasons, particularly in Europe. Funding the research should be the target to achieve a critical mass on a multidisciplinary level. There are only few academic institutions working on this research field and an increasing number of these institutions need to be involved, along with a network, particularly in Europe.

Opportunities, synergies and common themes

The research is multidisciplinary and involves remarkable synergies and complementarities with other technologies for energy. The study for electrodic kinetics on porous or patterned catalytic materials has a general interest for applications in the field of fuel cells in addition to other electrochemical processes. The control of the hydrogen isotopes mass transfer and solubility in metal hydrides also has an extraordinary link with hydrogen storage and palladium based membrane separation technologies. In addition it should be considered that such a technology, in perspective, may give, a heat source at about 100 °C and this opens a possible link with other emerging energy technologies such as thermoelectrical materials and thermoacustics jointly with piezoelectric materials. Common themes are catalysis, electrocatalysis, nano-structured, nano-photonic and sintering materials. Modelling and simulation, mostly based on first principles calculation, have a very important role because of the importance of developing a theoretical frame explaining the effect.

Recommendations to the Commission

- Include LENR in FP7 calls as research on materials as it has unlimited and sustainable future energy technology potential.
- Support the study in material science as a strategic approach to achieve the control of the technology.
- Support workshops, meetings, visiting exchanges in Europe and between European and US research institutions.
- Focus on the fundamental research aspects because of the synergy with other disciplines.

3.5 Piezoelectric Materials

Piezoelectric materials inter-convert mechanical and electrical energies. The same material can be used to convert mechanical vibration into electrical signal (sensor mode of operation), electrical signal into mechanical displacement or force (actuator mode of operation) or inter-convert the two types of energy (high frequency transducers in, for example, ultrasonic imaging).

However, a dedicated material is most often developed and optimized for each mode of operation. Because mechanical vibrations and noise are pervasive, there are many opportunities where piezoelectric materials can be used to collect this wasted mechanical energy and convert it into useful electrical energy.

The amount of thus created energy is relatively small but is not negligible. For example, weight of cars moving on a highway may give on the order of 2 kW/hour of electrical energy.3 This energy can be stored and used later for signalization.

The harvested energy cannot help solving world's energy needs. However it can supply energy in the cases where it is impossible, impractical or uneconomical to use batteries that must be replaced periodically.

Examples are imbedded systems in human body (harvesting mechanical energy of heart beats or blood flow), distributed surveillance systems, and inaccessible devices (e.g., far in the ocean, inhospitable environment).

Piezoelectric energy harvesting may indirectly lead to significant energy saving because energy needed for maintenance of energy supplies (fuel needed to access each component of a widely distributed system) could be greatly reduced.

Piezoelectric materials contribute to energy saving in another, more indirect, but essential way. For example, piezoelectric actuators are used for fine control of fuel injection in automobile engines, leading to significant reduction in fuel consumption. Other examples are piezoelectric pressure sensors and transducers for structural health monitoring in fossil-fuel and nuclear power plants. Piezoelectric actuators may be used for "smart" control of geometry of blades in wind turbines (more efficient harvesting of wind energy) or airplane wings (saving on fuel).

The most widely used piezoelectric materials are lead-based ceramics,

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[3] Innowattech, Israel National Road Company, and Technion ; Green Car Reports

Pb(Zr,Ti)O3. Polymers, polymer-ceramics composites, single crystals, thin films and lately nanowires are also used or are being intensively investigated as sensors, actuators and for energy harvesting.

The role of materials research in emerging energy technologies

Materials research has a key role in application of piezoelectric materials for energy harvesting and for other energy-related fields. Materials research can be linked to the following activities:

Development of new compositions / new materials:

New materials are needed for biocompatible systems, operation under extreme conditions (corrosive environment, high temperatures, low frequencies, fatigue during prolonged use), and nano-scale applications.

Materials research is essential to find replacement for today's most widely used piezoelectric material, Pb(Zr,Ti)O3, which contains 60% in weight of lead (Pb).

In fact, the present EU legislation states that as soon as suitable alternatives are found, all new piezoelectric devices will have to use active piezoelectric elements made of lead-free piezoelectrics. This includes millions of piezoelectric pieces used in applications as diverse as buzzers in watches, fuel-injectors, and medical ultrasonic imaging probes.

For new energy harvesting devices the future is almost certainly in lead-free piezoelectric compositions that yet need to be developed. Development of new, high-performance lead-free compositions is one of the biggest challenges of materials science.

Specific issues related to size reduction (down to nanosize):

The size reduction often entails degradation of performance due to several factors, including fabrication problems, because of coupling of active material to a substrate and change of surface/volume ratio. These issues most often can be solved only by engineering materials with adequate properties to compensate for possible reduction.

Tailoring of piezoelectric properties for specific applications:

The origin of electro-mechanical coupling is not completely understood even in materials that have been used for over 50 years, and certainly not on nanoscale, in new lead-free materials, and in composites, all of which are to be used in energy harvesting systems.

Technical and non-technical needs and bottlenecks

The needs and bottlenecks are closely related to the materials research issues.

Presently the most important problem is development of new lead-free piezoelectric materials and understanding of different contributions to the piezoelectric effect and electro-mechanical coupling in general (for example, in flexoelectricity). Development of high performance lead-free piezoelectric materials is both scientifically and technologically one of the most challenging problems facing the piezoelectric research community and industry.

At the beginning of development of new materials economic issues are an important barrier because the cost of development of new materials tends to be high; however, potential benefits are considerable (e.g., lower cost of disposal for lead free materials, positive contribution to the health of the environment.).

Another bottleneck is a supply of qualified materials science engineers. A possible solution is to create them through EU Initial Training Networks dedicated to piezoelectric materials and their applications.

Opportunities, synergies and common themes

Energy harvesting systems require handling of small signals (the problem commonly encountered in modern electronics), storage of small amounts of charge, operation under corrosive and extreme conditions, and miniaturisation of elements down to nano-scale.

Other piezoelectric devices share with energy harvesting need for operation under extreme conditions and lead-free variants of the active materials.

Recommendations on actions

There is a strong perception of the decreasing number of opportunities to get funding in FP programs for proposals that include a very strong component of materials research in “classical” systems (e.g., ceramics vs. nanosystems) or “classical” materials science (structure-property relations, processing issues, development of new bulk materials (crystals, ceramics)).

Materials research should be encouraged in general and not only those components that are related to currently fashionable topics.

3.6 Salinity Gradients & Osmotic Power

The use of salinity gradient renewable energy is a one of the energy resources classified as ocean energy. The IEA estimated the annual potential of this resource around 2000 TWh, roughly 10% of that resource is located in Europe. There are several technologies under development (only one demo prototype) to extract energy from salt deposits and brines, as well as the diluted salt in sea water mixing with the rivers. Membrane based Osmotic Power (PRO and RED) are the two most promising solutions for Osmotic Power generation, and both depend on the use of advance materials for their core element. There are other technologies:

- Capacitive Technologies generate electrical power from a "supercapacitor" alternatively polarised in fresh/salty water. Dielectric properties changes increase voltage for the same charge.
- In Hydrocratic generators, fresh water is introduced into the sea-bottom. Then, in contact with sea water, enters a vertical tube, to form a higher volume mixture flow that moves a turbine.
- Use of Vapour Pressure Differences between high and low salinity water, could eliminate the major problems associated with membranes conversion methods using techniques being developed for ocean thermal energy conversion.

The role of materials in the development of salinity gradient energy technologies.

In Pressure Retarded Osmosis (PRO), seawater is pumped into a pressure chamber that is at a pressure lower than the difference between the pressures of saline water and fresh water. Freshwater is also pumped into the pressure chamber through a membrane, which can increase both the volume and pressure of the chamber. As the pressure differences are compensated, excess water is used to generate electricity in a turbine. The flow of water from one chamber to the other is driven by the osmotic pressure that forces water transfer through semi-permeable membrane from a tank with diluted solution into a more concentrated solution tank. This process is controlled by the pressure in the concentrated solution (Approx. 250 m for sea water).

Reversed Electrodialysis (RED): In Reverse Electro-Dialysis, dilute and concentrated solutions are used in a module of several Cation and Anion Exchange Membranes (CEM and AEM respectively), between two electrodes for generating electricity. The compartments between the membranes contain dilute and concentrated solutions, while the membranes allow selective passage of ions and retain water. The ions move from the concentrated to the dilute solution. The flow of ions will continue until equilibrium is reached. To generate voltage enough to exceed the electrode reaction potentials several cells are stacked. A voltage is created across each of the membranes, so the overall output of the setup is proportional to the number of cells. This method is less sensitive to fouling and less pre-treatment is needed.

Identification of needs (technical and non-technical)

Current RED energy generation performance is max. 1.2 W/m2 with commercial ion exchange membranes and uncharged spacers. The energy output is reciprocally proportional to the resistance of the total stack. The stack consists of many cell pairs. Each pair has an anion exchange membrane, a seawater compartment spacer, a cation exchange membrane, and a river compartment spacer.

It has been calculated that 3 W/m2 is required to make salinity gradient energy economically feasible. To achieve this target, the total stack resistance has to be reduced drastically by lowering the sea and river compartment thickness, reducing the high resistance of the spacers and membranes in a stack and new materials have to be developed with super ion conductive properties:

Spacer integrated membranes (both spacers as membranes are both ion conductive and meet all ion exchange membrane properties (high counter-ion conductivity, high co-ion rejection, good strength, etc). Novel ion-conductive materials have to be developed, which can be applied in a fast, continuous, membrane manufacturing process. These materials should also be able to create an ion-conductive 3D structure. Special geometry is required to obtain good mixing and to prevent high pumping pressure. These materials should have the potential to meet the low cost price targets. Membrane integrated spacer: A thin dense ion exchange membrane film (1-10 micron) made on top of an open conductive spacer (additional requirements for the film strength and flexibility).

PRO membranes will need to pass from the current 1W/m2 to 5 W/m2 and it is not inconceivable hat a breakthrough in this development can also provide an increased efficiency of desalination:

- Membranes adapted specifically to Pressure Retarded Osmosis energy generation. Reversed Osmosis ones have high water permeability and an often good salt restraint value, but have dense support structure besides the film, PRO membranes will need also very little resistance to water flows, but it´s less restricted in salt rejection and pressure resistance. Membranes will be made be made from CA (cellulose acetate) or TFC (thin film composite). In order to avoid concentration polarization, that reduces the effective osmotic pressure, it will integrate fluid dynamics solutions, like turbulence and vortices generation structures, in the supporting material near the membrane.

- Development of optimal membrane modules will also be needed. The current desalination spiral elements (spiral wound) for flat membranes, and hollow fibre modules (used for kidney and blood-cleaning and pre-treatment of water) should not be optimal for PRO power. There is a need to develop larger modules (cost and footprint of facilities), which also has lower pressure drop than current modules to allow reducing the operational costs of installation and land use of the system.

Other Elements improvements will help commercial exploitation of salinity gradient energy. There is a need for pressure exchangers adapted to this application (similar to today's solutions in desalination but optimized for lower pressure operation, 10-15 bars). There is also a need for low cost water filtering to reduce pollution (fouling) of the membrane (low installation cost, low operating costs and low pumping energy consumption). Additionally antifouling and corrosion protection treatments or materials for auxiliary elements will be another improvement topic for research.

Synergies and complementarities with other energy technologies

The main synergy of will be between the materials research for RED and PRO membranes as well as materials for other auxiliary elements (Pressure exchangers, Light and robust, scaled formations free, pressure vessels and tubes, Pumps for Redox solutions,…), and the material used for Forward Osmosis and Reversed Osmosis Desalination and Electrodialysis. Membranes for PRO can be used in batteries, as well as RED ones in PEM Fuel Cells.

There are also important synergies with other energy technologies material developments. There will be synergies between batteries and supercapacitor technologies developments for the development of nanoporous carbon electrode materials that could be used in Salinity gradient Capacitive Technologies, or Electrodes for RED. Also there will be full system synergy development with open cycle OTEC for vapour pressure differences methods (vacuum systems, turbine, collectors, etc...) if this technology is develop in the near future. Hydrocratic solutions can benefit from the development of ducted tidal turbines(composite based), placed in vertical as well as long plastic tubes future developments used for example in OTEC, and wave energy PTO using sea water can benefit of pumping systems materials and sea water pressure turbines.

Recommendations to the Commission

The dedicated experts would like to make the following recommendations*:*

- Material and process technology development is key to success for salinity gradient energy. Support R&D collaboration between material, process, membrane and energy generation partners.
- Promote the research of membranes solutions and auxiliary systems materials (low cost plastics, composite, ceramics bearings, ...) that can benefit several energy technologies.
- Increase support to research of specific PRO and RED membranes. Novel materials are required to make super-ion conductive membrane integrated spacer for commercial maturity in 2050.
- Evaluation of recyclability of used materials, full LCA and cost analysis for production, operation and recycling of used elements, especially membranes, due to large amount of elements foreseen.
- Demonstration projects of suitable technologies for near to market promising concepts, once R&D phases are advancing.

3.7. Thermoacoustic Technology

Thermoacoustics (TA) is an emerging generic cross-cutting energy conversion technology in which compression, expansion and displacement of the working gas is performed by an acoustic wave instead of by pistons and displacers. It can be applied in a vast number of applications to convert heat to acoustic power (engine) or and use this acoustic power to pump heat to high or low temperature levels (heat driven heat pump). Acoustic power generated from heat can also be converted with high efficiency to electricity and vice versa of which the principle is shown in figure 3.7.1

The main advantages of this technology can be summarized as follows:

- High thermodynamic efficiency.
- Working fluid could be air or an inert gas like helium (no environmental risks).
- Silent operation.
- No moving parts in the thermodynamic cycle,
- External combustion machine, can work with any heat source.
- Can also work with small temperature gradients (e.g. solar or waste heat).
- Both TA-engine and TA-heat pump can operate over a large temperature range
- Large freedom of implementation

The role of materials in the development of TA technology.

The performance of TA devices is currently limited by some technical and economic factors:

In order to optimize the output power over weight ratio, the working gas needs to be at high mean pressure (10 to 50 bar). This, and the strong thermal gradient across the regenerator, leads to choose steel as the usual construction material. Nevertheless, the high conductivity of metals causes thermal losses. Probably a fibre based sintered

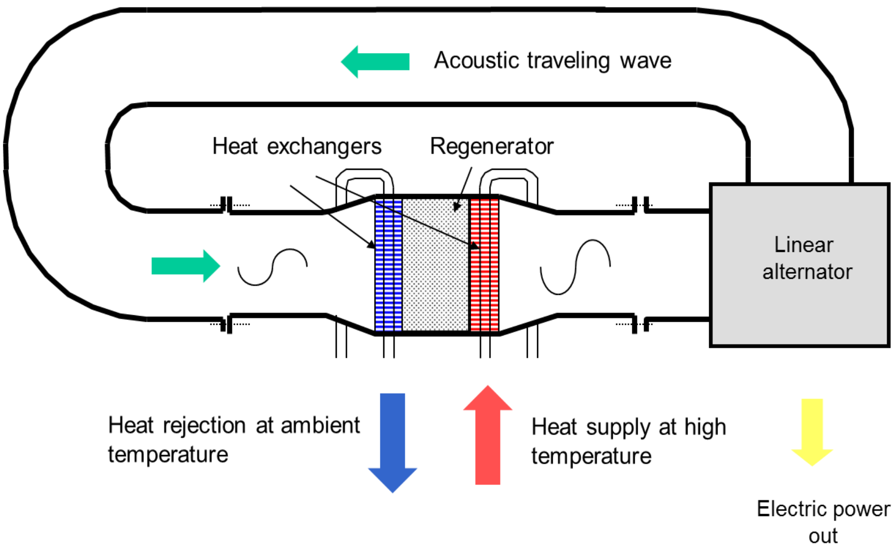

Figure 3.7.1 Basis configuration of a thermoacoustic system converting heat into electricity.

ceramic material will make TA more efficient and cost effective.

The core of the TA device is the stack or regenerator. A regenerator should have properties that are difficult to reach simultaneously: low thermal conductivity but high specific heat, smooth surface to reduce viscous losses and high volume porosity (60-80%) and pores or channel diameters in the order of 30-100 µm.

Temperature drop across the in- and output heat exchangers strongly affect the performance, in particular in heat pumps and low temperature driven engines. Optimal heat exchangers in thermoacoustic applications need to have a similar channel dimensions as the regenerator. Tubes cladded with metal foam of carbon tubes could be an option here.

For the conversion of acoustic to electric energy a linear generator is used. This type of alternators requires large NdFeB magnets resulting in availability, high cost, and vibration problems. Other conversion devices or materials therefore could be potentially interesting: electret membranes, piezoelectric ceramics.

In some configurations streaming suppression requires insertion of a thin membrane. This membrane must withstand fatigue and should have high durability.

Identification of needs (technical and non-technical).

Technical needs:

Research on a high tensile strength material with low thermal conductivity to replace steel.

Goal: reduce weight and static thermal losses by conductivity and improve the specific output power (Watt/kg) and be compliant to the PED.

Stack or regenerator. Research on fine structures with high heat capacity and heat transfer and low heat conduction and viscous loss. In the end these materials or structures should be available at low cost per unit volume.

Goal: further improve cycle efficiency and enable mass production.

Heat exchangers: Research on structures with high fluid and gas sided heat transfer and heat conduction and low viscous loss.

Goal: Reducing temperature loss and enable mass production.

Linear alternator. Research on magnetic materials and design optimization. Research on piezoelectric, capacitor and electret materials.
Goal: increase overall efficiency, increase power level (> 1kW) and reduce cost per kW.

Flexible materials for membranes

Research and development on the mentioned issues should pay attention as well on reduction of (production) cost of the individual components and materials in order to make the claimed potential low investment per unit output power becomes true.

Non-technical needs:

Funding the research.

Create awareness on this technology in the related industries (Automotive, heat pumps, air conditioning, geothermal, biomass boilers, biogas plants, solar concentrators…).

Political support.

Include TA technology in the study programs of engineering.

Some kind of bonus or fiscal incentives to companies investing in TA research or waste heat recovery with TA technology.

Funding start-ups that can bring this technology to the market.

Norms: TA devices are not considered anywhere, leaving a kind of legal void.

Synergies and complementarities with other energy technologies.

The industry and energy sectors in which TA technology can help reaching the 2050 goals are:

- Automotive and transports in general.
- Co- and tri-generation with biomass and natural gas (domestic and large scale)
- Geothermal applications (both low and high enthalpy).
- Waste heat recovery in the industry.
- Solar powered cooling or air-conditioning.
- Co- and tri-generation with solar concentrators.
- Upgrading of biogas (TA separation of gas mixtures, liquefaction).
- Low cost liquefaction of CH4 and H2 for storage and distribution

Recommendations to the Commission.

The dedicated experts would like to make the following recommendations:

Include and support research on thermoacoustics as a generic applicable, cross-cutting energy conversion technology in FP7 and future calls.

Organize a series of congresses on the subject, academic-industrial exchange missions and other dissemination activities.

Bonus or other Government incentives on solar cooling, cogeneration or renewable source generation in general with TA machines.

Specific economic support for start-ups that can produce in EU, create jobs and bring TA technology to the market in short term.

Removing eventual legal voids and norm barriers that can hamper the entry to the market of TA technology (needs a specific research).

3.8 Thermoelectric generators

The EU Heads of State and Government set a series of demanding climate and energy targets to be met by 2020, known as the "20-20-20" targets to reduce the CO2 emissions, to increase the use of renewable energy source, to decrease the use of primary energy source. Up to now, the way the world's overall energy resources have been consumed and transformed in other more practical energy forms (such as electricity) is mostly via thermal energy. After utilization, at mean efficiency of about 40% [1], the major part of the thermal energy produced is rejected in the atmosphere and oceans as waste heat. Hot gases (T>600°C) can typically produce electricity via heat engine (thermodynamic cycle), however it becomes less economically advantageous for hot gases and warm fluids in the low and medium (RT<T<600°C) temperature ranges. Thermoelectric generators (TEGs) are an alternative to transform part of this waste heat and natural heat source in the RT-600°C into electricity. If via these TEGs, we could recover a mere 1% of the primary energy contained in coal, natural gas, oil, and nuclear energy that we consume in the UE-27, we would get 191 TWh/y of electricity [2]. Hence, each percent of primary energy recovered can be sold 19.1 billion Euros per year (10 Euro/10^5Wh). Also, if one could improve by 1% the efficiency of all engines thanks to TEGs implemented in vehicles, the CO_2 emission would reduce by 42 millions tons CO_2/year [3]. Those numbers imply a massive implementation of TEG co-generators in Europe.

The role of materials research in emerging energy technologies

Thermoelectric generators (TEGs) are semiconductor devices that generate electrical power from a temperature gradient (ΔT). TEGs are composed of two semiconductor legs (one p-type, one n-type) connected electrically in series and thermally in parallel. The efficiency of the TEGs is directly related to the material properties (thermal conductivity K, electrical conductivity σ and Seebeck coefficient S)

$$ZT = \frac{\sigma S^2 T}{k}$$

regrouped in the so-called dimensionless figure-of-merit ZT defined at the temperature T.

The introduction of nanostructures in thermoelectric materials has led to significant improvement of their properties. Up to now, one of the main strategies has been to decrease the thermal conductivity via phonon scattering. More effort is required for (i) understanding of the interplay between thermal, electrical and entropy transports; (ii) controlling nano-structures that can be used in actual devices; and (iii) improvements in materials for soldering, ceramic plates, packaging, etc. Some interesting combinations of atoms have been considered to make cheap and less toxic TE materials (e.g. Mg_2Si, $CoSb_3$, ZnSb, ZnO, other oxides), but more explorative work is needed to consider new class of materials. Also the understanding of the fundamentals, such as the effect of interfaces, crystallinity, doping, etc on the thermoelectric properties is needed. Materials obtained directly from solution-based methods, like sol-gel or electrodeposition [4], are advantageous since they ensure scalability at the industrial level (competitive price). New reliable and cheap techniques to sinter and compact the nanostructured material into a nanostructured bulk material [5] appear crucial. There are also early results that indicate that TE material could eventually be created directly from solution processes, without even the need for sintering or compacting (e.g. conducting polymers [6]). Beside semiconductor materials, another completely different strategy barely explored is to consider an electrochemical reaction for the thermoelectric power generation

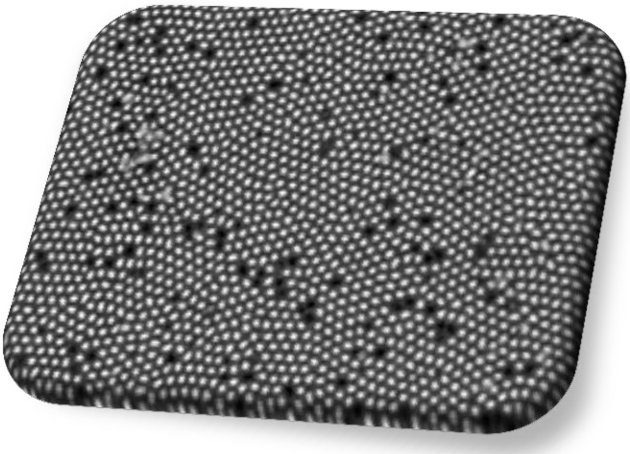

Figure 3.8.1: Array of Bi_2Te_3 45 µm-long nanowires embedded in porous alumina obtained by electro deposition.

(thermo-electrochemical cells [7]).

Technical and non-technical needs and bottlenecks

Technical needs

A massive implementation of TEGs put requirements on the thermoelectric (TE) materials and thermoelectric generators. TE materials must be: efficient, stable, environmentally friendly, composed of elements abundant in nature, and synthesized with a scalable method. Also, low-cost manufacturing process of the TEGs must be addressed. Nowadays manufacturing constitutes 50% of the cost for a TEG. At the moment, such materials and manufacturing method do not exist or they are not explored sufficiently and constitute the main bottle neck for using this technology.

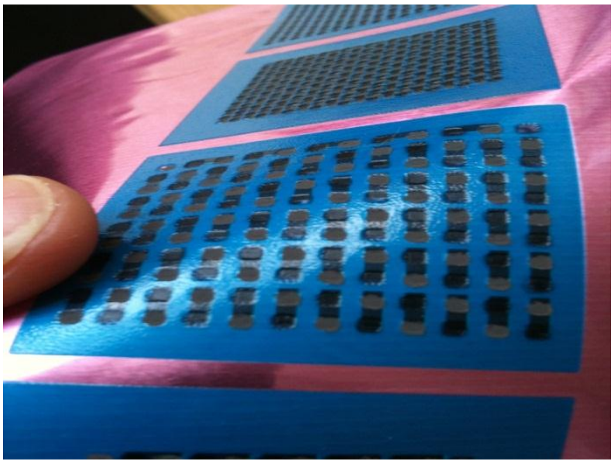

Figure 3.8.2 Open structure of a thermoelectric generator based on conducting polymer legs filling cavities obtained by printed technology.

Bottle necks

Several publications with high ZT values have been published but not yet reproduced. This indicates that thermoelectric properties are not simple to measure accurately (metrology, standardisation).

Some high ZT materials possess complex nanostructures fabricated with sophisticated physical methods difficult to scale up. Sometime even thick films (>10 µm) cannot be decently obtained.

TE materials for low temperature range (T<250°C) are based on Bi_2Te_3 alloys. Those alloys are toxic for the environment, composed of non-abundant elements. There is no recycling path for those materials.

No cost effective strategy to manufacture thermoelectric modules.

The underlying physics for thermoelectric properties are not understood enough. Theoretical modelling cannot be used effectively to predict the thermoelectric properties.

Opportunities, synergies and common themes

Compared to other intermittent energy alternatives, TEGs can provide constant sources of electricity. TEGs have no mechanical parts that can wear out. TEGs need little maintenance and are compact compared to heat engines. For low temperature waste heat and natural heat sources, there is no competing technology, thus a huge opportunity.

Thin and flexible TEGs are envisaged as power sources for medical sensors sending information on internet to the hospital. TEGs can power device for point-of-care (or home-) diagnostics to reduce cost for the health care.

Low temperature TE materials are used also in Peltier coolers. Large area, flexible coolers constitute new business opportunities for the packaging industry and the medical care.

Recommendations on actions

The dedicated experts would like to make the following recommendations on actions: "To focus on fundamental and explorative research to create: (i) efficient, abundant, scalable and non-toxic TE materials working in the mid- and low-temperature range [RT-600°C]; and (i) low-cost manufacturing methods to be able to functionalize large areas and produce electricity from large volume of hot fluids coming from waste heat and natural heat sources."

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3.9 Structural Power Composites

The world is becoming more "electric" with devices such as batteries and supercapacitors now a vital part of everyday life. Not only is there the increasing electrification of transport, portable devices and homes, but there is also the need for better storage of electrical energy to overcome the intermittency of renewable power generation. Small scale energy storage systems are vital, one example is the electric/hybrid car, others include diesel-electric trains, urban buses, load-levelling in houses, uninterruptable power supplies and mobile applications. In many applications, considerable fuel savings (~40%) have been achieved by using super-capacitors as energy buffers. Crucial to understanding the requirements for energy storage systems is the fundamental interplay between four parameters; energy density, power density, longevity and cost. Fundamentally paired with the drive for better energy storage is the need to reduce the demands on these systems as a whole. For a city car 98% of the expended energy is associated with the vehicle weight (i.e. only 2% is aerodynamic drag). Therefore, rather than increasing the capacity of the power source, halving the weight of the car will almost halve the energy required. So it has been recognised that adopting composite materials will give savings, making fully electric vehicles with a reasonable endurance achievable. Considerable further savings can be made by utilising multifunctional composites; materials in which the constituents simultaneously and synergistically undertake two roles (in the instance of structural power; electrical energy storage whilst carrying mechanical load). This should not be confused with multifunctional structures, in which distinct components are packaged together to minimise mass (e.g. embedding thin-film batteries within a laminate).

Role of Materials Research in Structural Power Development

The development of structural power materials is challenging, but the benefits could be considerable. If the technical hurdles are surmounted, they could lead to huge weight savings in a range of applications; essentially, materials currently utilised in a structural capacity will provide the electrical energy, potentially dispensing of the need for a conventional energy source at all. It should be remembered that this is a spectrum of materials; by modifying the relative proportion of the constituents, the relative dominance of the electrical and mechanical characteristics can be tailored to match the application. Polymer composites have now reached a level of maturity at which adventurous and novel configurations can be considered. We now have an unprecedented ability to synthesise, tailor and fabricate composites, as well as an understanding on modelling materials and their microstructures. The laminated architecture mirrors the electrode configuration of conventional electrical devices.

The US Army Research Labs have made considerable advances in developing structural capacitors, batteries and fuel cells whilst Imperial College has been working on structural supercapacitors for hybrid vehicles (FP7 STORAGE). Similarly, SWEREA SICOMP (Sweden) and BAE Systems have been developed structural batteries. Considering the composite constituents, there have been significant developments in the fibre reinforcements. For batteries the focus has been to maximise the ion percolation into the fibres whilst for supercapacitors the approach has been to increase the fibre electrochemical surface area without compromising mechanical properties. For the matrix, the approach has been to nanostructure the constituents to ensure structural robustness whilst allowing ion migration. These requirements are mutually opposed, which has made matrix development very challenging. Finally, the interface between the reinforcement and matrix is vital to both electrical and mechanical performance, but is as yet poorly understood.

Technical and Non-Technical Needs and Bottlenecks

There some critical aspects need to be addressed to reach maturity. Most notably;

Power Density; Low power density is a fundamental issue and is associated with the relatively low conductivity of the electrodes (carbon fibres) and the rigid matrix (consequently inhibiting ion migration). Without reaching power densities near those of conventional devices (~1kW/kg), these materials will not mature.

Matrix dominated mechanical properties; As with conventional polymer composites, the mechanical performance of these materials is dictated by properties such as delamination resistance. The electrical functionality of the matrices, and conflicting demands on the fibre/matrix interface, further depresses these properties.

Cost and fabrication; For structural power materials, components will probably need to be fabricated in a moisture free environment (<50ppm), requiring investment in new infrastructure and processing methodologies. Furthermore, these materials are not all amenable to finishing processes (e.g. drilling) that can lead to short-circuiting of the electrodes and thus loss of electrical performance.

Ownership Issues; given the immature nature of structural power materials, issues such as durability, repair and recycling have not yet been considered.

Opportunities, Synergies and Common Themes

Although the research to date has focussed on high-performance applications (e.g. aerospace), one key strengths of these materials is the wide range of potential applications. As performance improves, these opportunities have sparked interest from sectors such as mobile devices, infrastructure and mass transit, and also for energy harvesting applications. The influence of mechanical deformation on the electrical characteristics may provide a route to convert applied strain energy (such as flutter in wings) into electrical energy.

The highly multifunctional nature of this topic, bringing together two very different fields (electrochemical and structural materials) is providing fertile ground for the development of new technologies. For instance, it has led to the synthesis of novel material architectures, stimulating the development of new monofunctional electrical and mechanical materials. Furthermore, the research is providing very different solutions to current issues associated with conventional composites, such as improved electrical conductivity. Finally, generic matrix developments and are anticipated to feed into conventional electrochemical research.

Recommendations for Actions

The dedicated experts would like to make the following recommendations*:*

Fundamental Science; current research is goal driven, focussing on increasing energy density, and little effort so far has been expended on the fundamental science. In particular, the characteristics of the fibre/matrix interface at which mechanical load transfer and ion migration must simultaneously occur, needs to be studied.

New Matrix Chemistries; underpinning the development of structural power materials are the multifunctional matrices which are required to have both mechanical rigidity and allow ion migration. Current methodologies focus on nano-structuring to allow the benefits of the individual constituents to be imbued onto the material. These nanostructured materials need to be assembled with considerably more specific control than has been achieved to date. Alternative approaches may be identified for this critical aspect of the material development.

Integration of Manufacturing Methods; the highly multidisciplinary nature of structural power materials means that component fabrication will draw upon very diverse technologies, such as making structural components in extremely dry processing conditions. To bring these materials into sectors such as automotive, marine and infrastructure, new methodologies for fabrication need to be developed.

Design and Engineering Methodologies; since these materials are truly multifunctional, the current approach for component design (i.e. optimisation of the individual components) needs revision. For a particular application, the relative weighting of mechanical performance and electrical energy demands need to identified, and then approaches devised to efficiently utilise these materials. This process is further complicated by the need to consider ownership issues.

In summary, structural power composites are a paradigm shift for energy materials, and have the potential to make a considerable difference to how we store and deliver energy in 2050.

3. 10 Materials and Design

This section provides a focus on Materials & Design and specifically it provides a summary on the role of materials in the development of energy technologies, Identification of needs (technical and non-technical), Synergies and complementarities with other energy technologies & Recommendations to the Commission.

This section will look at the 2050 horizon, and look to answer: *what actions should start now in order to reach the commercial maturity that one would expect by 2050?*

The Commission has stated a 2050 objective for the EU of a secure, competitive and low-carbon energy system. There are a variety of potential scenarios in terms of energy mix that will be deployed by 2050, which will be important in achieving Europe's long-term decarbonisation goal. In addition to decarbonisation, the effects of 'peak' conventional energy along with the implications of a rising middle class in emerging economies in a 10 billion world will have made the need to have a wider energy mix vital.

Whilst much of the other contributions in this report have a specific energy solutions focus this section will be wider in scope. It will look at the phenomena of critical materials and the role of product design in mitigating this challenge.

The role of materials in the development of energy technologies.

The Strategic Energy Technology (SET) Plan sets out a medium term strategy valid across all sectors. The key energy technologies are as follows:

Wind; solar; bio energy; smart grids; nuclear fission and CCS and with development and demonstration technologies being;

Second generation biofuels, smart grids, smart cities and intelligent networks, Carbon Capture and Storage, electricity storage and electro-mobility, next generation nuclear, renewable heating and cooling.

The main issue for most of these technologies is the resources required in not only the immediate future – which will be significant, but also over the longer timeframe . (COM 639, 2010)

The Commission has stated that there will be significant research into energy materials, which will allow the EU energy sector to stay competitive despite dwindling 'rare earth' resources. The challenge is that the transition from conventional energy to the energy system outlined above will place unviable pressure on the dwindling 'rare earth' resources. Of note this 'materials criticality' aspect is currently sometimes completely omitted from the discussion.

The question is not only what technologies can be developed (along with the corresponding material demand) but in what timeframes. In other words - not only what, but also, when. This is because the widespread deployment of clean energy technologies could lead to imbalances of supply and demand of, for example, rare earth elements (REEs) along with other critical materials. To assess these risks, there needs to be a comparison the projected levels of demand for each key material with projected levels of supply.

The key materials list varies with which country and or region one looks at. The sum total of the list represents a significant proportion of the periodic table of elements. The EU has published a list in the document Critical raw materials for the EU, Report of the Ad-hoc Working Group on defining critical raw materials (*European Commission, June 2010)*

Identification of needs (technical and non-technical)

This question leads to a complex response. The Critical raw materials for

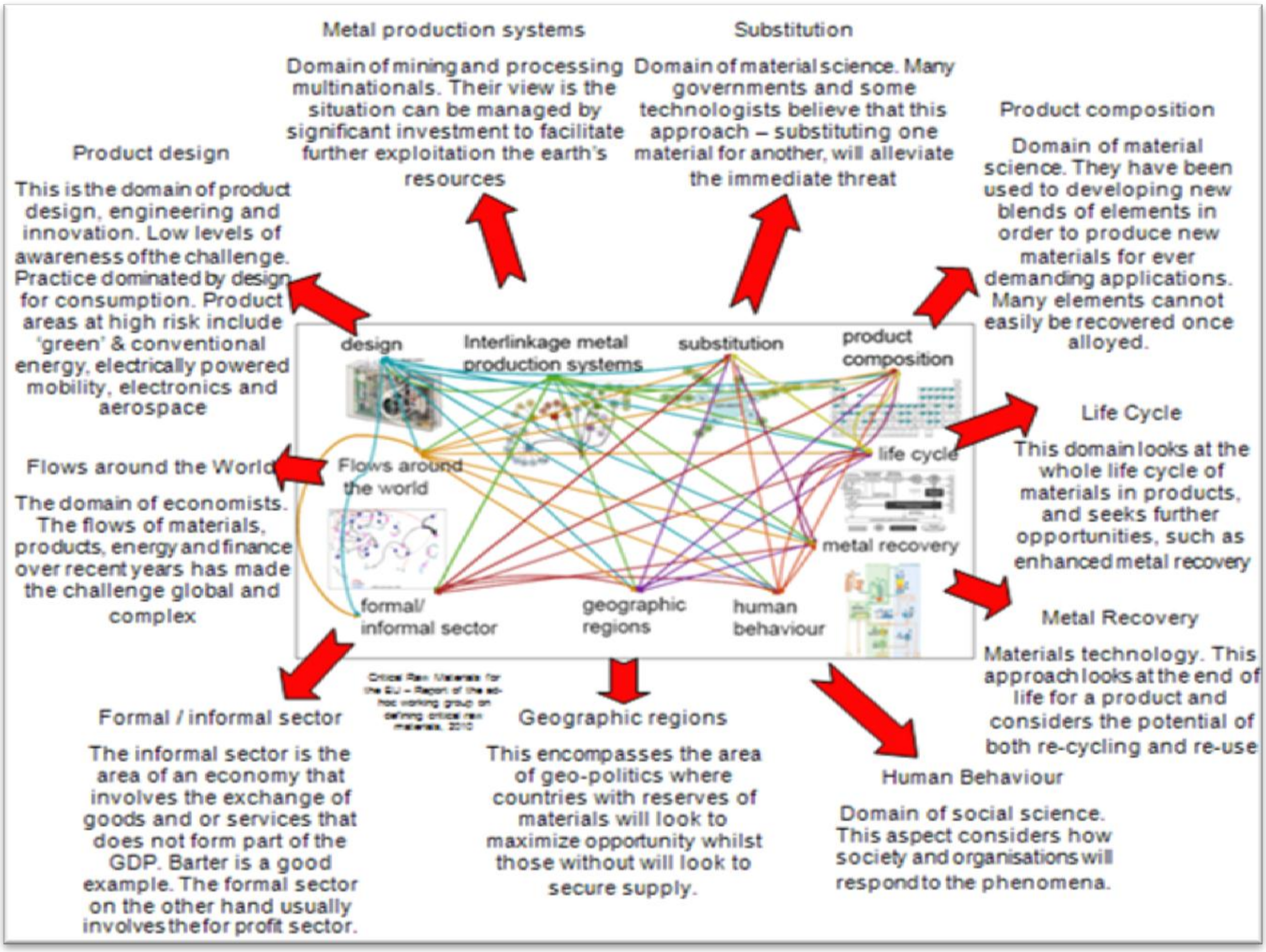

Figure 3.10.1 Visual representation of the challenges and needs.

the EU document contained a diagram below, figure 3.10.1, which has been expanded to show challenges and therefore needs (Peck, et al, 2010):

What is notable in figure 3.10.1 is that the product designers are often unaware of the materials that are needed to manufacture the prefabricated assemblies they use (Brehmer et al, 2011). Also, the complex nature of the phenomenon as represented in figure 3.10.1 may require the use of advanced computer based modelling.

Synergies and complementarities with other energy technologies

The synergies and complementarities with other energy technologies, with respect to materials for energy in 2050, is that they are, to a varying degree, dependent on critical materials. This of course could (will have to) change but the current knowledge base is poor and the scenarios are dynamic and complex. As stated by the US dept. of energy: The projected energy transition will see a substantial increase in the demand for some critical materials with limited basic availability and limited diversity of supply over the medium term. Left unaddressed, this reality will severely hamper the United States' ability to transition to a clean energy economy.(Critical Materials Strategy, 2010). The same applies to Europe.

Recommendations to the Commission

The dedicated expert would like to make the following recommendations*:*

There is no widely accepted definition for materials criticality. Europe needs a common terminology and shared language on the topic.

The Commission should ensure that materials criticality thinking is included in all relevant publications. The range of EC policy proposals on critical materials are sound but a focus on time frames needs further work – this should be addressed.

The field of product design does not currently address the topic widely – this must urgently change. The Commission can support this change.

There needs to be a promotion by the Commission of multi-disciplinary activity – for example research by joint teams of material scientists and product designers.

The current research activity has a North Western Europe focus (i.e. UK, NL, D). With the support of the Commission this national activity needs to become more coordinated and widespread.

The challenge is global and links to third countries needs to be developed in relation to the topic. The Commission can facilitate such links.

References:

- COM(2010) 639, Energy 2020 A strategy for competitive, sustainable and secure energy, European Commission, 2010.
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- Peck, D, Diederen A.M., Bakker C., Materials Scarcity? – demarcation of the etymology for the emerging challenge, Poster 3D-002, ERSCP-EMSU conference, Delft, The Netherlands, 2010.
- Brehmer M, Smulders F.E.H.M., Peck D.P, Critical Materials: A research agenda for product development, IASDR, 4th World Conference on Design Research, Delft, 2011

Critical Materials Strategy, US Department of Energy, 2010

Chapter 4

The role of materials in the development of energy technologies

Given the range of technologies and topics there was no simple statement of the role of the wide range of materials under consideration. The expert's views can be summarised as follows;

Materials for artificial photosynthesis would give a direct way of producing solar fuels without the need of intermediate energy carriers; however, no functioning artificial photosynthetic device has yet reached the level of maturity needed to be useful outside laboratories.

Wind turbine blades have many drawbacks that can be solved by developing bamboo composites and Bamboo has many other advantages apart of the low cost and positive carbon sink.

The first concept of high altitude wind energy production via the use of kites has been proposed about 30 years ago, but some 20 years after that, material and technological developments made the concept deployable on a competitive cost based scale.

The main advantages of the LENR technology are that the energy source is unlimited and available everywhere, gives high power density and it has a comparative absence of environmental impact.

New materials are needed for biocompatible systems, operation under extreme conditions (corrosive environment, high temperatures, low frequencies, fatigue during prolonged use), and nano-scale applications. Materials research is essential to find replacement for today's most widely used piezoelectric material, contains 60% in weight of lead (Pb). The origin of electro-mechanical coupling is a challenge even in materials that have been used for over 50 years, and certainly so on the nanoscale, in new lead-free materials, and in composites.

In Pressure Retarded Osmosis (PRO), seawater is pumped into a pressure chamber that is at a pressure lower than the difference between the pressures of saline water and fresh water. The flow of water from one chamber to the other is driven by the osmotic pressure that forces water transfer through semi-permeable membrane from a tank with diluted solution into a more concentrated solution tank.

Reversed Electrodialysis (RED): In Reverse Electro-Dialysis, dilute and concentrated solutions are used in a module of several Cation and Anion Exchange Membranes (CEM and AEM respectively), between two electrodes for generating electricity.

In order to optimize TA devices the output power over weight ratio, the working gas needs to be at high mean pressure (10 to 50 bar). This, and the strong thermal gradient across the regenerator, leads to choose steel as the usual construction material. Probably a fibre based sintered ceramic material is an option.

Temperature drop across the in- and output heat exchangers strongly affect the performance, in particular in heat pumps and low temperature driven engines. Optimal heat exchangers in thermo-acoustic applications need to have a similar channel dimensions as the regenerator. For the conversion of acoustic to electric energy a linear generator is used, these types of alternators require large NdFeB magnets. Other conversion devices or materials therefore could be potentially interesting: electret membranes, piezoelectric ceramics.

The introduction of nanostructures in thermoelectric materials has led to significant improvements. Some interesting combinations of atom shave been considered to make cheap and less toxic TE materials (e.g. Mg2Si, CoSb3, ZnSb, ZnO, other oxides). Materials obtained directly from solution-based methods, like sol-gel or electro-deposition are advantageous.

Polymer composites have now reached a level of maturity at which adventurous and novel configurations can be considered. We now have an unprecedented ability to synthesise, tailor and fabricate composites, as well as an understanding on modelling materials and their microstructures. Finally, the laminated architecture mirrors the electrode configuration of conventional electrical devices.

Developments on structural capacitors, batteries and fuel cells plus working on structural super-capacitors rely on development of new or improved materials.

The challenge is that the transition from conventional energy to the energy system outlined above will place pressure on critical element resources. Of note this 'materials criticality' aspect is currently sometimes completely omitted from the discussion. Of interest is material demand and in what timeframes. Widespread deployment of clean energy technologies could lead to imbalances of supply and demand of, for example, rare earth elements (REEs) along with other critical materials. The sum total of the list represents a significant number of elements.

For many technologies the focus of RTD on materials is on improving existing classes of materials. To a large extent this is true independent of technological maturity. There are some cases for which the best way forward is to develop new materials with similar or improved properties, for example when there is a strong element of criticality and/or their use is foreseen to be limited or prohibited by (future) legislation. Thus research on either developing new or improving existing materials often is essential for the functioning of emerging energy technologies, and to ensure these emerging energy technologies can become commercially viable.

Chapter 5

Technical and Non-Technical Needs and Bottlenecks

Common themes of needs and bottlenecks were clear despite the range of technologies and ideas in the workshop. Dealing first with the technical needs and barriers identified by the experts;

There is a need for improved developments in material science concerning the structure of the respective materials. This is true of both the bio-inspired/nature inspired solutions as well as lab developed materials. Issues such as tensile strength, heat properties, strength to weight ratios, rigidity, etc. were common themes.

The electrical properties and performance of materials are for many a barrier that need further work to be satisfactorily overcome.

Processing and manufacturing challenges were raised by many experts as issues that were preventing further diffusion of their technologies.

The cost of overcoming the technical challenges was for some a major concern as the deployment in the 2050 timeframe could not happen without investment to overcome the technical obstacles now.

Concerns over so called 'critical materials' were raised by a number of experts. The cost and ease of availability of certain key elements was uncertain in both the short term as well as in the 2050 horizon. For some these concerns were allied to uncertainty regarding recycling such 'critical' materials.

Also for advanced materials that do not include critical elements recycling of materials and reuse of components will play a significant role in the future. Noting that recycling of materials often leads to a degradation of the properties of the materials and this needs to be carefully considered. This issue could to be alleviated by design for the entire life cycle, both at the level of materials and products.

In terms of non-technical needs and bottlenecks there was one overarching theme – the need for increased research investment. It was felt that this is best overcome via governmental – industry collaborative funding. Issues over ownership / IPR issues were, however, raised.

In this context it was felt that it might be beneficial to divide problems (i.e. calls for proposals) into sub-problems, in other words to define only the problem not the solution in the call text. This was noted in a comparison with other schemes such as incentive prizes, e.g. Innocentive in the US and the X-prize that may have very focussed requirements of performance of materials, products or services.

During the discussions it was felt that society and governments do not fully appreciate the size of the challenge. The experts agreed that general trends in the consumption of energy across both in EU and globally has a bearing on technologies that will be developed. To that end there was a discussion on the projection of energy demand in 2050.

The experts agreed that the costs in not only R&D but also power generation infrastructure will be significant.

Another common theme was around skills and knowledge. It was felt that there is not enough capacity in the labour market to meet the research and diffusion needs either now or in the future.

In addition it was felt that there was a need for much more multi-disciplinary activity to take place (the workshop itself provides an example of this).

A number of experts felt that there are no simple fixes for power generation in the 2050 horizon.

Chapter 6

Opportunities, Synergies and Common Themes

In the workshop the experts used Table 1 below to explore the synergies and common themes. This process was conducted by each expert indicating where they felt there was a significant correlation between their technology / topic and the listed criteria. Note that of the 10 submissions only 9 are listed. This is because the tenth – 3.10 Materials and design, fitted better into the scheme, not a technology, but rather as a criterion for all technologies/materials.

Areas of common themes (light grey shaded on table) can be listed as:

- Fibre reinforced structural materials
- Structural material degradation
- Joints and joining techniques of structural materials
- Power electronics functional materials
- Product Design
- Condition monitoring techniques
- Nanostructured materials
- Composites
- Critical materials
- Modelling and simulations
- Education and training

This gave rise to consideration of opportunities. The experts were of the view that further research and development in all of these areas would be of real benefit to all the technologies. Albeit differences in normal operational conditions (time scale, temperature, chemical environment etc) could imply vastly different requirements of the materials used for each technology. Some of the experts saw strong links between their respective technologies leading to other levels of synergies being identified, such as the source of energy, e.g. heat, wind or sun light.

	Artificial Photosynthesius	Bamboo for Wind Power	High Altitude Wind on-ground energy generation	Low Energy Nuclear Reactions	Piezoelectric Materials	Salinity gradients & osmotic power	Thermo-acoustics	Thermo-electricity	Structural Power Materials
Structural materials									
Fibre reinforced		x	x		x	x	x	x	x
High strength fibres			x			x			
High temperature resistant materials	x	x	x	x	x	x		x	
Temperature range (ºC) min	RT	-20	-50	RT	0	0	-200	-100	-50
max	300	100	120	100	600	45	400	700	200
Degradation	x	x	x	x	x	x		x	x
Steel components and joints		x	x	x	x				x
Other joints and joining techniques		x	x	x	x	x	x	x	x
Advanced concrete		x					x		x
Functional materials									
Separation membranes	x			x		x			x
Catalysts	x			x		x			x
High Temperature Superconductions			x	x			x		
High temperature heat storage							x		
High temperature insulation		x			x		x	x	
Power electronics			x		x	x	x		x
High temperature fluids							x	x	
Product Design	x	x	x			x			x
Manufacturing									
Coatings	x		x	x	x	x		x	x
Condition monitoring techniques	x	x	x	x	x	x	x	x	x
Organic synthesis	x					x		x	x
Inorganic synthesis	x			x	x	x		x	
Nanostructured materials	x			x	x	x	x	x	x
Tribology						x			
Composites		x	x	x	x		x	x	x
Sintering				x	x	x	x	x	
Critical materials (of the 14 in EU RMI)	x		x	x	x			x	x
Need for substitution	x		x	x	x			x	
Horizontal and non-technical issues									
Modelling and simulations	x		x	x	x	x	x	x	x
Standards & standardisation		x	x					x	x
Metrology				x				x	
Regulations and regulatory issues		x	x			x			x
R&D Funding	x			x	x			x	x
Education and training	x	x	x	x	x			x	

Table 1: Common themes and synergies

Chapter 7

Conclusions

This section contains the conclusions of this report as agreed by all the experts.

Some of the proposals for emerging energy technologies were in themselves novel materials whilst others were working on solutions that employ current materials.

There was a discussion on the increasing 'cost' in winning energy with the age of 'easy' energy over.

The group agreed that no single technology would be a total solution in itself and that developing an energy mix will become even more important in the future.

It was felt that Europe must take the lead in development of energy technologies and associated technologies.

Recycling of materials and reuse of components will play a significant role in future scenarios.

Recycling of materials often leads to a degradation of the properties of the materials and this needs to be carefully considered.

It was clear that an understanding of technology fundamentals, up-scaling and demonstrators are all very important in the development of new energy technologies.

Broad R&D funding calls and more 'bottom-up' calls would help avoid some of the barriers to novel technologies and concepts. In addition such technologies and concepts should be considered for R&D funding.

There is an opportunity to promote research that aims at finding synergies of a wide mix of energy technologies.

This would also promote the involvement of persons/organisations/companies that are not among the usual R&D stakeholders in EU projects.

It might be beneficial to divide problems (i.e. calls for proposals) in sub-problems, in other words to define only the problem not the solution in the call text.

It is of note that the range of technologies and ideas being presented would at first glance lead one to consider there would be few common themes and opportunities. It can be seen however that the opportunity for cross-disciplinary work can lead to opportunities and synergies being discovered.

The experts agreed that general trends in the consumption of energy across both in EU and globally is of interest. To that end there was a discussion on the projection of energy demand in 2050. There was recognition that demand requirements would affect the technology mix.

The conclusions from the written summaries can be seen in the areas of common themes and are listed below. It is in these areas that the greatest communality in research benefit could be found.

- Fibre reinforced structural materials
- Structural material degradation
- Joints and joining techniques of structural materials
- Power electronics functional materials
- Product Design
- Condition monitoring techniques
- Nanostructured materials
- Composites
- Critical materials
- Modelling and simulations
- Education and training

The participants agreed to make this report publicly available, e.g. on the NMP website http://ec.europa.eu/research/industrial_technologies/index_en.html

Chapter 8

Recommendations on Actions

This section contains the conclusions of this report as agreed by all the experts. In doing so it expresses recommendations of the experts:

- Further material science research concerning research into the structure of the respective materials.
- Further material science research into the electrical properties and performance of materials.
- Further research into new materials or materials solutions.
- Processing and manufacturing challenges needs more research.
- Sufficient funding to overcome the obstacles in the up-scaling of the technologies.
- The ‘critical materials’ phenomena needs further investigation.
- Society and governments needs raise awareness in order to fully appreciate the size of the challenge. The costs in not only R & D but also power generation infrastructure will be significant.
- Investment in skills and knowledge. There is currently not enough capacity in the labour market to meet the research and diffusion needs either now or in the future.
- There is a need for much more multi-disciplinary activity to take place.
- The use of advanced computer based complexity modelling should be investigated.
- There is a need to develop a recognition there are no simple fixes for power generation in the 2050 horizon.

Annex I

Agenda of the workshop

FORWARD LOOKING WORKSHOP ON MATERIALS FOR EMERGING ENERGY TECHNOLOGIES

Friday 28 October, SDME 8F, Square de Meeûs 8, DG RTD, Brussels

8:30	Registration
9:00	Welcome address
9:05	Tour de table
9:15	Presentations on the role of materials research in emerging energy technologies

- Artificial photosynthesis
- Bamboo for wind power blades
- High altitude wind on-ground energy generation
- Low energy nuclear reactions
- Piezoelectric materials
- Salinity gradients & osmotic power
- Thermoacoustics
- Thermoelectrical materials
- Structural power materials
- Materials and design

12:00	Lunch
13:00	Discussion on technical and non-technical needs and bottlenecks
14:00	Discussion on opportunities, synergies and common themes
15:15	Recommendations on actions
16:30	Comments on the feedback and potential report
16:45	Concluding remarks

Annex II

List of participants

Participants	Affiliation / Service
Bo Albinsson	Chalmers University of Technology
David Peck	Delft University of Technology
Dragan Damjanovic	EPFL- École Polytechnique Fédérale de Lausanne
Emile Greenhalgh	Imperial College of Science, Technology and Medicine
Kees de Blok	Aster Thermoakoestische Systemen
Marcello Corongiu	Sequoia Automation
Mario Rosato	Sustainable Technologies SL
Marisol Martin-Gonzalez	CSIC, Instituto de Microelectronica de Madrid
Pedro M. Mayorga	EnerOcean S.L.
Vittorio Violante	ENEA - Ente Nazionale per l'Energia Atomica
Willem de Baak	Fujifilm
Xavier Crispin	Linköpings Universitet

Commission staff	Service
Aurelien Pitois	European Research Council Executive Agency
Carlos Saraiva Martins	European Commission, DG for Research and Innovation
Erno Vandeweert	European Commission, DG for Research and Innovation
Johan Veiga Benesch	European Commission, DG for Research and Innovation
Maurizio Maggiore	European Commission, DG for Research and Innovation
Mykola Dzubinzki	European Commission, DG for Research and Innovation
Renzo Tomellini	European Commission, DG for Research and Innovation

Rapporteur :
Prof. David Peck, Delft University of Technology, the Netherlands

Acknowledgement:
The workshop organisers would like to thank the experts and all the participants for sharing their time and insights, and for enabling such a productive meeting on a challenging and complex subject.

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Materials are fundamental to economic, social and industrial development. They form the basis for the functionality of the built environment, products and technologies that are vital to modern society. This means that they can be the key innovative trigger in the development of many new products and technologies.

The Materials Unit of the European Commission (DG Research and Innovation, Directorate "Industrial Technologies") organised a workshop in Brussels on the 28th of October 2011 entitled "Forward Looking Workshop on Materials for Emerging Energy Technologies". The aim of the workshop was to identify research and development of new materials that support emerging low carbon energy technologies for market deployment by 2050. The objective was also to identify possible priorities, bottlenecks and synergies in the field of emerging energy technologies (with the potential for industrial development) and to gather ideas on how to progress on the successful deployment of materials with improved performance.

Mindful of the importance to maintain the complementarities to previous workshops and technology assessments, 12 distinguished experts were invited from a variety of fields; artificial photosynthesis, thermoelectrics, piezoelectrics, salinity gradients, osmotic power, thermoacoustic power, structural power materials, materials based design, low energy nuclear reactions and high altitude wind power.

The workshop provided a learning opportunity and a fruitful exchange of ideas among a highly qualified interdisciplinary group of people. This report contains summaries of the discussed technologies and materials. The report identifies many of the key issues related to research on, and development of, new materials in support of emerging low carbon energy technologies for market deployment by 2050. A conclusion by the experts of key issues and themes, gleaned from the presentations and discussions, is contained in this report.

Studies and reports