SusChem Hybrid Materials Workshop Report

'Setting the future materials research agenda for Sustainable Chemistry'

3-4 March 2010, Conference Center Jean Monnet, Luxembourg

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Dutch Polymer Institute

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Content

General introduction

According to the United Nations, in the coming 15 years, the world population will increase by 20% from 6.5 to reach 8 billion inhabitants. During this same period of time, the International Energy Agency estimated the energy demand would increase by 50% and will reach 15 billion tons of oil equivalent per year. This trend can generate important tensions which will affect particularly raw materials and energy. The price of both resources will continue to increase. There are urgent needs to increase the use of renewable energy and better use of raw materials to design 'smarter' and 'cleaner' products and processes which are less harmful to the environment. To drive these initiatives more effectively, European Commission has been playing key roles by setting up many environmental and research policies. The instruments to implement these policies include the Action Plan for Energy Efficiency, the Renewable Energy Roadmap, the N&N (nanosciences and nanotechnologies) and also other European technology platforms. The European Technology Platform for Sustainable Chemistry (SusChem) is one of the instruments to boost chemistry, biotechnology and chemical engineering research, development and innovation in Europe.

Chemistry is vital to contribute to improve the quality of modern life. The appropriate use of chemistry will enable European society to become safer, more sustainable and 'greener'. This requires break through innovations and a successful and healthy European chemical industry.

Innovation is a key driver for future European competitiveness. Chemistry innovation is a key component of the sustained competitiveness of the chemical industry. Furthermore, new sustainable chemical materials and technologies can improve public confidence in the chemical industry.

To catalyse the process for innovation and with the support from the European Commission (EC), SusChem and Dutch Polymer Institute (DPI) have taken the initiative to organize a workshop on Hybrid Material in Luxembourg on March 3 and 4, 2010. The workshop brought together specialists from different background who are willing to share their ideas and experiences in new materials and material combinations in order to bring the most appropriate solutions towards sustainable product development.

Scope of the workshop

The workshop has gathered experts from both industry and academia from different fields to discuss different topics.

The workshop started with the plenary session which included the general introduction from the European Commission Officer (Renzo Tomellini, Head of the Materials Unit), the representatives from SusChem (Dr. Rùdiger Iden) and DPI (Dr. Jacques Joosten), and followed by the key note speakers from industry to share their ideas on future material needs for the next 10 years. The voice of the industry stake holders has intended to lead the build up of value chains with the material producing companies. On the other hand, the voice of scientific academia has offered new concepts and technologies to support the industrial applications.

The proposed topics are highly related to value-added materials and energy management (generation and consummation) which is highly linked to environment protection and pollution.
The five selected topics are hybrid materials for:

1 Automotive
2 Solar Energy
3 Solid State Lighting
4 Civil Engineering
5 Aviation and Aerospace

These five topics are in some cases inter-related at different levels and have high impact on our society and daily life. The ideas and proposals generated from any of the topics can be fully or partially further leveraged to other fields to initiate other new ideas and developments.

Objectives of the workshop and methodology of the report

After the plenary session, five different parallel sessions in the respective fields were organized. The sessions were started with the presentations from material supplier, the academia representative to share their experience, and followed by a discussion to achieve the following objectives:

- Identify technical hurdles and bottlenecks
- Capture new ideas
- Define potential R&D projects
- Prioritize projects

The participants were invited to express their opinions, to share their experience, to brainstorm new ideas and to define new potential projects and opportunities. New projects / ideas have been categorized into different areas of interest so that it can be compared to other fields to find out common areas of interest. The common areas of interest having the highest impact will be used by the EC to serve as input for future research initiatives.

Five rapporteurs were appointed by the EC officers to attend the plenary sessions with all participants. The five rapporteurs were separated and attended the five parallel sessions in order to take notes during the discussions. The opinions, experiences, new ideas and proposals for potential R&D projects were recorded and a summary report was written by the individual rapporteur according to the report format and content proposed by the general rapporteur. After receiving the five individual reports, the general rapporteur inserted these individual reports under the section 4 (**Summary of the workshop**) of the final report written by the general rapporteur. The final report was sent to the responsible SusChem team for review and approval. The SusChem team distributed this final report to the participants to seek for feedback. After receiving the feedback from the participants, the SusChem team modified the report and the report was sent to EC. The EC officers would consider using this proposal for future research initiatives.

Summary of the workshop


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1 Automotive

Rapporteur: Joseph Gan, Chairman: Natalia Scherbakoff

1.1 Background information

The automotive industry is one of the largest and most multi-national of all industries. It is a key indicator of economic growth and a major contributor to the gross domestic product (GDP) of several Member States and the EU. This car industry provides more than 1 and 0.3 million jobs for Germany and France respectively. Technology development in vehicles is likely to play a major role in the future, particularly in addressing concerns about oil dependency and the environmental impact of transport. The innovation and the successful implementation of new technologies in European car industry will contribute significantly to the economical growth and create job opportunities in the Member States.

Transport is a major user of energy and contributes considerably to carbon dioxide (CO_2) emissions. The adoption of the Kyoto protocol by the EU, calling for a significant reduction in greenhouse gases, is a major driver towards cutting emissions. The EU and individual Member States, in cooperation with manufacturers, have pursued a policy of emission reduction for many years. Emission standards have been progressively tightened over the last two decades, but the increasing number of vehicles has limited the overall improvement in air quality.

Dr. Jean Claude Steinmetz from Rhodia / France presented an overview of the impact of car on the society and the environment, the implication of legislation on the OEMs to reduce carbon dioxide and the different responses to the regulations through new concepts and designs for cars. Some critical car design aspects should be addressed to reduce carbon dioxide emissions: internal friction, aerodynamics, rolling resistance, inertia, reduced performance such as maximum speed and /or acceleration, and improved engines. He concluded that innovation is critical to make sustainability a reality and the success can be achieved by close and open partnership with all actors of the value chain.

Dr. Ton Peijs from Queen Mary University of London presented the use of more than 15 different polymers to build cars in order to reduce the weight of the cars. He noted that ELV (the End-of Life Vehicle) legislation would probably impose the use of recyclable materials to make 'Green Composites', such as natural fibre composites. Different new bio-materials, smart materials, nanofillers, bioinspired materials and new technologies are being investigated for different applications.

1.2 Trends and future needs of end-users

The weight of different generations of cars manufactured over the last 20 years by different major car companies showed the trend to increase in weight. This increase comes from the use of more electronic components and devices to improve comfort and safety for the passengers. Another trend is the increased use of polymers and other multi-functional materials in the car. The use of polymers aims to achieve the following objectives:

- Weight reduction
- Cost reduction
- Freedom of design
- Tailored properties
- Safety
- Noise reduction
- On-line painting
- Recyclability

Some polymers and blends of these polymers have been fully evaluated to reach its optimized performances. Innovation and breakthrough technologies are needed for these materials to reach the next step of performance. A single research institute or organization or a small group of consortium has not the required resource and know-how to achieve these objectives. The tasks involved are too complex and inter-related. It requires the close cooperation of the key stake holders from material designers to the end-users.

1.3 R&D topics discussed during the sessions

There were about 30 participants representing 25 organizations from both industry and academia. All the participants were actively involved in the discussion and had the opportunity to express their ideas, views, agreement and disagreement. The topics discussed can be classified in three categories and each topic is summarized in the following three sections.

1.3.1 Sustainability

1.3.1.1 Energy management and CO_2 Emission

The impact of the car on the environment, especially in terms of its contribution to CO_2 emissions and global warming is going to increase with the increasing number of cars due to the growing population. It is proposed to find new energy sources or new power engines which generates no or lower level of CO_2. New material solutions are needed to have better storage of energy which can be generated onboard.

Rolling energy is another source of energy consumption. It was considered to develop green tires using hybrid materials with special interface design to reduce friction between contact surfaces and extend the technology to heavy weigh transportation. New manufacturing processes and modeling tools are needed to support the development work. Such developments will help to address the EC regulations in term of maximum levels of the tires rolling resistance.

The extra safety equipment incorporated in vehicles has increased their weight. At the same time, this has been countered by the use of light-weight, yet strong, materials such as lighter weight steel, aluminum, magnesium alloys, composites and plastics, in vehicle construction. It was proposed to develop innovative lightweight thermoplastic composites with high performance properties and investigate the use of more natural fibers composites, bio- and nano-solutions. New joining solutions for hybrid systems to maximize interface adhesion and assure easy assembling. Predictive modeling and reverse engineering are needed to accelerate the developments. The weight reduction potential would be above 100kg/car.

1.3.1.2 Recycling

New production techniques have been introduced to deal with these new materials, with laser welding playing a major role. As manufacturers have adopted these new materials, they also had to ensure that they were easy to recycle in order to be compliant with the End-of Life Vehicle (ELV) Directive. This may have limited the adoption of some materials, mainly of plastics where the difficulty of separating materials has restricted the number used.
It was proposed to adopt mono-material solution which streamlines the number of materials used in cars and lowers the supply chain and recycling costs to achieve the objective of 'design for easy recycling'. The full life cycle inventory assessment has to be considered when new materials and processes are to be adopted.

1.3.1.3 Safety devices

Car transport is responsible for 40,000 deaths and nearly 2 million injuries on European roads every year, resulting in a considerable burden on health services and both social and economic costs. It is a well known fact that driver behaviors can have a negative impact on the environment and is a major factor in the incidence of road accidents. It was proposed to develop better sensors and devices that monitor driver reaction and that can help to avoid collisions with other objects.

1.3.2 Functionality

It was proposed to consider the following functionality when developing new materials to address weight reduction, reduce CO_2 and NOx emissions and assure a sustainable development:

- New polymers designed to make a fuel tank
- Materials and surfaces having better adhesion between contact surfaces
- Polymer materials having high strength and transparent properties to reduce weight of structural parts and use more environmental friendly materials
- Hybrid materials having shape memory properties
- Materials having self healing properties for low cost surface reparation for example
- Smart materials to monitor damage, to detect dangers etc;
- Coating materials having multi-functionality (corrosion resistance, UV resistance, self cleaning, single layer etc)
- Intelligent surface with sensor function
- Corrosion resistant materials for new fuel systems
- Wear resistant materials
- Halogen free materials to obtain flame retardancy

It is of great importance to study the fundamental aspects of interface between different components, different surfaces and different hybrid materials (for example fibers and resins in composites) with a system approach to involve different stakeholders in the full value chain. The hierarchical and interface design for Hybrid Materials and Components (composite design interfaces) is needed to ensure better compatibility and synergetic effects.

It is essential to build and collect sufficient data to set up multi-scale models to predict the structure properties of the intermediate and final parts of cars. Simulation models are very useful to accelerate the development speed and lower the cost.

It was proposed to gather all stakeholders to set up some demonstrator programs having the following characteristics:

- 700kg material solution car
- Mono material car to facilitate recycling
- Low cost material solution car (less than 1k€)
- Bio-car
- Less than 50g/Km CO_2 emission car
- Car having multi-functionality far beyond mobility

These programs would help to link all the stakeholders to work together to address the challenges, opportunities, to build up large consortia and networks to share experiences, and know how with an integrated solution approach.

1.3.3 Processes

Processes were considered to have very high impact through the whole value chain for the construction of cars. Process to make new hybrid materials, process to assemble and disassemble hybrid materials and parts of a vehicle, process to predict the influence of individual component characteristics on the final part properties, process to scale up the small laboratory materials to large industrial quantities, process to make new shape and forms etcetera, are equally important when designing new materials to be used in a new vehicle. It is critical to combine both chemistry and process during the development of new materials in order to meet overall cost position, industrial safety and environmental requirements.

It is critical to develop new methods to shorten the long validation process when replacing a raw material by another material or hybrid materials in order to accelerate the development phase and to lower production costs.

It was also proposed to develop new characterization techniques for OEMs so that all the stakeholders have the same requirements when developing and designing new materials.

1.4 Classification and prioritization of different topics

The topics discussed in the parallel session on the first day were prioritized during the morning session of the second day of the workshop. Almost all contributors of the first day session attended the second day session, and agreed with the priority order as listed below.

1.4.1 Prioritized topic related to hybrid materials

- Lightweight solutions for emission reduction
  New material concepts such as thermoplastic hybridized applications
- Tires Rolling Resistance for emission reduction
  - Wet grip and Noise reduction
  - Wear performance
  - Predictive tools and modeling of surface interactions
- Coating materials having multi-functionality (corrosion resistance, UV resistance, self cleaning, single layer etc)
- Intelligent surface with sensor function
- Wear resistant materials
- Halogen free materials to obtain flame retardancy

1.4.2 Prioritized topic related to process

- Development of modeling and reverse modeling tool to design new hybrid materials
- Development of new methods to shorten long validation process
- Process to assemble and disassemble hybrid materials

1.5 Technical hurdles and bottleneck

Three main hurdles for the development and implementation of new hybrid materials in European automotive industry were identified during the workshop:

The **first hurdle** was the lack of quantitative modelling tools which can predict the performance and reliability of composite structures under realistic utilization environment. New tools based on e.g. multi-scale modelling are required to predict the performance, reliability and damage tolerance of composite structures and the influence of an individual component on the final system.

The **second hurdle** was the lack of coordination and cooperation between all the stakeholders involved in the car industry due to its complexity and huge number of stakeholders. The absence of OEM's participation to the workshop was regretted by the participants.

The **third hurdle** was to attract more students to study chemistry and continue their career in R&D so that there are enough PhD students and researchers to contribute to innovation. It is very important to link education to industrial applications in order to restore attractiveness of chemical industry.

1.6 Conclusions and recommendations

The overall conclusion of the session workshop is that more research and development in hybrid materials is needed to contribute significantly to the European automotive industry to increase its competitiveness. Public sector and industry need to cooperate closely in both fundamental studies and applied material development involving the stakeholders of the full value chain. European Commission plays a critical role in linking all the stakeholders together to identify the right R&D directions and funding innovative R&D projects. The setting up of appropriate policies and regulations, for example the level of CO_2 emission requirement and the recyclability of materials, by the European Commission would help to drive the automotive industry to focus on the appropriate R&D projects.

The main recommendations of the workshop are:

- Fundamental and applied research on novel materials for the prioritized topics proposed in Section a4 should be supported through a close partnership between public sectors and private companies.
- Fundamental research on interface properties such as adhesion and compatibility in hybrid materials.
- Development of multi-scale modelling tool to predict materials properties and the influence of improvement of individual component on the performance of the final system.
- Set up some demonstrator programs having special characteristics listed in section a32.
- Creation of a European centre of excellence for hybrid materials should be considered. The centre of excellence should play a leading and supporting role to enable better coordination of research projects / activities for all the stakeholders involved in the automotive industry.

It should be mentioned that only a small number of material suppliers were present in the workshop and it may not represent the opinions of hundreds of material suppliers that are involved in the European automotive industry. Furthermore, there were no representatives from the OEMs, particularly the vehicles manufacturers. Some specific automotive workshops should be organized in the future to follow up the specific topics mentioned in section a4.

The presentations from plenary and parallel sessions were well prepared and clearly described the future material needs. The participants were actively involved in the discussion and many questions were asked. The length of the presentations and discussions were appropriate.

2 Solar Energy

Rapporteur: Maria Vamvakaki, Chairman: Steven Tierney, Deputy Chairman: Harold Gankema

2.1 Background information

World energy requirements are expected to increase by ~60% between 2004 and 2030. In 2008 the total worldwide energy consumption was 474×1018 J, 80 to 90 percent of which was derived from the combustion of fossil fuels. As we have used about half of the available petroleum resources, the estimates of remaining non-renewable worldwide energy resources are 0.4 YJ from fossil fuels and 2.5 YJ from nuclear fuel. Assuming that our rate of usage remains constant, we will run out of conventional oil in about 37 years (2047) and of coal in 130 yrs (2140). Moreover, security of supplies and environmental concerns related to global warming and sustainability are expected to move the world's energy consumption away from fossil fuels. Energy efficiency and renewable energy are said to be the two pillars of sustainable energy policy. Both strategies must be developed concurrently; efficient energy use is essential to slow the energy demand growth so that the emerging renewable energy supplies can decrease significantly the fossil fuel use. If energy use continues to grow rapidly, renewable energy development will chase a receding target. A sustainable energy economy thus requires major commitments to both efficiency and renewable energy supplies.
The main advantage of the renewable resources is that they are always available, unlike non-renewable resources which are expected to be depleted eventually. Most of earth's available energy resources are renewable resources. Some countries have already taken action in this direction and further steps are proposed as a result of the Kyoto Protocol. The renewable sector has been growing significantly since the last years of the 20th century, and in 2005 the total new investment was estimated to have been 38 billion US dollars. In 2004, renewable energy supplied around 7% of the world's energy consumption. Germany and China lead with investments of about 7 billion US dollars each, followed by the United States, Spain, Japan, and India. This resulted in an additional 35 GW of capacity during the year. The European Commission has proposed that the energy policy of the European Union should set a binding target of increasing the level of renewable energy in the EU's overall mix from about 10% today to 20% by 2020.

Among them solar energy is the most widely available, with 89 P(1015)W of solar power falling on the surface of the earth, and can easily supply the world's energy needs. Thus, while it is not possible to capture all, or even most, of this energy, capturing less than 0.02% would be enough to meet the current energy needs. Barriers to further solar generation include the high price of making solar cells and reliance on weather patterns to generate electricity. Also, solar generation does not produce electricity at night, which is a particular problem in high northern and southern latitude countries; energy demand is highest in winter, while availability of solar energy is lowest. This could be overcome by an efficient energy storage and distribution system that would allow the generation of energy when and where available, to be used when required. Globally, solar generation is the fastest growing source of energy, seeing an annual average growth of 35% over the past few years. Japan, Europe, China, U.S. and India are the major growing investors in solar energy. Advances in technology and economies of scale, along with demand for solutions to global warming, have led photovoltaic to become the most likely candidate to replace nuclear and fossil fuels.

Photovoltaic production has been doubling every 2 years, increasing by an average of 48 percent each year since 2002, making it the world's fastest-growing energy technology. In 2007 grid-connected photovoltaic electricity was the fastest growing energy source, with installations of all photovoltaic increasing by 83% in 2009 to bring the total installed capacity to 15 GW. Nearly half of the increase was in Germany, which is now the world's largest consumer of photovoltaic electricity, followed by Japan. Solar cell production increased by 50% in 2007, to 3,800 megawatts, and has been doubling every two years. Dr Markus Scharber, Director of Innovation and IP of Konarka Technologies Inc presented an overview of the photovoltaic technology to date and the future trends and requirements in the field. The need for development of high efficiency and life endurance photovoltaics (PVs) at low cost was stressed. The goal set for the future is the Development & Manufacturing of a low cost PV-technology based on printed PVs on Plastics by an efficient R2R technique operating at low temperatures.

2.2 Trends and future needs of end-users

The earliest commercial solar technology remains the basis for the most prevalent devices currently used, known as inorganic solar cells, and commonly referred to as silicon cells which are based on highly-ordered crystalline silicon. Another class of solar cells that has recently attracted significant academic and industrial excitement is the bulk hetero-junction 'plastic' solar cell. Research by a rapidly growing community of scientists across the globe is providing new insights into the fundamental physics, the materials design and synthesis, the film processing and morphology, and the device science and architecture of bulk hetero-junction technology. Future progress in the fabrication of high-performance cells will depend on our ability to combine aspects of synthetic and physical chemistry, condensed matter physics, and materials science. The need for new materials that will lead to low cost PV production by a continuous facile process is particularly stressed. These new materials must possess high power conversion efficiency, to present new design opportunities and to be of low cost that will lead to PVs with high efficiency and facile processing. The main criterion set by Martin Green is the extremely high efficiency. The third generation PVs known as advanced thin-film photovoltaic cells, exhibit high power conversion efficiencies and have attracted particular interest to provide higher efficiency and lower cost per watt of electricity generated. They have been developed by the combination of dye sensitized solar cells and bulk hetero-junction solar cells. The former are based on nanoporous TiO_2 surrounded by a dye layer and dispersed in an electrolyte solution, while the latter use a composite material layer the bulk hetero-junction which supports the transport of carriers and electrons to the electrodes. Hybrid materials that combine the properties of an organic with good optical properties with an inorganic crystalline material with good transport properties are particularly advantageous in this direction.

The needs for the development of the organic photovoltaics (OPV) technology in the future were summarized as follows:

- Improved or novel p-type / n-type materials
- Multiple junction concepts needed to drive efficiency increases
- Flexible products
- Establishment of roll-to-roll manufacturing processes to reduce costs to <0.5 €/Wp
- Target efficiency > 10% and lifetime >10,000 h within a few years

The EU Photovoltaic Technology Platform among others has set a typical turn-key system price (module price and balance-of-system price (*power-related part & area-related part*) of 2.3 €/Wp for 2015 and 1.5-1.8 for 2020 excl. VAT which will be expected to decrease to 0.5 €/Wp in the far future.

2.3 R&D topics discussed during the sessions

There were about 20 participants representing 18 organizations from both industry and academia. All the participants were actively involved in the discussion and had the opportunity to express their ideas, views, and visions. The first presentation was given by Steven Tierney, Project Leader of Merck Chemicals, UK representing the materials supplier sector and the second by Jef Poortmans, Program Director Photovoltaic, IMEC, Belgium, representing academia.

2.3.1 Materials

In terms of materials used in PVs the state-of-the-art in the OPV technology was presented. The active material history in OPVs followed the introduction of MEH-PPV: PCBM in 1992 by Sariciftci, to MDMO-PPV: PCBM in 2001 and finally P3HT: PCBM in 2003. Merck's benchmark polymer is P3HT, while the need for polymers with lower Eg in order to harvest a wider area of the solar spectrum has led to the development of other materials, such as P3HS, which however also suffer low conversion efficiencies. The market development of OPVs based on Merck materials has led to a National Renewable Energy Laboratory (NREL) certified PCE = 6.4%, which was press released by Konarka in May 2009 and a world record PCE = 7.9% press released by Solarmer in Dec 2009. The main materials competitors are BASF/Ciba, supplier of P3HT, which also focuses on p-type polymers (bulk hetero-junction) and p-type 'diketodipyrrole polymers' with a patented PCE > 3%. A second materials developer is Plextronics which targets is semi-conductive blend inks (Plexcore PV®) that are based on p-type polymer (*e.g.* P3HT) & n-type fullerenes (*e.g.* PCBM) with a PCE=5.4%. Mitsubishi Chemicals has developed tetrabenzoporphyrin materials (p-type) for OPV & OFETs with PCE ~ 4-5% and a roadmap towards PCE 8-10% based on these materials. Many acceptor candidates were also tried among them conjugated polymers, fullerenes, carbon nanotubes and perylenes, however, C60 and C70-derivatives are the best performing candidates to-date. Nano-C (USA), Frontier Carbon (Japan) and Solenne (The Netherlands) are acceptor (n-type) suppliers of various fullerene derivatives with improved photon harvesting properties and raised LUMO energy levels that lead to an increase in V_{oc}. Recently, numerous copolymers combining the donor-acceptor moieties along the polymer chain have been developed. Copolymers containing thiophenes, fluorenes, carbazoles, cyclopentadithiophene and metallated conjugated polymers are among the most widely used however, their conversion efficiency is between 3.5-5%. Despite the developments in the field there is still a need for novel low Eg polymers based on donor-acceptor (D-A) polymer structures with incorporated novel donor monomers with a deeper HOMO energy in order to increase the V_{oc}.

The materials challenges and needs in the field of OPVs are the following:

- Higher efficiency p-type / n-type materials. Suitable band gap and LUMO-separation sufficient but not too high
- Lower cost p-type / n-type materials
- p-type polymers with scalable synthesis methodology for their sustainable development
- Improved hole-injection layer materials
- Low cost alternatives to ITO (anode material)
- Lower cost substrates & barrier layers
- Materials development to advance multiple junction devices
- Opportunities for hybrid materials
    - Encapsulation layers
    - Electrodes

The above will allow to achieve a target of 10% efficiency and lifetime >10,000 h within a few years, However, the need to develop quickly the OPV technology was particularly stressed given that the existing / competitive inorganic PV technologies and their cost will also decrease in the years to come (economy of scale).

2.3.2 Processing / Formulation

Apart from the development of materials with an appropriate band gap and band gap offset and high carrier mobility, the role of nanotechnology in several emerging and novel PV-technologies was emphasized. The performance of organic solar cells or inorganic-organic hybrid solar cells is strongly linked to the nanomorphology of the active films, necessary for efficient excitation diffusion. The challenges to be met there are to obtain the required film nanomorphology which is strongly influenced by the processing/formulation steps and its stabilization in the lifetime of the device.

Control over the film nanomorphology has been achieved by:

- Thermal annealing
- Slow solvent drying
- The presence of additives to the solution
- Addition of non-solvents to induce polymer aggregation in nano-particulates in the range of 10 nm or the growth of crystalline fibers by slow cooling of the solution

The **stability** of the device is determined by several phenomena

- Intrinsic stability of donor and acceptor
- Stability of the nanomorphology
- Stability of the organic material-metal interface
- Encapsulation

Certain approaches to stabilize nanomorphology have been pursued:

- High-Tg polymers (i.e. PPV) which restrict possible migration and segregation in the film
- Polymer cross-linking (i.e. UV exposure) after film formation

2.3.3 Tandem solar cells

Despite the use of advanced materials and the control of the film nanomorphology, single junction devices do not seem very promising for large increase in the conversion efficiency in OPV technology. Tandem cells (or multi-junction cells) were proposed as an alternative technology to overcome the limitations of thickness of OPVs and attain conversions efficiencies well above 10% and potentially 15%. The first reported organic tandem cell was based on small molecules with thin metal layers in between. A critical point in their production is the fabrication of a series of interconnection layers with the thin metal layers being in the range of 1-2 nm. The first solution-processed tandem cells based on polymer fullerenes and inorganic oxides have been prepared and showed promising results in term of efficiency (6.5%). Thus it has been rather generally accepted and agreed that tandem cells should be further investigated.

2.3.4. Nanoparticle-based solar cells

Finally, nanoparticle-based inorganic solar cells have been developed by non-vacuum application technologies (printing, slot die, spray coating) and are rapidly expanding due to the broad variety of compounds developed (Cu_2S, $CuInS_2$, PbSe, CuInSSe, CuInGaSe, Cu_2ZnSnS_4) The main problem in these systems is not the quantum confinement but rather the low-T sintering features (in some cases compatible with plastic substrates). This challenge is also applicable for the contacts (both transparent TCO's and opaque contacts).

2.4 Classification and prioritization of different topics

The target in the field was set for an OPV with > 10% module efficiency, at €50/m^2, and >5yrs lifetime in 2018. To achieve the above target intense research in the fields of materials development and processing is necessary.

The different topics were classified and prioritized in the two above fields as following:

2.4.1 Materials research

- New generation of semi-conducting materials for OPV
- Tandem cell configurations (>15% efficiency possible)
- Device performance vs. chemical specs (material purity and characterization and reproducibility)
- Substrates: low cost PEN
- Low cost encapsulation layer (Target: 10-20 euros/m^2)
- Non vacuum processable
    - Topcoats: low temperature curable anti-reflective topcoats
    - Oxygen and water barrier layer. Target: 10-3 to 10-4 grams/(m^2.day)
    - Electrodes (solution processable electrodes): e.g. transparent, graphenes, silver nanofibres
- ECO footprint
- Raw material / formulation selection: development of tools and methods; e.g. high throughput screening
- Formulation e.g. stability and phase separation optimization

2.4.2 Processing research

- Low cost mass printing technology e.g. roll-to-roll and beyond
- Tandem cell configurations (>15% efficiency possible) via solution processes
    - Interface/connecting layer, transparent electrodes
- Development of demonstrator / facility
- Adapt processing conditions to ingredients
- Formulation: Stability/Phase separation prevention or controlled

Certain **remarks** were made regarding the successful implementation of any efficient energy plan.

- Energy storage is a requirement for the successful implementation of any durable source (thermo-solar). This should be implementation in a European dimension.
- Ways to market the new product must be found? The co-existence of different PV technologies is foreseen in the future each one of which will serve a unique market (attributes, unique selling points for different markets; business model)
- Since several topics (materials and processes) are also applicable to other sectors and in particular to printed electronics e.g. OLEDS a common European policy in these directions must be found.
- Finally, dye-sensitized solar cells were not in the scope of the group's research approach because it is believed that this technology has already greatly advanced in the east and Europe does not have the required expertise to become a world leader in this direction.

2.5 Technical hurdles and bottlenecks

The main bottleneck identified in the field is the low efficiency of OPVs. To overcome this problem, both new materials but even more important the combination of the different components in order to make a better material must be developed. In terms of new materials low Eg polymers and in particular donor-acceptor copolymers were proposed. The failure of many innovative materials to achieve high performance in solar cell devices has been blamed on 'poor morphology' without significant characterization of either the structure of the phase-separated morphology or the nature of the charge carrier recombination. The role of thermodynamics in the nano-morphology and the difficulty in defining the required interfaces was emphasized. This is related to research on thin films and coatings and in solution processing of complex hybrid materials. By controlling the 'nanomorphology', which is critically dependent on minute experimental details at every step, from synthesis to device construction, a clear path to >10% power efficiency of solar cells which can be fabricated at a fraction of the cost of conventional solar cells is seen.
Other bottlenecks were identified in the PV technology related to the barrier layer materials and their ability to reduce the permeation of H_2O and O_2 through the packaging material. This problem is a common drawback in the solid state lighting sector.

A significant drawback was identified in the lack of high-throughput screening set-ups to select the most promising among the numerous materials developed in a lab scale. This would require a facility for printing OPVs (industrial demonstration plant) or a pilot-level modular testing plant in a European level.

A significant prospect is seen in tandem cells however, their development requires the effective control over more complex processing steps and multilayer processes. Further investment in this direction is required in terms of research and development but this would be worthwhile both for the progress it will offer in the OPV technology but also because it is related to advancement in other sectors i.e. electronics and devices.
Due to the above, silicon is expected to remain the major cell technology in the near future while the co-existence of several PV technologies is foreseen in the next 10ths of years to come each having its own assets for different market segments.

2.6 Conclusions and recommendations

Despite being a new technology, OPVs exhibit a steady increase in performance since 2000, which has reached today a power conversion efficiency of 7%. This corresponds to a growth rate of 1% / year over the last decade. Given this performance OPVs are emerging as a complementary technology to the existing silicon and thin film solar cells that will target a market with specific needs for flexible low cost solar cells. However, it needs both time to evolve and growth, but also funding (in analogy to the previously well funded silicon technology), to help it mature.

Europe's position presents certain strengths/opportunities but also drawbacks which should be considered for the implementation of an efficient solar energy R&D plan and for the advance of EU to a worldwide leader in the field of OPVs:

- Strengths / Opportunities
    - Existence of significant expertise in OPV technology
    - Equipment development has advanced
    - Sufficient printing capacity available
    - Intelligent / SMART grid (infrastructure) can be designed to cover the whole European area
- Weaknesses
    - Energy cost level (compared to China)
    - Dye sensitized solar cells. (The technology has already reached a stagnant and it is believed that there is no much room for improvement. The leader in this area is Japan and Europe has little chance to make a real breakthrough.)

Finally, further advancement of EU in this sector requires, besides the above-mentioned R&D strategic support, the consideration of certain political aspects:

- Life Cycle analyses of the different technologies
- Subsidies Si *vs.* OPV
- REACH implications and moving to China
- OPV lower energy requirement compared to Si cells
- SMART GRID (Solar, wind, nuclear, etc.) implementation to have a two way traffic of energy in Europe

3 Solid State Lighting

Rapporteur: Grazyna Zakrzewska-Trznadel, Chairman: John van Haare

3.1 Background information

Artificial lighting is one of the main sources of human development. It is also a main consumer of energy taking into account all buildings together: residential, commercial and industrial. Efficient means of lighting are the conditions for further development of civilization. Considering the fact that conventional lighting is insufficient and consumes much of energy, more potential for large energy savings in this field exists, than in any other area. The economic, sustainable lighting solutions can offer significant opportunities for improvement of human life. They translate to significant economic savings, cleaner environment and enhancement of household safety.

Grid-based electric lighting consumed about 2,650 TWh of electricity worldwide in 2005 that made about 19% of total global electricity consumption. The annual cost of grid-based electric lighting is about 1% of global gross domestic product (GDP). The end users pay energy bill of $234 billion, accounted for two-thirds of the total cost of the electric lighting service ($356 billion), which includes lighting equipment, labour costs and energy (*Light's Labour's Lost: Policies for Energy-efficient Lighting, Int. Energy Agency, Paris, 2006*). Half of this energy can be saved by switching to efficient and cold solidstate lighting sources. The high efficiency of solidstate sources already provides energy savings and environmental benefits in a number of applications. Broad implementation of such smart light systems could result in tremendous benefits in lighting, automobiles, aviation, transportation, communication, imaging, agriculture, and medicine. Whereas the efficiency of conventional incandescent and fluorescent lights is limited by fundamental factors that cannot be overcome, the efficiency of solid-state sources is limited only by human creativity. Novel manufacturing methods of new materials with tailored properties and the ability to process them with low cost and moderate energy consumption create new opportunities for lighting devices' market. The European Technology Platform for Sustainable Chemistry (SusChem) grouping outstanding teams in Europe in the field of chemistry and material science is a good arena for transfer of knowledge, discussing the directions of new materials development and promoting the innovation.

One of the main topics discussed during Hybrid Materials Workshop 'Setting the future materials research agenda for Sustainable Chemistry' organized by EC and SusChem was the possibility of further development in the field of Solid State Lighting. During the introductory session on third of March Volker van Elsbergen, Project Manager OLED Lighting Philips, delivered a very informative lecture on the state-of-the-art and new challenges of Solid State Lighting, followed by the next two speeches during the parallel session devoted to this subject. Pierre Barthélemy, Global Business Deployment Manager, Organic Electronics Solvay NBD, delivered the lecture 'Setting the future materials research agenda for Sustainable Chemistry – Solid State Lighting'. In short words he presented the company as a supplier of very high added value materials. Solvay decided to focus on three future business segments: organic light emitting diodes (OLEDs), organic field effect transistors (OFETs) and Organic Memories. In his speech, Mr. Barthélemy told about the new trends in lighting based on OLED, OLED current materials and devices, as well as the threats and opportunities of this branch. In the conclusions he emphasized a huge opportunity for European Industry coming from developing OLED Lighting as a multidisciplinary effort of all market players towards decrease of energy consumption and cost reduction.

The main showstoppers for promotion of OLED are in:
- Stable, phosphorescent emitters (blue) and complementary materials (hosts, charge transport);
- Barrier (to O_2 and H_2O) for flexible substrates;
- Printing: the use of orthogonal solvents between successive layers.

The contribution of the second speaker of the parallel session, Dr. Nazeeruddin from Institute of Physical Chemistry, Swiss Federal Institute of Technology, broaden the knowledge about the new possibilities in development of materials for OLED, their properties and chemical structures of the compounds applied. In his lecture, entitled 'Engineering of Materials for OLED's Applications' Dr Nazeeruddin focused on triplet emitters for OLED, transition metal complexes (Ir3+), the possibility of colour tuning via HOMO and LUMO control (by the position of substituent in organometallic complexes, through the use of different ancillary ligands), the influence of isomerisation and fluoride substitution on the properties of triplet emitters. He described hybrid organic-inorganic light-emitting devices (HOILED) as a potential, stable light source. In concluding remarks Dr. Nazeeruddin presented long term expectations concerning materials for cheap, efficient OLED.

3.2 Trends and future needs of end-users

The workshop showed that the market potential for solid state lighting is growing. It is expected that in 2016 the market will reach $9.7 billion. Commercial OLEDs market in 2010 is limited to small displays (mobile phones); the larger displays (TV) are already announced. Only prototype devices for lighting are available. Product-technology innovation will continue to drive growth in lighting and other applications.

The lighting with OLEDs is very beneficial. Unlike all other light sources, OLEDs are flat and directly emit homogenous light over the complete surface. The other advantageous features of OLED are as follows:
- Large area and thin,
- Efficient,
- Colour-tunable,
- Transparent,
- Flexible,
- Nice to look,
- Easy to integrate,
- Totally customized,
- Design freedom.

To be competitive in the market, the OLED devices should exhibit:
- High efficacy ~100 lm/W in white,
- Long operational lifetime ~100.000 h,
- Large area processing,
- Low cost production.

It looks that the future belongs to the OLED with large area, customised to the users and designers of new devices, easily processable, efficient and low cost. Very important feature is colour tunability and brightness that allow wide application of OLED not only for illumination but also for lighting in every place.

3.3 R&D topics discussed during the sessions

About 13 participants from different organizations, from both industry and academia participated in the session. Two presentations delivered by representatives of industry (Solvay) and academia (Swiss Federal Institute of Technology) gave the base for discussion during the session. The main topics of discussion concerned different aspects of material development, device manufacturing and processing. Cost aspects of the ventures in the field of SSL were discussed, as well as competition of other countries outside Europe in regard of possibility of loosing some markets, jobs, etc.

The topics discussed were:

3.3.1 Material aspects mentioned by disputants:

- Efficacy of small molecules (triplets) is higher compared to polymers (singlet).
- Polymers possess only one layer potentially containing all functionalities that can make them cheaper than small-molecule materials with dedicated functional layers.
- Light out-coupling problems are evident - only 20% of light leaves the device. The possible countermeasures: matching of refractive index of the layers between ITO and the substrate, the adjusted scattering layers, etc.
- Phosphorescent blue emitter with long lifetime is necessary. White colour as a combination of orange/blue emitters is possible to obtain.
- HOILEDs hybrid organic-inorganic LEDs combine advantages of organic and inorganic materials.

The target is to use high molecular weight organic compounds by attaching bigger ligands stabilizing small molecules and decreasing the evaporation temperature. These temperatures are also reduced by combination of organic-inorganic components in one hybrid material, i.g. HOILED.

3.3.2 Process aspects:

- Target efficiency (>100 lm/Watt), long lifetime is necessary.
- Material quality influences significantly the life time; purity of the material ensures high efficiency; isomers free/fluorine free blue emitters are the targets of technology
  - Different material batches of different suppliers: strong variation from batch-to-batch does not allow keeping the stable properties of the final product. Better purification of the materials for real long lifetime is necessary.
  - The impurities, in fact, do not only come from materials, but also from manufacturing the devices.
  - Quality control with advanced, accurate analytical analysis during processing is indispensable.
  - Colour tunability is a technology issue, not material problem.
  - For every new emitter, the other complementary layers need to be optimized. Modelling, on device and material level, is necessary to optimize the whole device layout.
  - The use of other conducting materials, e.g. graphene, instead of metals is an option for replacing expensive electrodes (ITO).

3.3.3 Device aspects:

- Barrier/encapsulation: suitable glues (epoxy), flexible substrate with decent barrier properties are the targets.
- Transparent cathode: window as lighting element (in a long term).
- Light Emitting Electrochemical Cells – another solid state lighting device can possibly be used.

3.3.4 Cost aspects:

- ITO is too expensive, replacement of ITO for instance, by ZnO/Al and high conductive polymers like PEDOT will be advantageous.
- Wet chemical processing is a chance for cheaper production: the use of orthogonal solvents is necessary; cross-linking of of materials post-deposition is needed.
- Development of new electroluminescent materials containing other metals is desirable: indium is an expensive metal, as well as iridium.

3.4 Classification and prioritization of different topics

The workshop was finalized with conclusions concerning prioritization of the R&D topics for the sector discussed during the session. These topics were grouped into three categories related to materials, devices and processing methods. They are presented below in the importance order, assigned by the participants of the section, who are experts in the SSL field.

3.4.1 Materials

- Focus on thermally and photo-chemically stable triplet emitters with excellent (device) efficiency.
- Developing phosphorescent blue triplet emitter with long lifetime.
- Developing new materials for barrier layers against oxygen and water for polymer substrates that are easily processable.
- Metrology and characterization for batch-to-batch reproducibility needed.
- Every new emitter materials (potentially) demands optimisation of the full material stacks in the device – modelling on material level.
- White light single molecule emission.
- Cost effective triplet emitting materials.
- Side- or end- triplet emitter functionalised polymer materials.
- Flexible substrates/devices: technology that adapts to shapes and designs.
- Life cycle analysis is necessary.

3.4.2 Devices

- Based on material parameters improve device modelling to predict device performance.
- Alternative transparent anode to replace ITO.
- Improved efficiency (> 100 lm/W) by enhancing light outcoupling, developing a high refractive index matching material between ITO and glass substrate.
- Use the wave guided light (gratings)
- Transparent air and water stable cathode (illumination of buildings).
- Lifetime improvement – accurate prediction of lifetime based on material and device characteristics.

3.4.3 Processing

- Wet chemical processing for cost effective production of large area solid state lighting panels.
- Integration of production technologies, materials tuned for the production technology, LCA.
- Flexible substrates with sufficient barrier against water and oxygen: seal the device between two foils or apply the barrier layer by the in-line process.
- Flexible and robust process.

3.5 Technical hurdles and bottlenecks

One of the disadvantages and technical hurdle of existing materials is low efficiency because of the light out-coupling problem (photons trapped in material and glass layers). In conventional OLEDs only 20% of the generated light leaves the device due to refractive index mismatch. The possibilities to avoid this problem were presented during the workshop discussions.

Material quality creates also the problem for reliable production of OLED devices. It was revealed that materials from different suppliers behave in different way, as well as different batches differ one from another. The precise characterisation of the samples assuring the reproducibility may overcome the problem.

Many aspects of processing present hurdles to the realization of (cheap) OLED light sources. Achieving high material purity, low cost, high brightness and long operation time is the most important challenge for the future. Low material purity decreases emission efficiency and operational stability of OLEDs. Analytical techniques enabling the measurement of the purity of organic materials with high accuracy are important for detection of all impurities deteriorating the performance characteristics of OLED. The measurements are necessary for the proper design and optimization of OLED layers. Modelling is a very useful tool for predicting the materials behaviour.

The bottleneck for development of SSL devices can also be the difficulty of finding the good team for international co-operation, composed of the members who do not compete but collaborate each other. They should have complementary functions: from materials' suppliers to device manufacturing companies and designers of the whole systems. Academic leaders possessing fundamental role in development of the new knowledge should participate in the teams.

Funding schemes through European Framework Programmes strengthen Europe in the world competition. Fast development of the OLED in Asian and American countries creates a competition field and certain risks for European industry. However, another way to deal with this threat, as some of disputants pointed out, is enhancement of the research teams from the third countries to participate in European projects.

To assess European potential concerning materials for OLED and SSL market the strengths & weaknesses in this field should be identified. The major hurdles for European companies are expected from the fast developing economies of Asian part of the World.

The discussion during the workshop revealed the potential strengths & weaknesses:

3.5.1 Strengths:

- Two leading lighting companies are in the field of SSL: Philips & OSRAM.
- Many leading companies in materials development area exist.
- Strong synergy potential between chemical industry, manufacturers and end-users is observed.
- Clusters of academic expertise in EU have been already formed. The examples: Cambridge, Eindhoven-Aachen-Leuven triangle, Dresden, Darmstadt.

3.5.2 Weaknesses:

- Many Asian companies reach competitive level based on OLED display experience.
- Asians can drive technology (gradual) developments to details.
- The possible threat expected: what happens when EU looses this technology next to displays? (loose jobs, contribution to GDP, etc.)

3.6 Conclusions and recommendations

It was stated that replacing all current lighting with SSL will save:

- Energy of the production process of lighting devices.
- Energy during operational use.
- Resources by efficient use of materials (small amounts).

It is evident that the industry needs more robust organic materials and systems that are more stable and do not change efficiency, colour, brightness, etc., during the life-time. High molecular organic compounds – metal complexes with big ligands may be good direction for research. The hybrid materials (HOILED) combining organic-inorganic components are very promising.

In general, the main challenges for Solid State Lighting are as follows:

- To improve efficiency of light generation.
- To improve efficiency of light out coupling.
- To improve the quality of light: tunable colour, brightness.
- To reduce the costs.

To be honest, the experts in SSL field tried to assign the time schedule for the future development. It was intensely discussed during the workshop session and finely the participants reached an agreement concerning that. The roadmap for SSL development was formulated as below:

- 2010-2011: blue phosphorescent materials, understanding the influence of material properties on device performance and visa versa, first steps in multilayer device modelling, first steps in wet chemical processing;
- 2012: batch-to-batch reproducibility/purity fully understood. Clear device specs and standards, sufficient efficiency;
- 2015: reliable device lifetime operated under realistic conditions;
- 2017: cost effective production, LCA.

The roadmap, once again, presented the main directions in which SSL branch will be developed.
Solid State Lighting presents several convergences with the other fields in which new lighting possibilities are expected: aviation, automotive industry, civil engineering or solar energy – the potential end-users of SSL devices. These branches were found also their place during the past workshop, where they addressed their needs and expectations concerning the new materials. The convergences can also be seen between the fields, in which the new materials are developed: first of all, disciplines with the prefix 'nano', e.g. nanotechnology, nanomaterials, nanoprocesses, etc. Looking for the common area of the research in different scientific domains it is possible to use resources, both financial and human, in rational and economic way.

It was pointed out that high quality products (materials, devices) need intensive collaboration on European level. The best results could be achieved by complementary research and organized actions towards the solution of common problems: the replacement of conventional sources of light with modern, economic devices based on SSL will be a target. Different companies supplying materials and research institutions developing novel products will bring their experience together to design one, advanced system. All participants of the eventual consortia should have the same interest, which is a new, high quality device based on novel materials.

Definitely, the innovation is a key driver for future European competitiveness. To strengthen the competitiveness of European industry the appropriate mechanisms promoting the innovative solutions are necessary. The role of European Commission in these actions is unquestionable. Adequate policies and funding schemes may help to extend the SSL research and development with following implementation of the best solutions.

The role of SusChem Technology Platform in organizing the research space in Europe is crucial. The next events, creating the arena for open dialogue and exchange of knowledge, similar to this workshop, are necessary.

4 Civil Engineering

Rapporteur: Alessandro Fraleoni Morgera, Chairman: Wendel Wohlleben

4.1 Background information

An overview on the construction industry was given by Dr. Christian Hubsch (BASF, Germany). The construction industry is by far the biggest private one in the world, and as such contributes to 30% of the global greenhouse gas emissions, to the 40% of the worlds energy consumes, to the 12% of the world`s water consumption, causes 10% of the world´s emission of fine dust, and can account for up to 80% of a city's carbon footprint. Moreover, it displaces the most productive land (~250 million hectares world wide, most of it primary agricultural land), it often operates in geographical hazard-prone zones, and the 40% of its wastes goes to landfills. Overall, the construction industry consumes half of the world's resources.

In addition to these numbers, Dr. Mannink (TNO, The Netherlands) showed that about the 40% of the used materials in the world is related to the construction industry, and that the 80% of our lifetime is spent in a building. In Europe, with 2,7 million enterprises, 7,2% of total employment, and a total of 26 million workers depending, directly or indirectly, on the construction sector, the construction industry is by far the major industrial sector, and the biggest industrial employer. The fragmentation of the sector is extremely high, 2.7 million enterprises, mostly in the form of SMEs (95% of them with fewer than 20 operatives, and 93% with fewer than 10 operatives).

Other points that were highlighted in the general presentation of the construction industry were the following ones:

- The sector is characterized by a very low technology level, and by a low average education level of the workforce.
- Innovation in this sector is hard to be pursued because of the company fragmentation. The end user typically gets what is offered, and is not pushing for new products, so it cannot be an effective market driver, unless new business models are developed.
- Because of the current financial crisis, about the 30% of the building companies today existing will close in the next years, if everything goes ok (sustained recovery) it will take five to ten years to get back to the pre-crisis situation. Hence, an issue of job recovery in the field is present.
- A non negligible part of the environmental impact of the industry comes also from the materials transport, from the point of production to that of use. If the materials would be lighter, this impact would be reduced.
- The long life and high price of a building are causes of absence of care for its costs of maintenance and operation. The most important thing to the builder, currently, is that the house must not have structural problems during the timeframe covered by the guarantee.
- The renovation sector is a consistent part of the overall construction sector (about 10 houses out of existing 100 ones should be renovated each year).

4.2 Trends and future needs of end-users

Key trends in the sector for the next 50 years will include improvements in energy efficiency, lowering of the labor component with respect to the overall building costs, increase of the added value of materials, reduction of the carbon footprint, rationalization of the building design, recyclability issues. These improvements will be driven mostly by political regulations, economic and cultural conditions, rather than by the market. For example, political decisions like that of EU of having zero energy buildings from 2019 on are key drivers of the market.

If we look at resources, metals will be in shortage in ten years. Many of them are already used in the existing buildings in the form of metal-ion-containing minerals, so it is very difficult to think about their recycling.

One of the strongest demographic trends in the near future will be that of densification of cities, which will in turn translate into a stronger need for new solutions in terms of materials, building and infrastructure design, resulting also in a lower carbon footprint per person.

All the above mentioned changes in the construction knowledge base and technology will be driven essentially by the new (hybrid) materials. In fact, the best way to achieve the proposed sustainability goals is to implement multifunctional, lightweight materials, able to improve existing functions (like thermal insulation) and to introduce new ones (like for example thermal inertia). It is anyway necessary to consider the issue of recyclability already during the design of materials.

Another important trend in the future will be the necessity to make people conscious of the building energy consumption, by means of specific and well visible counters for electricity, heat, water, garbage amount. This will impact on the customer-driven request for a more sustainable building.

4.3 R&D topics discussed during the sessions

Cities densification will impact heavily on a number of aspects of the building industry. There any many architect communities that are actively following this debate. In addition to the lower carbon footprint, densification of cities is a way to save land, hence to increase the sustainability of the urban development, and the overall societal, technological, environmental consequences of this phenomenon are the subject of intense research.

For example, the incoming scarcity of metals will result in a more rational design of the city development. Also the theme of the new design of building components is subject of considerable attention. In fact, to improve the building components (windows, roofs, walls, etc) from the point of view of sustainability, they must be fully redesigned (more precision in the coupling of components to avoid air/water leaks, for example, shapes designed for assembling/disassembling, etc).

In addition to that, the development of new materials will allow for the creation of new functions, mostly related to maintenance (lowering its costs or decreasing the time needed for it) and to energy (functions helping dealing with energy creation, harvesting and saving, as well as energy storage). These features will be mostly embedded in novel functional surfaces, rather than in the building structure.

The 'new design' concept is of particular interest also for the recyclability and modularity of the building components. Systems that are easy to assemble and disassemble are important, since they will save on construction time (allowing more extensive pre-fabrication) and will allow implementing recyclability. Although this approach will require definitely a re-thinking of both the current production processes and the design rules for construction materials, it will be a 'must do', driven by both policies and societal needs, and not an incremental innovation made just to gain in market share. Linked to this topic, the issue of the integration of all the building systems and infrastructures (like for example windows, inner and outer surfaces, water pipes, air-conditioning plants, etc) under a rational management was discussed. In this frame, the future buildings will also have to be somehow modular and flexible, able to respond to changing needs of the people living therein (for example ageing, births, changes of activity to be carried out within the building, etc). To do so, important new functionalities of the whole building, like inner and outer surfaces (walls, windows, doors, floors, roofs, ceilings), will need to be given multifunctional properties. Examples of these properties are sensing, energy production and spending monitoring, self-cleaning, photocatalysis (for air and dirt), energy harvesting, switchable energy filters, and switchable colors. The multifunctional surfaces of the future buildings will also embed properties like lighting and messaging, antimicrobial and antiallergenic activity, health monitoring, moisture control, anti-graffiti (also in response to more strict regulations), self-healing.

Health is another important issue, not only for homes but also for offices. As an example of the impact of these measures, it has been found that improving the work conditions under the health point of view (better lighting, healthier air) results in more productivity (less absenteeism, less illnesses).

Research and development may be helped also by demonstrator projects. Demo projects conceived as applications of already known technologies, as the Smart Energy Home (demo project of a energy-efficient house promoted by SusChem, http://www.suschem.org/content.php?pageId=3688), help in gaining experience and in building a positive image of the industry.

More pragmatic and imagination-hitting projects like ultrahigh skyscrapers (as for example the Burji Khalif in Abu Dhabi), which represent a challenge with respect to the state of the art, help in overcoming the current technological hurdles, and to push forward the research in the field. For example, for constructing the Burji Khalif new kinds of concrete, with a low weigh and an exceptionally high resistance, have been developed. Even if in Europe the increasing demographic trend is reduced with respect to China or India, and hence there is no need for developing such projects on the European sole, the European companies operating in the field may take advantage of participating to such projects by developing the necessary technology and exporting it.

For achieving these ambitious goals many types of hybrid materials are envisaged to be used / developed in the next years.
With respect to structural issues, insulation (thermal and acoustic) will be of high interest for sustainability.

In particular, structural foams, non-woven fibers, switchable insulations, flame-retardant insulators will be considered for being incorporated into the building structure. Also functional windows (energy harvesting glasses, replacement of glasses with plastics, carefully designed frames, etc) will have a strong impact on the sustainability of the future buildings.

Wood for buildings is also a material that should be the subject of intense R&D. For example, the technology for its preservation should be improved, as well as its structural properties (it's anti-seismic, and can be used in combination with other materials to build very resistant, yet lightweight, structures). In the field of renovation huge amounts of soft wood has to be substituted by hard one. In addition to that, wood building parts can be added by new functionalities, like for example self-monitoring/sensing of the structural integrity. Finally, wood-based fiber boards are extensively used in the construction industry, and their characteristics may be greatly improved (lightweight, new functionalities).

Water was also considered as an important issue in the field of sustainable buildings. In particular, problems like installation of pipes without leaks or advanced leak repair systems, collection and purification of pluvial waters, recovery and purification of used waters, methods for avoiding flooding due to sudden precipitations (water-retaining tiles, for example), water-efficient fabrication of raw materials for buildings, hot-cold water installations, production of hydrogen from water via photocatalytic water splitting were considered as important topics to be included in the R&D agenda of a sustainable construction industry.

With respect to sustainability, concrete with reduced clinker content has extremely low embodied energy, and as a side-effect it may even be more resistant than normal one.

Moreover, the concrete solidification process must be faster than the current one, to speed up the construction times and to save on labor costs.

However, to reach these goals the real understanding of the concrete behavior at various loads of clinker, or added by different additives (nanostructured or not), like TiO_2, vegetal fibers, carbon nanotubes, must be gained. This will require considerable R&D efforts, which are worth to be sustained since high performance; low environmental impact concrete will play a fundamental role in determining the sustainability of a building. This because the lightweight obtained increasing the structural properties of concrete will help in lowering the carbon footprint of the whole construction, from the production of the concrete (lower energy requirements for the fabrication and transport) to the final building finishing. The main issues to be solved will be related to a clear understanding of the interfaces between the concrete and the additives, so to be able to design new, lightweight concretes with high crack resistance.

New materials will need new designs. This will be true in particular for achieving a true modularity of constructions, so to be able to implement 'recyclability on site' (i.e. be able to dismantle the building and to use the dismantled parts already on site to fabricate (re-assemble) a new building).

Also new concepts, like for example differential properties for materials assigned to different tasks (i.e. concrete that develops different characteristics on the surface and in the bulk), will be developed, thanks to R&D efforts in the near future.

In view of the above, numerical modeling tools (multi-scale, finite elements) will be needed, able to describe the behavior of fiber-loaded concrete. The models already developed for polymers and polymer composites may be of help in this realization. For example, BASF developed a numerical model able to predict environmental effects like global warming, ozone depletion, etc, consequent to the characteristics of the construction components (concrete, insulation, windows, etc.).

These objectives will be achieved only if new paradigms of 'holistic' R&D will be pursued, as for example in a close collaboration in the full value chain, ranging from the materials producers and suppliers, to the architects, to the municipalities, regions, public entities. These collaborations will start from the new materials design, which will influence the whole R&D process.

Finally, the civil engineering field should consider also the asphalt and related topics (road construction and maintenance, asphalt formulation, inclusion of draining materials like exhausted pneumatics, etc). After a brief discussion, it was decided to postpone these considerations and to focus the rest of the session only on buildings, while it was recognized that the topic deserves further attention in the future.

4.4 Classification and prioritization of different topics

The research topics have been organized under two main categories, i.e. Drivers (themes that can shape, speed up or in any case influence the market), and Materials Topics (eminently technological points, linked to the development of new concepts, new materials or designs).

4.4.1 Drivers:

Themes of market demands:

- Flexible buildings, modular & rebuildable
- Densification of cities
- High performance structures
- Faster construction (less labor)
- Reduce embodied energy
- Scarcity of raw materials (minerals, metals)
- Supply functional surfaces
- Systems integration & (multi)functionality
- Renovation
- Wood integration
- Water management

Innovation drivers:

- Business models of construction investors
- End user: include & educate
- Enhance comfort, health & beauty
- Adapt to changing population

The R&D Topics were also subdivided into different categories, depending on the functional role of the considered material/theme.

4.4.2 R&D Topics:

High performance materials:

- Concrete rheology
- Composites & alloys
- UHP (Ultra High Performance) concrete with fibers (start from scientific understanding & modelling)
- Concrete with SiO_2, TiO_2, CNT*
  *provided risk assessment
- Differentiated properties upon differentiated structural needs (biomorph)

Energy & resource efficiency issues:

- Reduce clinker (raw materials are abundant)
- Lightweight prefabricated modules
- Insulation
- New Design of Materials (for prefabrication, processing, recyclability)

Systems approach:

- Systems approach to mounting & fixation
- Concrete with sensing / monitoring / self-healing properties
- Energy-producing facades
- Redefinition of windows (with multifunctional properties)

Wood-related topics:

- Preservation
- Combinations with other materials
- Upgrade of soft woods to hard ones
- Self-monitoring / sensing
- Wood Plastic Composites (functionality, lightweight, reduced smell)

Surfaces and coatings:

- Self-cleaning, photocatalytic (air, dirt), anti graffiti (regulations)
- Energy-harvesting
- Switchable (color, radiation filter)
- Lighting, signage
- Self-healing
- Anti-microbial, anti-allergenic
- Functional road surfaces
- Health-monitoring
- Moisture control

Water-related topics:
- Fix and avoid leaks
- Hot/cold generation
- Purify & monitor (membranes)
- Flood control
- H2 production

Insulation-related topics:
- Structural foams
- Non-wovens
- Replace glass
- Switchable
- Redesign frames
- Low-f-noise & thermal
- Flame retardancy (replace bromides)

4.4.3 Prioritization of topics

- *Prioritization of topics related to materials scarcity and resource efficiency*
  Novel Structures and properties, composites, alloys, UHP concrete + SiO2, CNT (upon health hazards assessment, fibers (modeling), less clinker, wood composites, structural foams, fiber boards

- *Prioritization of topics related to comfort, durability and low maintenance costs*
  Multifunctional surfaces for use / maintenance phase, self-cleaning, -healing, moisture control, anti-microbial, photocatalyis

- *Prioritization of topics related to renovation, systems and integration*
  Multifunctional surfaces for energy management, energy-harvest, switchable surfaces, lighting, and moisture control

- *Prioritization of topics related to densification of cities, energy and material scarcity*
  Efficient production of basic materials, concrete rheology control, design for fabrication, processing, recyclability; mounting and fixation

4.5 Technical hurdles and bottlenecks

The innovation pace is too fast, and many constructors won't keep it, and won't even like it. In fact, one of the most important bottlenecks for innovation in this field is represented by the production environment which is very fragmented. Many constructors prefer to adopt old but tested solutions rather than innovative ones, for reasons of both economic and habit nature.

Moreover, there are strong differences in the construction techniques and materials changing from Country to Country. Climate, culture, aesthetics, regulations contribute to differentiate at a great extent the construction paradigm not only from Country to Country, but even from Region to Region.

The introduction of new, expensive materials finds problems with the industry, which is very fragmented and, besides inner resistances, it is difficult to be reached from the product distribution networks. The only way to reach it effectively is to improve the distribution network, powering it as it is needed. Regulations may help in some cases, but if they are too strict they may cause the closing of numerous little companies, and the crisis for the whole sub-suppliers sectors.

The fragmentation of the value chain makes it difficult also to achieve a technology improvement driven by the increasing energy prices, although this point is not intuitive. The best achievable for an average constructor is the optimization of the existing process steps, but no radical innovation can be carried out in the current system. The more innovative the product is, the more difficult it will be to convince the stakeholders to use it (they must change their production process; change the suppliers, to lower their storage levels and to change their technical background. Also because of the low average education level it is time- and resources-expensive).

The sustainability of the building industry is also deeply affected by the renovation sector (about 10 houses out of existing 100, each year, need to be renovated). Many times the stakeholders (especially the maintainers) think in terms of 'if one thing is not made to last that much, the owner will have to call me again to fix it'. Therefore, there is a strong resistance to changes, especially in the renovation sector (but also in the fabrication one). On top of this, local culture and building appearance have to be taken into account for understanding the output of new constructions and renovation.

4.6 Conclusions and recommendations

For increasing the innovation development in the field, the role of consumers should be enhanced. They should be better informed, and be given incentives for asking innovation to the builders and maintainers. This approach must be coupled to the regulations. Moreover, the whole business model must be changed. For example, it is possible to think about the home not as a one-shot selling, but as a service coupled to maintenance, with bunches of services (for example periodic repainting of the walls, servicing to the windows or to the heating system, lighting systems updates, etc). This approach would incentive the maintainer to work always at its best for getting back to the house as least as possible and the constructor to offer integrated services, hence to project the building at its best possibilities.

To avoid problems in the short term it is needed:

- To reduce the needed resources (from example, building littler houses, or rationalizing the buildable areas).
- To decouple the economic growth and the environmental impact (i.e. to reduce the environmental impact with respect to the wealth level).
- To change the material chain, so to help lowering the need for scarce materials.

An important point that must be implemented in buildings is the recyclability, which has to be designed in a way to be able to dismantle the building and to use the dismantled parts already on site to fabricate (re-assemble) a new building.

5 Aviation and Aerospace

Rapporteur: Henrik Raeder; Chairman: Sybrand van der Zwaag

5.1 Background information

The European air transport sector contributes to about 2.6% of GDP of the Member States and creates approximately 3 million jobs[1] in Europe. Its effects on the European society and its economic development are even more far-reaching than these numbers indicate. Air transport has a considerable lubrication effect on a range of cultural and economic activities in all modern societies and enables our way of doing business and our lifestyle. The aviation and aerospace industry – with its advanced technology and well developed systems for maintaining safety and reliability – is a major provider of solutions and a source for innovation in many other industrial sectors, for example the automotive, energy and medical sectors. Its total contribution to the economy is estimated to be in excess of 10% of GDP. For a few decades, the air transport sector has grown by about 5% annually.

The spin-off effect for technology from the aviation industry to other industrial sectors is particularly pronounced for materials technology. New composite materials, joining technologies, surface coatings and computer models have been rapidly adapted by other sectors as soon as their reliability has been proven by the aviation industry.

The air transport industry faces two main challenges: cost and environment. In order to stay competitive on the global sale, European aviation industry has cost efficiency and cost reduction as main targets for all development activities. At the same time, the industry faces considerable environmental challenges, first of all related to the effect of CO_2 emissions on the climate. Today's most energy-efficient aircrafts consume 2-3 litres of fuel per passenger per 100 km.

[1] ACARE SRA2, Advisory Council for Aeronautics Research in Europe, Strategic Research Agenda 2008 addendum, www.acare4europe.com.

Materials technology, in the wider sense including computer modelling, interfaces and surface science, is a key instrument to meet both challenges. New ultra-light hybrid materials reduce the crafts' weight and thereby the fuel consumption and the operating costs, beyond that of the current fibre-polymer composites. New surface coatings reduce friction and cuts fuel consumption as well. Advanced monitoring systems and repair methods increase the lifetime of components thereby reducing replacement costs and environmental impact of parts production. A governing idea of the workshop was to explore the large number of new materials technologies, in particular hybrid materials, which may be used to address the key pair of challenges: cost and environment.

5.2 Trends and future needs of end-users

Dr. Bruno Beral, Head of Structure Research and Technology, Airbus Industries, introduced the perspectives for aviation materials in the plenary session. The ideal airplane would be extremely light weight, have wings with variable geometry, run on renewable energy, and would make no noise. After its lifetime, all its parts would be reusable or recyclable. Although far from the present-day situation, this vision is a valuable guiding start for the industry.

The vision is aligned with the customers' expectations: low operating costs, high productivity and availability, low environmental impact, and simple operation and maintenance. Improvements of the structural part of the aircraft will contribute to meet these expectations: lower operating and maintenance costs, less emissions and noise, and higher availability and productivity. Large expectation are therefore attributed to new hybrid and multifunctional materials and coatings, e.g. for multifunctional airframes with smart technologies capable of structural health monitoring, structural adaptation and self healing.

Dr. David Tilbrook from Hexcel R&T, a leading supplier of composite materials, presented the penetration of advanced composite materials in the aircraft industry, from a supplier's point of view in the parallel session. During the recent decades, the use of composites in aircraft have increased dramatically, from 5-6% in the 1980s (A310, Boeing 767), 10-15% in the 1990s (A340, Boeing 777), to 23% in the new A380 and up to 52% in the planned A350 and Boeing 787. This development has been the result of steadily increasing performance, reliability and diversity of the materials.

Tilbrook identified five main classes of challenges for composite materials in aircrafts: performance, functionality, manufacturing, environment and knowledge. Performance challenges are for example resistance to high and low temperature cycling, compression resistance, damage tolerance, and reduction of life cycle costs. Functionality challenges are structural health monitoring, management of noise and electrical hazards, validation of bonds, and integration of smart systems. Main manufacturing challenges are recycling and re-use, fabrication of large complex parts, and reduction of manufacturing costs. The environmental challenges are related to finding alternatives to petroleum feedstock, to lowering the energy use in manufacturing, and to designing for repair, recycling and re-use of parts. Finally, there are considerable challenges related to in-depth knowledge of long-term ageing effects, prediction of materials properties and characterization. In conclusion, he stated that advanced composite materials are a key enabling technology to respond to the global environmental challenges.

Prof. Theo Dingemans of Delft University represented the academic sector with a presentation about polymer-based hybrids for aerospace applications. The current generation of composites consists of a continuous fibre component (e.g. aramid, glass, carbon) and a polymer matrix that is either a thermoset (e.g. epoxy) or a thermoplast (e.g. PPS, PEEK). For some applications, the composites are laminated with metal foil, resulting in a three-phase composite (GLARE, glass-aluminium-resin). The resin and fibre components have traditionally been designed as separate components, resulting in materials with a natural chemical incompatibility.

The wish list for composite processing includes high-T_g amorphous polymers with low thermal expansion coefficient (CTE), excellent solvent resistivity and easy processing, ability for joining and welding, compression stability, and compounding of complex structural parts with high fill grades. One answer could be to use reactive oligomers (telechelics) instead of monomers for the processing. Nanocomposites are also considered for a range of aerospace applications, but similar processing problems exist. Obtaining high loadings of carbon nanotubes (CNT) and good dispersions remain problematic and structural properties do not surpass state-of-the-art polymer-fibre composites. However, work is going on to prepare continuous fibre ropes of CNT and initial results appear promising . New reactive resins with tuned affinity to CNT and other nano-fibres should be developed and the cost has to be reduced. It is clear that polymer-based hybrid materials will play a prominent role in future aircraft and spacecraft design.

New materials will have both structural and functional tasks, e.g. sensing and actuating (morphing surfaces), energy generation and storage, and self-healing abilities. In the US, NASA plays a leading and supporting role to enable new materials in the aerospace industry. Since there is no institution in Europe that parallels this role the establishment of a European (virtual) centre of excellence for aerospace materials should be considered.

5.3 R&D topics discussed during the sessions

About 20 representatives, forming a well balanced blend of academia, research institutes, materials suppliers and aircraft building industry some with very senior positions, were present at the workshop. Nearly all the participants were actively involved in the discussion and had the opportunities to express their ideas, views, agreement and disagreement. The principal challenges for hybrid materials were approached from 4 perspectives and the main findings are listed below. Irrespective of the direction of perspective two overarching challenges were agreed to apply and to set minimum requirements to be met: reduced (life cycle) cost and improved sustainability. The sustainability challenge includes a series of environmental issues, e.g. CO_2 footprint, materials scarcity and lifecycle issues like recycling of materials and reuse of parts. The discussion revisited these overarching themes several times as a basis for evaluating the various detailed challenges.

5.3.1 Topics related to existing hybrid materials

One basic challenge for the hybrid materials used in present-day aircrafts is the design optimization of complex composite structures. To overcome this challenge new knowledge and new modelling tools are required. Research to improve the understanding of interfaces in composite materials, e.g. the fibre/polymer interfaces, should lead to improved modelling tools. By applying the new modelling tools, lighter structures with longer lifetime and higher reliability than present-day structures can be realized. Damage models should increase the damage tolerance of structures. The modelling tools should also be used to off-set barriers to certification of new structures and materials.

Another serious challenge is that most composite materials that are in use today are electric insulators, which creates risks for uncontrolled electrical charges and sparks. Modification of existing composites to make them electrically conductive at all levels was proposed as an important development topic.

Other topics mentioned were the need for composites structures with better and more reliable performance under humid conditions at high temperature than present-day materials (hot-wet performance), and the need for fibre composites with higher compressive strength.

[2] K. Koziol et al., High-Performance Carbon Nanotube Fiber, Science 318, 1892 (2007)

5.3.2 Topics related to new hybrid materials

Development of new polymers specifically designed for hybrid materials was mentioned by several participants as an important research topic. The new polymers should be tailor-made such as to have an excellent fibre-polymer interface by nature, thereby controlling and improving the performance. They should be manufactured from renewable sources or possibly from old recycled material, having high damage tolerance, and could have self-healing abilities. They should be easy to repair, and at their end of life be easy to recycle or reuse. Furthermore, the number of different polymers in use should be reduced (one-fits-all vision).

New or modified reinforcement materials that could improve the performance of the hybrid materials were mentioned as a topic for further research. Conventional fibre types such as glass and aramid are interesting candidates for further development, but most interest was associated with the new carbon fibre types, e.g CNT and other carbon nanostructures.
There is a need for better methods and materials for repair of existing or near future composite structures.

Multifunctional coatings were highlighted as an important research topic related to the new hybrid materials. Such coatings cover a wide spectrum of applications, for both the exterior and interior of the aircraft. External applications are e.g. electrically conductive coatings, coatings for drag reduction, self cleaning surfaces, and de- or anti-icing surfaces. For the aircraft's interior, self-cleaning and air-cleaning surfaces can be applied.

There is a need for improved control and certification of bonds, as well as new materials and systems for repair. Self-healing sandwiches, cellular materials and in-situ mechanical health monitoring were also mentioned. Finally, the development of simple systems for morphing of large structures was mentioned as a topic.

5.3.3 Topics related to the manufacturing

Many of the topics mentioned were related to the quality and control of the manufacturing process and the final components, e.g. control of tolerance, thermal expansion coefficient (CTE) and thermal strain. There is a need to reduce the energy consumption and amount of waste in manufacturing. New developments are required to improve the scalability and ability to produce thicker structures than today's (up to 50 mm) and robotic lay-up of the composite material. Thermoplastic polymer processing was mentioned as a topic for further research.

5.3.4 Topics related to future planes

A main topic for the realization of future planes with renewable and less fuel consumption, less noise and lower cost is the concept of 'adaptive wings'. This concept includes large 'morphing' structures with variable geometry, functional coatings that adapt to the environment and air stream, in-situ health monitoring and self-healing abilities.

Other topics mentioned were related to new types of fuel and energy sources, e.g. materials for storing new types of fuels and materials for electrical flight (batteries and engines).

5.4 Prioritization of the topics

The topics discussed in the parallel session on the first day were prioritized during the morning session of the second day of the workshop. Virtually all contributors of the first day session attended the second day session, and agreed with the priority order as listed below.

5.4.1 Prioritized topics related to existing hybrid materials:

- Modelling tools to optimise design, including damage and interface modelling.
- Materials development (electrical conductivity at all levels, hot-wet performance, compression strength, damage tolerance).

5.4.2 Prioritized topics related to new hybrid materials:

- Modelling tools to optimise design, including damage and interface modelling.
- New polymers dedicated to hybrids (from renewable sources, recycling and re-use of old materials, 'one-fits-all' polymers, reversible thermosets, self-healing polymers).
- New reinforcement materials (carbon and other fibres, CNT and other nano-carbon structures, short fibre reinforced dispersion compound systems).
- New materials being more repairable than present-day solutions.
- Multifunctional coatings (electrical conductive, drag reducing, self cleaning, de-/anti-icing, air cleaning.
- Control and certification of bonds.

5.4.3 Prioritized topics related to the manufacturing:

- Quality and process control (CTE behaviour and thermal strain, tolerance control, process simulation).
- Energy saving.
- Waste avoidance.

5.4.4 Prioritized topics related to future planes:

- 'Adaptive wings' concept: large structures with variable geometry, adaptive coatings, in-situ health monitoring and self-healing.

5.5 Technical hurdles and bottlenecks

Four main bottlenecks for the development and implementation of new hybrid materials in European aviation and aerospace industry were identified during the workshop:

The first bottleneck is the lack of knowledge and accurate quantitative modelling capability that limits the industry's ability to predict the performance and reliability of composite structures over long periods of use under realistic conditions. New tools based on e.g. multi-scale modelling are required to predict the performance, reliability and damage tolerance of large and complex structures and repairs.

The second bottleneck is the lack of new breakthrough polymers that can enable a step-change in performance, life-time, sustainability, and reduced cost. Tailor-making polymers for specific fibres would be one approach to overcome this bottleneck.

The third bottleneck is related to the market and the structure of the European materials supplier industry. There is a mismatch between the size and capabilities of the materials producers and the needs of the aviation industry. The aviation materials market is dominated by small and medium sized suppliers because it is too small for the large polymer producing companies. The small and medium sized suppliers rely on short-time budgeting to survive, while development of new materials requires long term efforts. This bottleneck can be overcome by approaching wider markets than aviation in parallel, e.g. automotive, sports equipment and wind energy.

The fourth bottleneck is the limited number of funding sources for materials-related research and development. There is a strong need for partnerships between the aircraft industry, the supplier companies and public funding bodies. The European Commission should play a vital role since the aircraft and supplier industries are pan-European. It should be considered to promote the creation of a European centre of excellence for aviation and aerospace materials.

5.6 Conclusions and recommendations

The overall conclusion of the workshop is that research and development in hybrid materials may contribute significantly to enable the European aircraft industry to overcome its main challenges and bottlenecks. The R&D needs cover a wide range from fundamental studies to applied developments, making a strong partnership between public funding bodies and industry necessary. Fundamental studies on interface properties and multi-scale modelling should be financed primarily from public sources, while applied materials development and modifications should be the responsibility of the industry alone. In between, pre-competitive R&D on new hybrid materials and coatings, monitoring methods and applied modelling tools should be a task that is shared between public and private funding. Due to the pan-European nature of the aviation and supplier industry, the European Commission should play a vital role in this work.

The main recommendations of the workshop are:

- Fundamental research on interface properties in hybrid materials and multi-scale modelling of materials properties should be strengthened through (mainly) public support. The objective is to overcome the first bottleneck described in section 5.5.
- Applied research for in the prioritized topics listed in Section e4 should be supported through a strong partnership between public bodies and private companies.
- Further development and modifications of existing hybrid materials should be made by the aircraft and supplier industry in partnership with academia and research institutes. Targeting of wider markets (e.g. automotive, sports equipment, wind energy) may facilitate this investment.
- To optimise synergies and fully utilise complementarities on a European level, the creation of a European centre of excellence for aviation and aerospace materials should be considered. The centre of excellence should play a leading and supporting role to enable new materials technology in the aviation and aerospace industry.

While the recommendations as presented in this report were agreed upon by all present and support visions also expressed in other strategic documents aerospace related materials, it should be pointed out that only a handful of material supplier companies were present in the workshop. Although unavoidable for a workshop of this kind and size one should be aware of this weakness, considering the hundreds of supplier companies that are involved in the European aircraft industry. Furthermore, there were no representatives from the aircraft engine industry or from academia working with engine technology. The special requirements from this industry for high performance, high temperature hybrids, e.g. ceramic matrix hybrid materials were therefore not discussed in the workshop. Finally, as the workshop focussed on aviation, there were no representatives from the space industry.

The length of the sessions and the times for discussions were considered to be appropriate to meet the objectives for the workshop.

Common technology trend, technical requirements, common topics of interests having potential impacts

There are many common technology trends and technical requirements for the above five topics presented, particularly for the automotive industry, aviation / aerospace and civil engineering. The general common trends are better energy management (consumption, preservation and generation), improved and cost effective hybrid materials and better prediction tools.

The common topics of interests and technical requirement can be classified into the following four categories:

a. New hybrid materials

The new hybrid materials should have the following characteristics and functionality:

- Light weight structure having sufficient mechanical properties.
- Smart materials having sensing, self-monitoring, self-cleaning, self-healing, shape memory properties.
- Multi-functional materials having corrosion resistance, wear resistance, UV resistance, transparency and moisture resistance.
- Materials having capability to generate and/or store energy.
- Halogen free materials having flame retardancy to replace halogenated flame retardants.
- Materials having better recyclability so that it can be re-used to make new structures and devices (cradle-to-cradle concept).
- Low cost materials and/or materials obtained from renewable resources.

b. Prediction and evaluation tools

- Different multi-scale modeling tools which are able to predict the material properties, to optimize different structural designs, reliability and damage tolerance, the influence of an individual component on the final system, and the life time of different devices.
- High throughput tools to accelerate the screening of different materials and properties.
- Validation tools to shorten the long evaluation time when replacing an existing material by another (hybrid) material.
- Demonstrator programs and facilities to allow the evaluation of different devices and materials in the final system.

c. Manufacturing and recycle processes

- The set-up of standardized evaluation processes and methodology to make new hybrid materials, assembling and disassembling of hybrid materials.
- Development of evaluation and prediction process for the scale up of materials to large industrial quantities.
- Life cycle analysis and recyclability of different materials.
- Lower manufacturing and recycle process costs.

d. Fundamental studies

- Compatibility between different hybrid materials.
- Interface properties between hybrid materials.
- The influence of molecular structure on the material properties (mechanical, thermal, electrical, moisture sensitivity, adhesion, isolative and conductive properties of heat, noise, electricity etc.).

General conclusions and recommendations

The overall conclusion of the workshop is that research and development on materials may contribute significantly to enable the European industry for the above five industrial fields to overcome its main challenges, bottlenecks and to improve its competitiveness in order to preserve jobs and technology leadership.

The research and development effort needs to be coordinated between public funding bodies and industry necessary to cover a wide range of expertise from fundamental long term studies to industrial applications and developments.

Long term fundamental studies and prediction tools, as listed in the above section, should be financed primarily from public sources, while materials development and application modifications should be the responsibility of the industry.

The creation of centers of excellence (COE) for different fields of expertise to better coordinate different R&D efforts is highly recommended. These centers of excellence can help to link different players in the whole value chain to work together and to improve collaboration between different sectors, materials suppliers and end-users, industry and academia, materials developers and equipment manufacturers.

The COEs can be initiated by the EC via the appointment of several research institutes or universities and industry leaders in the respective field which are interested for participation in such initiatives. The interested parties can organize some special events and meetings to discuss in detail about the organizational structure and specific goals to achieve. Upon the creation of these centers of excellence, the EC can help to strengthen these new materials research by coordinating and funding new research programs and initiatives together with the academia and industry. The involved members can share the responsibility to engage other stakeholders of the full value chain to participate in the proposed research programs and activities. Through the different funding schemes supported by the EC, the academia can focus on the fundamental studies and the development of prediction tools needed by the industrial partners and the industrial partners can use these results and tools to develop new materials which can in return help to validate the fundamental theories and prediction tools.

It should be mentioned that there were not sufficient representatives from the OEMs to contribute to the workshops. SusChem Technology Platform can support future initiatives in organizing next events to create the arena for open dialogue and exchange of knowledge.

Innovation is a key driver for European competitiveness. There is definitely a strong need to strengthen materials research in future EC research programs and initiatives in order to reach the next level of materials performance in different application fields. To strengthen the competitiveness of European industry, the appropriate mechanisms promoting the creative solutions are needed. With many material manufacturers present, Europe holds a strong competitive edge compared to Asia and the USA. Maintaining the competitive edge and keeping materials development in Europe deserves strong support from the EC as this industry sector creates a large number of job opportunities, also down the value chain, and strongly contributes to the EU economy and sustainability. The role of European Commission in these actions is unquestionable. Appropriate policies and funding schemes will help to drive the stakeholders of the whole value chain of different sectors to work together to maintain European technology leadership for the future. EC investment will pay off in future growth of the GDP and strongly improved sustainability.