

STRATEGIC ENERGY TECHNOLOGY PLAN

Scientific Assessment in support of the Materials Roadmap enabling Low Carbon Energy Technologies

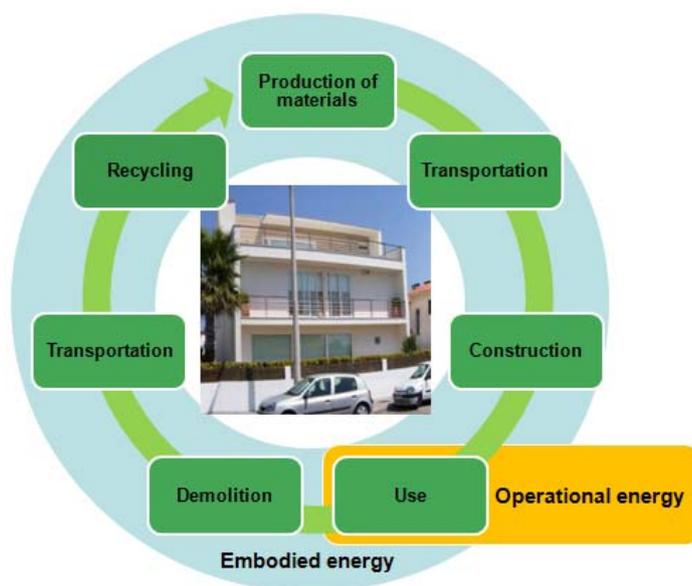
Energy efficient materials for buildings

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Preamble

This scientific assessment serves as the basis for a materials research roadmap for Energy efficient materials for buildings technology, itself an integral element of an overall "Materials Roadmap Enabling Low Carbon Technologies", a Commission Staff Working Document published in December 2011. The Materials Roadmap aims at contributing to strategic decisions on materials research funding at European and Member State levels and is aligned with the priorities of the Strategic Energy Technology Plan (SET-Plan). It is intended to serve as a guide for developing specific research and development activities in the field of materials for energy applications over the next 10 years.

This report provides an in-depth analysis of the state-of-the-art and future challenges for energy technology-related materials and the needs for research activities to support the development of Energy efficient materials for buildings technology both for the 2020 and the 2050 market horizons.

It has been produced by independent and renowned European materials scientists and energy technology experts, drawn from academia, research institutes and industry, under the coordination the SET-Plan Information System (SETIS), which is managed by the Joint Research Centre (JRC) of the European Commission. The contents were presented and discussed at a dedicated hearing in which a wide pool of stakeholders participated, including representatives of the relevant technology platforms, industry associations and the Joint Programmes of the European Energy Research Associations.

Chapter on *Energy Efficient Materials for Buildings*

For the Roadmapping Exercise on Materials for the European Strategic Energy Technology Plan

Introduction, Summary and Main Conclusions from Experts Contributions

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ABSTRACT

In the context of the SET-Plan road-mapping exercise on Materials, “Energy Efficient Materials for Buildings” have been identified as one of the challenging topics with potentials for relevant energy saving. The Experts have identified areas of possible improvements and decided to focus on reduction of i) Embodied Energy, ii) Energy in the Building Use, for some of the most important and energy-relevant building materials.

This report not only summarises main conclusions from the single Experts reports, but also includes common agreed recommendations for future research on energy efficient materials for buildings as discussed and defined during the Expert meeting (24/02/2011) and the Stakeholders meeting (31/03/2011). The Experts original reports are separately presented, as they include many detailed important information and suggestions.

References are not included in this Summary Report, as they are widely addressed in single Experts report. The Reader should thus refer to single reports for literature.

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Section 1: Technology and System State of the Art and Challenges

Building materials form the basis of any kind of construction. They determine the foundation, the structural strength and aesthetic expression of constructions and thus provide safety and comfort for all members of society. Due to the volumes needed, the construction sector is the largest raw material consuming industry. In Europe, the volume of building materials used exceeds 2 billion tons per year. The properties and combinations of materials also determine the **energy demand of buildings (about 40 % of global energy consumption)**, thus further increasing their environmental significance. In average about 20% of the overall energy consumption during a building's lifecycle is so-called **embodied energy** in materials and components, but this share increases along the improved energy-performance. In passive houses, the share may reach about 50% already. This change together with increasing demands of resource-efficiency emphasizes needs to develop and launch new energy-efficient materials that also improve the energy-efficiency of buildings. Even small improvements in the environmental performance of building materials would have a huge overall beneficial impact, *probably higher impact than that achievable focusing on any other kind of materials*. Today about 50 % of all construction costs are devoted to maintenance, repair and rehabilitation. Improvements in *functional durability* of building materials will therefore have significant impact on the total embodied energy and are of high environmental relevance.

The **operational energy use** is mostly determined by the passive environmental performance of the construction and insulation materials and the active influence of technical systems (e.g. HVAC, users, etc.). The second aspect is addressed in other activities and will not be considered in this SET plan roadmapping exercise for *Materials*.

Against this background, the main challenges and opportunities of the European building materials have to be considered. Successful answers to these challenges will help the industry to maintain and strengthen its leading position in the global market place.

A description of industry figures for the different materials is included in GMR report. In the production of the most important building materials, as ceramics, steel, glass, cement, bricks, natural stones, wood, plaster/gypsum boards, paints, insulation materials, cool roofs, etc. European industries have leading positions in the world market. All these materials can significantly improve the energy performances of buildings in different climate areas.

Challenges relating to the energy consumption in the buildings stock can be responded by current best practices to a great extent. However, these practices are mainly applicable to new buildings. The largest possibilities to reduce carbon dioxide emissions are in the **existing buildings**. 90 % of the buildings in 2050 will be built before the year 2000. Reducing emissions is a large task when refurbishing the existing building stock. Each year only about 1,5 % of the buildings in Europe are renewed or refurbished. At the existing rate it will take more than 60 years to renew and therefore some political decisions are necessary for financing an accelerated pace of change. Social awareness is highly needed so that political programs implement energy efficient refurbishment as 1st priority measure, therefore legislation and funds are allocated to that purpose. As a side effect it will also create a lot of new employment. Of course, new buildings should be constructed with special efforts to make them energy-efficient and low carbon emitters during their entire lifespan – from building and maintenance to demolishing. Novel materials should fulfil requirements of all facets of the sustainable development.

The development of energy-efficient materials for buildings is a complex issue because of the following reasons:

- Buildings are complex systems that must provide multiple functions.
- Buildings have individual characteristics because they depend on the unique site location. The variation of site conditions has the same scale as the building itself, unlike other products (cars, for example) that are only affected by geographical variations at the scale of sub-continent (climate, mostly).
- The relationship between material properties and building performance can be complex.
- The service life of buildings is very long (ISO 15686, 2000). This again contrasts with most other products that typically have a service life one order of magnitude lower (cars, electrical and electronic equipment). In addition, the actual service life very often largely exceeds (duplicates) the reference service life (that for a typical building is usually considered as 50 years (CEN 1990, 2002), even if it can be shorter for components as windows, decorative tiles or ICT components).
- Most of the environmental aspects – including the expected operational costs – have to be considered intensely already during design and erection. Later adjustments of buildings during lifetime are typically less effective, very complicate and expensive

As a consequence all Experts have described the Life Cycle of buildings. The figure 1 summarizes the view. Renovation can be an additional step in this cycle.

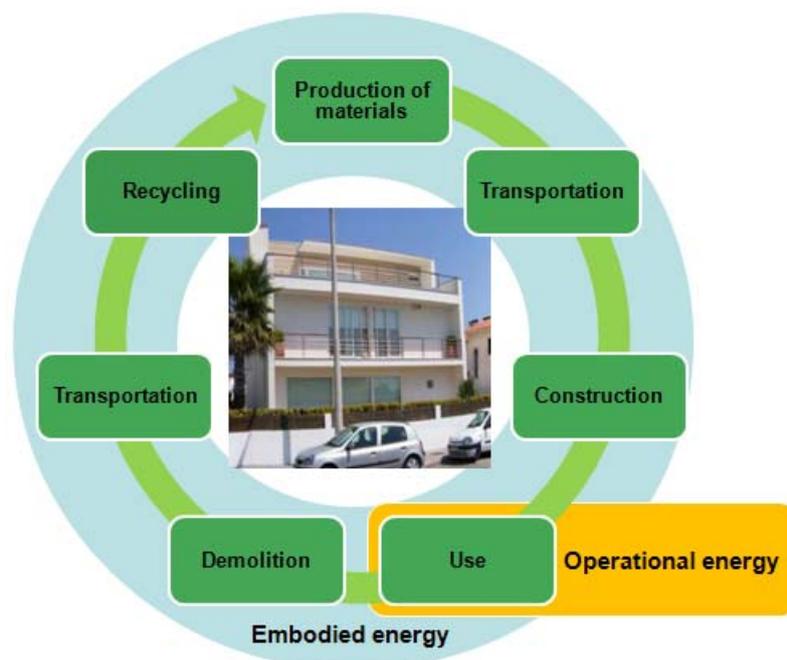


Figure 1. Life cycle analysis of a building (Gervásio, 2010)
(From the contribution of Luís Simões da Silva)

1.1. General comments

- Importance of solutions targeted to the renovation of existing buildings
- Importance of cost effective solutions and life cycle costing approach: cost effectiveness needs to be quantified in terms of a metric such as net present value per tones of carbon emissions saved, for example

- Importance of harmonization of embodied energy assessment methods – consistent with broader sustainable development objectives. (See report from Michael Sansom)
- Importance of building design and quality of execution of construction works in order to guarantee that predicted performance is achieved (need for education, training, modeling and monitoring tools in building practice)
- Material innovations need to combine high technical performance and durability with energy efficiency and low environmental impact
- There is a need for research on long term technical performance of new/emerging building materials
- Testing is required to ensure on-site performance in real building use conditions and correct assessment of the thermal and environmental performances of the building at both design and in-use stage. This requires a characterization of the products, thus enabling their performances simulation in building thermal codes

In order to have maximum achievable impacts from material innovation, it has been decided to analyse and focus on “materials and operational energy use” and “materials and embodied energy”

1.2. Materials and operational energy use

1.2.1. Scope

The transition towards energy efficient buildings presents us with three main tasks to fulfill:

- Reducing energy demand of the existing building stock and in new building practice
- Producing energy locally on a building level, with use of RES
- Transitioning towards smart grids – enabling to feed decentralized energy surpluses generated at the building level into the grid and decarbonising the grid so that the energy used in buildings has less associated carbon emissions

The general problem can be explained for example using the UK’s hierarchical approach. The levels set for each of the three targets needs to be assessed based on a robust cost effectiveness assessment that addresses buildings and the other areas included within the SET-Plan. (From the contribution of Michael Sansom)

This report focuses primarily on the energy demand side of energy efficient buildings and how this can be optimized by improved and new materials.

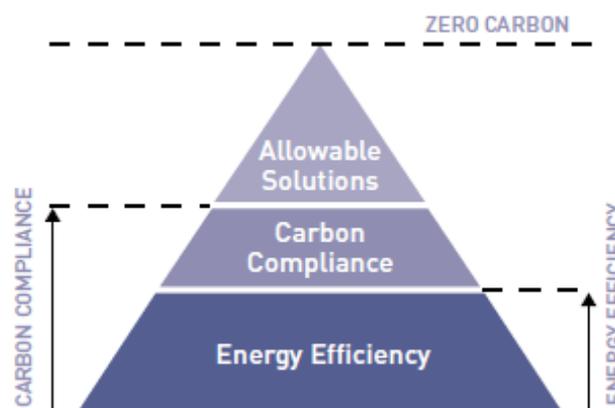


Figure 2. UK’s hierarchical approach to zero carbon buildings.
(From the contribution of Michael Sansom)

1.2.2. Measures and technologies contributing to the optimization of operational energy performance

Building energy consumptions emanates from a variety of sources, some of which are related to the building envelope or fabric, some to the equipment in the building, and some to both. Opportunities for reducing energy use in buildings through innovative materials are therefore numerous, **but there is no one system, component, or material whose improvement alone can solve the building energy problem.** Many of the loads in buildings are interactive, and this complicates cost/benefit analysis for new materials, components and systems. Moreover, building materials must be designed not only to satisfy energy efficiency and indoor comfort, but also to have optimal structural and aesthetical functionalities. For all these functionalities, material **durability** is of fundamental importance and must always be considered to last the long service lifetimes of buildings and compete successfully in the marketplace.

In order to determine the potential contribution of the different materials, it is necessary to know typical % of energy losses and use (Figure 3): it can be stated that **almost 35 % (for quite well insulated buildings, higher for most existing buildings) of the energy use can be directly connected with losses through the envelope or infiltration,** thus making the impact of building materials extremely important.

The provision of **healthy and comfortable buildings** in which to live, work and play is a crucially important issue for the construction sector in the coming years. Much of this relates to the **quality of indoor air and ventilation.** The development of functional coatings, e.g. self-cleaning or with microbiological action for healthcare buildings, is now a reality and significant further innovations in this area are expected over the coming decades.

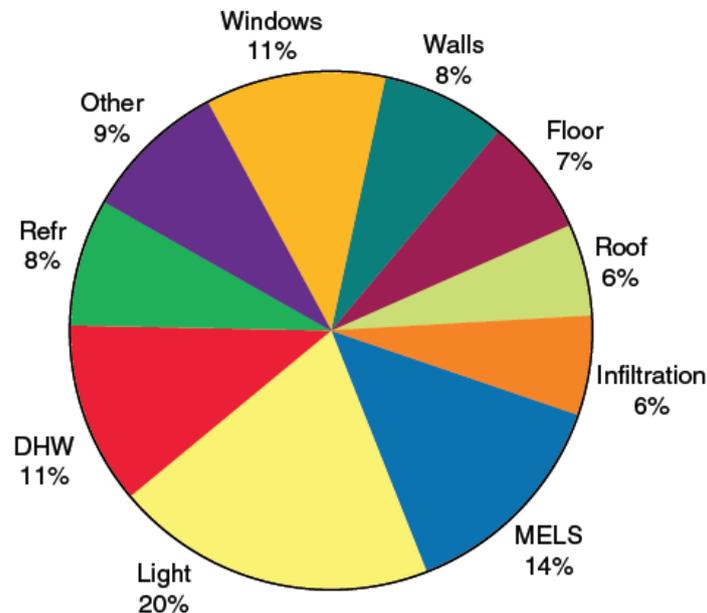


Figure 3. Relative average disaggregated end uses and losses of energy in buildings (Judkoff 2008). MELS means miscellaneous electric loads of plug loads; infiltration means leakage of air into and out of conditioned space; DHW is domestic hot water.

(from the contribution of Heli Koukkari and Gian Marco Revel)

The building envelope materials are considered to be at the core of this roadmapping exercise as defined, building technical system components are not assessed in this roadmap. So the possibilities to improve energy efficiency in use are:

A. Optimization of thermal losses and gains

- Thermal resistance
- Thermal bridging reduction
- Air tightness
- Thermal inertia, energy storage capacity
- Optimization of solar energy gains
- Solar control
- Passive cooling
- Passive thermal gains - e.g. transpired solar collectors
- Natural ventilation

B. Further optimization of energy demand side – e.g. lighting. (Should be clarified if artificial lighting systems should be included in this exercise.)

- Natural daylight transmission through glazing
- Natural daylight directing elements – e.g. sun pipes
- Coatings for interior surfaces optimizing daylight influx

C. Integration of renewable energy technologies in building envelope components

E.g. building integrated photovoltaics.

D. Energy efficient systems components – *not addressed in this roadmapping exercise*

- High efficiency lighting
- Energy efficient HVAC systems
- LZC (Low or Zero Carbon) technologies
- System control and monitoring equipment

New scientific knowledge and radically new technologies are necessary in order to effectively address the inherent inefficiencies in the physical and mechanical properties of building materials and the technical limitations of the current materials. In order to define macro-areas of research to improve cross-fertilization (between different building materials, but also from other sectors), two main families of properties can be considered:

- bulk properties (e.g. thermal insulation, heat storage, etc.);
- surface properties (e.g. infrared reflectivity for outdoor, humidity-buffering surfaces for indoor control, surface active materials, self-cleaning or with microbiological action, electrochromic materials and low emissivity coatings for windows, etc.).

In both these families, nanotechnologies can be used to improve performances and durability. The development of new functionalities of materials are still in their infancy, but their further development can play a key role in the issues of improved sustainability and environmental aspects (outdoor and indoor).

Also hybrid materials or material compounds should be considered, not new (e.g. reinforced concrete), but with still promising approaches in the fields of bionic building and compound design based on promising new material combinations.

1.2.3. *Emerging materials in need of further research*

Insulation materials

- The whole family of insulation materials is of paramount importance for energy efficiency in use, in particular to be considered for retrofitting of existing buildings. Fossil fuel based (e.g. EPS, PUS,..) and mineral based (e.g. glass wool, stone wool,...) are still the most used and can be further improved. New solutions with similar performances but lower embodied energy (e.g. based on biotic renewables or biopolymers, see par. 1.3.3) should be fully developed.
- Nanotechnology applications leading to high thermal insulation performance, e.g. vacuum insulation panels, nano-cellular foams, aerogels (with thermal conductivity up to ten times lower than conventional insulation materials)

Structural components

- Thermal break materials and thermally broken products to reduce thermal bridging – particularly in steel systems, e.g. perforated steel studs, new material combinations, etc..
- Insulation materials capable of performing load bearing functions in order to reduce thermal bridges between building structure and outdoor climate.
- Materials combining structural properties and thermal resistance, e.g. hempcrete (hemp-lime blocks), lightweight concrete.
- High performance glues

Internal finishes

- Phase change materials enabling regulation of the indoor temperature in buildings with lightweight structures that can lack thermal capacity. PCMs can be integrated in e.g. gypsum boards. PCMs are capable to store and subsequently release a great deal of heat when they transform from one phase to another. PCMs are available on the market but their true impact on the control of indoor temperatures and energy-efficiency is under development. Performance durability and fire behavior must be checked.
- Internal liner products and coatings that promote internal day lighting entrance within buildings
- Advanced multi-functional ceramic surfaces (e.g. with natural indoor air quality or moisture control)
- Plaster boards are widely diffused and can be improved to include multi-functionality.

Glazed components – light directing elements

- Window frames and glazing with high thermal insulation performance, e.g. passive window frames, vacuum glazing
- Low emissivity glazing with optimization of solar energy transmittance and daylight transmittance
- Solar shading devices such as louvers, venetian blinds, and their mechanical control systems
- Nanotechnology window coatings - self-darkening glass (e.g., electro-chromatic glass) for solar protection; self-cleaning coatings; switchable glass e.g. from transparent to translucent condition
- Light directing elements guiding daylight deep into rooms and reducing the need for artificial lighting, e.g. in the form of reflecting louvers or light shelves, light-scattering panes, light deflecting prisms or holographic-optical elements.

- Prismatic roof lights and sun pipes – designed to improve the diffusion of natural light into buildings to reduced demand for artificial lighting
- ETFE-film very light translucent building components

Adhesives and sealants

A lot of CO₂ emission reduction interventions today are not executed because of barriers related to inefficient installation processes, labour-intensive finishing or mounting processes, etc. Advanced solutions such as those that could be supplied by advanced adhesives, sealants and polymer barrier layers, for example, can enable significant cost reductions of such installation or refurbishment processes, which in turn can make refurbishment interventions cost effective and thus can have an indirect (but very substantial) impact on CO₂ footprint reduction.

External finishes coatings

- Nanotechnology coatings with variable surface optical properties (solar spectrum absorptivity and infrared emissivity)

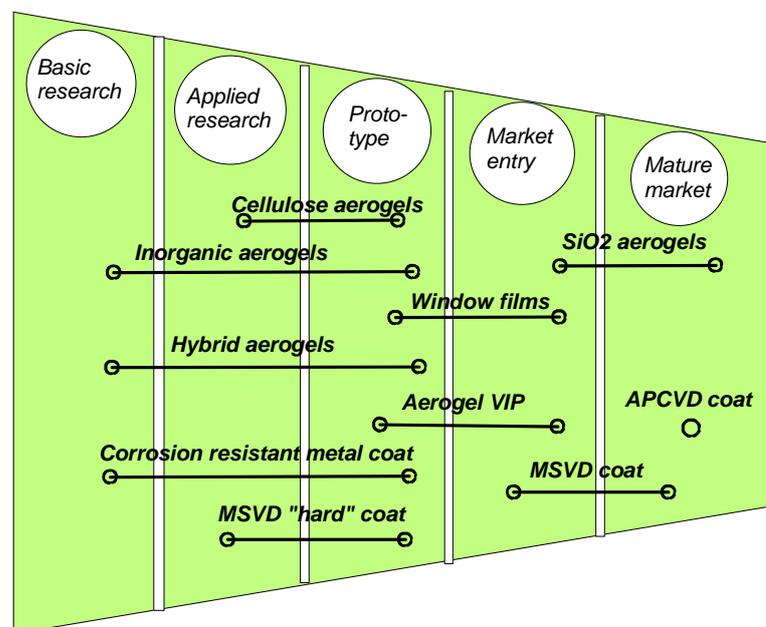


Figure 4. R&D stage of various nano-materials (Bax 2010; MSVD: Magnetron Sputtering Vapour Deposition; APCVD: Atmospheric Pressure Chemical Vapour Deposition; VIP: Vacuum Insulation Panel).

(From the contribution of Heli Koukkari)

Cost-effective integration of RES technologies and passive solar heat collectors in building envelope components

- Transparent solar wall heating wall systems making use of aerogels mounted on an absorbent external wall can capture solar heat and release it to the HVAC system for heating, hot water production, or directly to the interior environment at a later time.
- Transpired solar collectors (TSCs) integrated within external envelope systems. Generally, a TSC consists of an additional profiled metallic skin applied to a building's southerly facing elevation, comprising thousands of tiny perforations

uniformly spaced across the full face of the collector; solar radiation falling in on the collector is drawn into the building to provide heated/preheated fresh air.

- Building Integrated Photovoltaics (BIPV) is the term used for the architectural, structural and aesthetic integration of PV into buildings. A new generation of BIPV is now beginning to emerge based on flexible laminates and can be integrated directly into building products. Examples are integration of photovoltaic panels into roof cladding products or into solar shading devices. Recent advances in organic and thin-film PV technologies, produce PV materials that are more flexible, lighter weight and lower cost than conventional PV based on crystalline silicon.

Control systems, sensor and information technology

- Active, multi-functional materials emerge which improve energy consumption of buildings by nano, sensor and information technology for detection, regulation, control functions. This can be achieved by innovative nanotechnologies (e.g. material sensitive to electrical pulses), but also by full integration of ICT tools (e.g. embedded micro-sensors) in traditional materials.

1.3. Materials and embodied energy

1.3.1. Scope

Building materials significantly contributing to the life cycle embodied energy of buildings:

- Large quantities/masses of materials with rather low embodied energy intensities (e.g. concrete, brick)
- Highly processed materials used in smaller quantities (steel, aluminium)
- Layers that are frequently to be replaced during the building life cycle can also considerably contribute to the Life-Cycle embodied energy of the building (plastics, ceramic tiles)

Currently, the total life cycle operational energy represents about 80% to 85% of the total life cycle energy. However, as developments in the energy efficiency of the building envelope become more effective, the embodied energy becomes more and more important. For example, Figure 5 represents the balance between the cumulative operational and embodied energies of a building over its life-cycle, for different levels of insulation, showing that a small improvement of thermal efficiency leads to a significant increase of the proportion of embodied energy on the total energy balance. However, this applies mostly to new buildings, as in existing buildings structural materials, that represent a large share of embodied energy, are there and will not be changed.

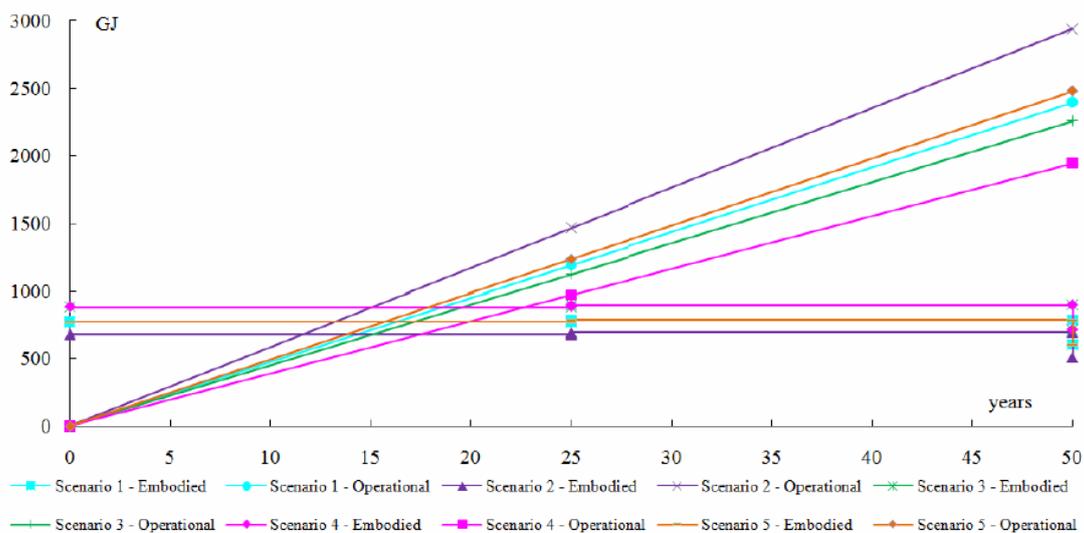


Figure 5. Balance of Life Cycle Embodied Energy and Life Cycle Operational Energy (Gervásio et al., 2010)
(From the contribution of Luís Simões da Silva)

1.3.2. Measures and technologies contributing to the optimization of life cycle embodied energy of building materials

The building envelope materials are considered to be at core of this roadmap, building technical system components are not addressed in the context of this roadmapping exercise.

A. Resource consumption

- Reduce need for raw and secondary materials e.g. by prefabrication, optimization of material use and technical performance

- Increase of recycled content, use of waste products and by-products from other industrial processes
- Use of renewable biotic or other low embodied energy resources

B. Production processes, transportation and construction

- Optimization of efficiency and energy consumption of production processes
- Use of locally sourced materials to reduce transport related energy consumption, particularly of importance for high weight building materials
- Optimization of construction processes e.g. by prefabrication, light weight building materials and structures
- Improvement of performance-based design concepts for optimization of required material properties in a holistic approach.

C. Building use phase

- Increase durability and lower maintenance needs of building materials
- Development of specific materials and processes for energy effective refurbishment.

D. Demolition and end-of-life treatment

- Increase DfD (Design for Deconstruction) product design allowing recycling or re-use
- Improvement of recycling techniques and assessment tools for recycled materials

1.3.3. *Improvements to common construction products*

Steel

Steel is manufactured by two main routes: one principally from iron ore, the other by reutilizing scrap from end of life products. The recycling of metal scrap is highly developed and economically attractive. For the first route, called 'integrated route' the energy requirement is much higher than for the secondary route (typically 18 GJ per ton of slab versus 2, 5 GJ). Energy consumption and carbon dioxide emissions from the European steel industry have decreased by 50% and 60% respectively over the past 40 years. Steel mills in Europe are now close to thermodynamic and physical limits and the margin for improvement in term of energy savings is therefore small but not negligible (10-15%). Progress will be driven by energy integration and optimization and by the recovery of waste heat, including low temperature heat. The European steel industry, supported by the European Commission, is undertaking a major program of R&D under the ULCOS project to reduce carbon dioxide emissions from steel production of today's best routes by at least 50 percent. Given the currently achieved advances and the fact that steel is largely used in other industrial fields, improving energy efficiency in primary steel-making is not considered here as a first priority.

Cement and concrete

The EU cement industry today utilizes more than 31 million tons of secondary raw materials and fuels. However, due to the high volume of material produced (e.g. cement production today is accountable for around 5 % of the anthropogenic CO₂ emissions) the cement and concrete industry still faces a number of environmental challenges. Even slight progress in production processes means significant steps in improving environmental impact. The cement industry has made significant improvements in production by using waste streams, e.g. tires to fuel cement kilns. The use of by-products as PFA and blast furnace slag (GGBFS) replacing Portland cement lead to considerable further CO₂ reductions. These cement replacements also have an important role to play in reducing the embodied carbon of concrete. Concrete and bricks account for more than 70% (in weight) of material consumption in the EU construction industry. They are currently largely down cycled as secondary aggregates for foundations and

road construction and are to a limited extent used to replace primary materials in concrete and brick production (up to 20%). There is still a big potential for further enhancing the environmentally beneficial properties of concrete, e.g. by further increase of the percentage of recycled aggregates. However, significant research activities are required to optimize such substitution to achieve similar structural long term performance as conventional concrete. On the other hand, the production process for aggregates, concrete and also natural stone have not evolved for many years. There is a large potential if labor-intensive manual lay-up can be changed to automated manufacturing methods.

Ceramics

During recent years, the clustered collaboration among ceramic manufacturers, raw materials producers and machinery manufacturers have played an important role in the innovation of ceramic products, by bringing important modifications from the point of view of the production process and decorating/finishing technologies. Energy efficiency in production processes has been improved introducing new burners, cogeneration technologies, alternative fuels, energy recovery from dryers, spray dryers, mills and kilns, but there is still room for improvement. Innovative measurement and control systems are of great importance in this field. Therefore, the combined research performed by ceramic producers and machinery suppliers is an opportunity to generate cost-effective breakthrough innovations in the sector, mainly by improving flexibility (i.e. reduction of not 1st class finished products and resources needed for the development of new products), thereby drastically modifying the production processes in terms of efficiency, energy consumption and the potential of obtaining completely new functions and properties. The same certainly also applies to other building materials such as cement.

In clay brick production, quarrying of raw materials is to a limited extent (20%) substituted with the use of selected waste materials and recycled aggregates such as paper pulp and crushed clay brick. Commercially produced extruded unfired clay units (bricks or blocks) have about 14% of the embodied carbon of fired clay bricks. Although fired bricks have a higher strength and water resistance than unfired clay, there are many situations where these properties are not required and the cost and energy savings from un-fired bricks can be realized.

In both cases developing new firing/drying technologies and/or the combination of new and traditional ones to reduce energy in manufacturing is one of the crucial.

Glass

All industrial glass is produced by melting. Melting glass at $\sim 1500^{\circ}\text{C}$ is a highly energy-intensive process which consumes ~ 80 million MWh/year. The process requires large-scale, continuous furnaces, in which fuels are combusted above a batch of continuously-fed glass raw material, and molten glass is drawn continuously from the furnace. Furthermore, a large percentage of the energy used in glass manufacture comes from fossil fuels (oil and natural gas).

Most efforts on glass industry energy savings have focused on improvements in the melting step. However, differentiation of technologies depending on the needed capacities, on the availability of energy sources, on the specification and quality needed in container glass, flat glass, glass fiber, glass wool, special glass is usually necessary and makes technological solutions more complex to implement. A life time of 3 to 12 years of the furnaces delays also the implementations.

30 to 40% energy savings have already been achieved during the last 30 years. Mainly due to: better insulation of the furnaces, improvement in refractory materials and in equipments, recycling of cullet's and reuse of defective products, changes in operating conditions. For the French industry a mean value of 6000 kWh/t in 1960, 4000 kWh/t in 1975 and 2500 kWh/t in 2005.

The melting step is common to all types of glass. The differentiation to the end product is also energy intensive but is specific to each kind of glass. Tin bath for flat glass, fiberization for glass fiber, glass non woven and glass wool, reception and curing oven for glass wool... are all specific equipments. It is sure that it is impossible to realize the objectives with only 1 technology. The big differentiation in end-products, the differences in capacities are all main reasons for the use of multiple and complementary solutions. Different ideas on new technologies have to be developed : Use of non-food biomass in the form of agricultural waste instead of fossil fuels, increase of recycled raw materials, use of new burner technologies are examples.

Aluminium

The use of aluminium in buildings and construction has kept growing over last years in spite of the decline of the sector as a whole. The European aluminium industry annually produces some 5 million tons of primary aluminium and recycles close to 4 million tons.

Due to its high intrinsic scrap value, both from a technical and economical point of view, aluminium is collected with a documented rate exceeding 90% from end-of life buildings, and is then fully recycled. Recycled aluminium retains the properties of the primary metal and saves 95% of the energy required for the production of the same amount of primary aluminium. However, products from recycled aluminum in some cases show weaker technical properties and have difficulties to comply with EU technical standards.

Renewable biotic materials (in particular for insulation)

Renewable biotic materials are by nature relatively low in embodied energy per unit of mass or volume. Particularly a shift to timber framed building constructions should be mentioned in this context, leading to significant gains in terms of embodied energy over heavyweight construction. Renewable biotic resources furthermore have a favorable carbon footprint since plants grow by absorbing CO₂. However, at end-of-life the sequestered carbon is released again, therefore a negative carbon footprint is only granted when the resource can be grown sustainable (meaning replenishment rates can follow extraction rates). For renewable such as hemp, miscanthus, bamboo a carbon-neutral cycle is considered possible, these biotic materials grow fast and have a favorable overall environmental performance. Hemp and miscanthus are used in bricks, concrete or in render composites, improving environmental performance, thermal resistance and in some cases strength.

Lightweight materials

Increased material efficiency, e.g. in the case of more slender structures and lighter materials, while maintaining or even enhancing product properties leads to material and embodied energy conservation and cost reduction. Optimizing dimensions and span distances of structural elements is of importance, giving the high embodied energy contribution of building structures. For similar reasons, lightweight concrete blocks (e.g. autoclaved aerated concrete), lightweight bricks or blocks are favorable over traditional concrete and brickwork from an environmental perspective. They are less resource intensive and have an improved thermal resistance compared to traditional concrete or brickwork. Also material transportation energy is in many cases significant and can be reduced using light materials. For example, in the ceramic industry low-thickness (e.g. 3 -5 mm) tiles or slabs are studied and produced.

These products allow lower transportation costs and easier handling on the construction site. Lastly, demolition works will be easier with lighter materials as these will also reduce the need for heavy machinery in the process with inherent increase in worker's safety and energy efficiency.

Prefabrication

Prefabrication leads to significant material savings, lower amounts of construction site waste and it presents an opportunity towards design for dismantling. Moving on-site construction activity to off-site production, leads to a more continuous activity independent of weather conditions, a better product quality and an improved control of technical and environmental characteristics. Efficiency of the construction process is of major concern to the industry. Factory production of elements, components and complete building systems (e.g. prefabricated beams, wall and floor panels, modules and other volumetric) is therefore considered to be vitally important to the future of the sector, as they allow production with lower energy consumption and costs. Prefabrication, easy handling and light materials, further than saving energy, also allow improving safety for workers, which is a serious concern for the construction industry. A much greater use of off-site factory production techniques is therefore envisaged over the coming years, also to optimize efficiency, even though issues connected with higher costs of transporting elements instead of transporting basic materials have to be solved (e.g. by proper logistics).

Design for deconstruction

Scarcity of resources, the need to improve the safety of the demolition process and minimize waste will lead to an extensive re-assessment of future demolition practices. Design for deconstruction aims at an easier disassembly and separation of building layers and building components in order to increase the potential for recycling and reuse of the materials. For building elements that are expected to be removed when still in good conditions (e.g. durable interior elements, roof or façade tiles and bricks), design for re-use is the preferable first option. Prefabrication of structural elements for example offers opportunities for re-use. Recently, brick manufacturers, aiming at an easier reclaim of bricks for re-use or recycling, have launched click-brick systems for constructing brick walls without the use of mortar. Recycling of clay bricks namely require that they have not been contaminated during their use phase with mortars, glues, wire and plumbing, paint and similar substances. For materials with short service life, especially when composed of non-renewable resources design for recycling is of vital importance. Many composite construction products although structurally efficient, are often difficult to separate and therefore materials can often not be recycled. The concept of design for deconstruction will become a reality together with innovative procurement options including uptake of product service systems and leasing. There will be a consequent need for adequate logging and tracking of materials and products through their full life cycle. The ultimate final goal will be a closed-loop system valorizing the materials to the maximum.

1.3.4. Emerging materials in need of further research

Nanotechnologies impacting durability and maintenance needs

Durability, environmental impact, overall technical performance are key parameters to be balanced in research towards and assessment of innovative building materials. Research and innovation towards prolonged product service life and minimum maintenance needs offers

significant opportunities. Currently, nanotechnology enables the use of new materials and surface properties to improve durability and reduce maintenance needs:

- Self-cleaning surfaces (e.g. lotus-effect, photo catalysis);
- Easy-to-clean surfaces which are smooth surfaces with reduce surface attraction, causing water to be repelled;
- Anti-graffiti coatings;
- Anti-bacterial surfaces, which enable bacteria to be destroyed and reduce the need for disinfectants;
- Protection of sensitive surfaces against UV sunrays (e.g., the use of UV absorbers that filter out the harmful rays in sunlight).

Bio-based plastics

One of the new growing industries is production of bioplastics. Annual growth of the European bioplastics market reached 48% in 2003 -2007 (Schen et al 2009). The world-wide production is projected to increase from its current about 360 000 tons to 2.33 million tons in 2013 and to 3.45 million tons in 2020. This is equivalent to average annual growth rates of 37% by 2013, and 6% between 2013 and 2020. The long term growth potential for bio-based products will depend on their capacity to substitute fossil-based products and to satisfy various end-use requirements at a competitive cost, to create product cycles that are neutral in terms of greenhouse gas and to leave a smaller ecological footprint, i.e. generating less waste, using less energy and less water (EU 2007 LMI action plan). The total maximum technical substitution potential of bio-based polymers replacing their petrochemical counterparts is estimated up to 90% but due to various types of barriers, this is a long term target (Schen et al. 2009).

Bio-based polymers use carbon from renewable sources such as sugar, starch, vegetable oils, and replace materials that are made using petroleum products. Polylactic acid or PLA, for example, is a relatively new biodegradable plastic made from corn, wheat or sugarcane. There are strong long-term hopes to replace even energy-intensive construction materials like steel and concrete. Biobased resins and natural fibers allow wood composites, hybrid composites and fiber insulations. Combination of various polymers and nanoparticles is one line of research. Biomaterials are manufactured from plants and trees (agricultural or forestry feedstock's). Fibers can be made from crops like hemp, flax, sisal, jute or straw. The manufacturing of films and polymers from starch is also in development, as is the production of adhesive systems based on tannins. There are also examples of getting the fibers from recycled paper for thermal insulation. Several big companies are developing or have already launched new products based on improved share of recycled and bio-based materials like e.g. Knauf's ECOSE® glass wool technology that uses starch-based resins.

Carbon negative cement and concrete

New types of cement are being developed that could reduce the embodied carbon of both cement and concrete dramatically. As an example in this field, there is on the market carbon negative cement based on a non-carbonate raw material, magnesium silicate, and uses a relatively low temperature production process. Overall, production absorbs more CO₂ than it emits. For every ton of ordinary Portland cement replaced by these cements, CO₂ emissions will be reduced by up to 900 kg. Research on carbon sequestering building materials presents us with further possibilities for "green" cement and "green" concrete, e.g. by incorporating of yeast to capture carbon dioxide from the atmosphere and convert it into solid carbonates.

The development of belitic cements seems a good alternative to the ordinary Portland cement. Belitic cements (based on C₂S silicate phase) have interesting unique properties: they can be produced in a conventional clinker kiln at a lower temperature (saving fuel) with a low amount of limestone (limited CO₂ emission). They also show low hydration heat and high chemical resistance, but they suffer from current limited application due to their scarce mechanical performance and the incompatibility with Portland cement admixtures. Geopolymers is other interesting alternative to the Portland cement, with a lower embodied energy. Geopolymer cements are an example of the broader class of alkali-activated binders, which also includes alkali-activated metallurgical slags and other related materials.

Section 2: Material Supply Status and Challenges

2.1 The Construction Market

In order to address the Material Supply Status and Challenges, the complex structure of the Construction Market and its supply chain has to be analysed.

The construction sector is one of the European Union's key industries both in terms of output and employment. The construction industry is Europe's largest industrial employer, accounting for 7.5% of total employment and 30% of industrial employment in the EU, contributing about 10% of the GDP. Construction activities consume more raw materials by weight (as much as 50%) than any other industrial sector. The built environment accounts for the largest share of greenhouse gas emissions (about 40%) in terms of energy end usage. Measured by weight, construction and demolition activities also produce Europe's largest waste stream, (between 40% and 50%) most of which is recyclable (EU, 2001).

In the period 2005-2007, the construction industry in Europe underwent a significant growth, where the year of 2007 represented the highest point in the construction boom. Between 2002 and 2007, the construction sector had a significant growth in terms of employment (17%) and turnover (41%), which was especially significant in the New Member States. The financial crisis in 2009 reverted the situation. From 2007 to 2009, construction markets have decreased, being the market for new house building the one that was mostly affected (a decrease of 35.3% in comparison to 2007) (ECORYS, 2010). Naturally, the downturn in construction activity had also a severe impact on the employment. The EU27 employment index for construction fell 7.6% between 2008 and 2009 and further 8.2% between 2009 and the beginning of 2010.

A long effort has been developed by the EC in order to assess the industry's performance and competitiveness. Following the Communication on the Competitiveness of the European Construction Industry (COM(97) 539 final), an action plan was agreed in 1999, between representatives of the European Commission, Member States and the Construction Industry. The aim of this action was "*To develop a strategy for the use and promotion of environmentally friendly construction materials; energy efficiency in buildings and construction and demolition waste management, in order to contribute to sustainability*". Three working groups were created to provide answers to the three main topics of environmentally friendly materials, energy efficiency and waste management.

More recently, the *Lead Market Initiative (COM(2007)860 final)*, a coordinated and concerted action plan introduced by the EC to facilitate the emergence of innovative products and services, has chosen Sustainable Construction as one of the six market areas of interest. In a preparatory document to the Lead Market Initiative, the main barriers to the sustainable development of the construction sector were identified and the roadmap (SEC(2007) 1729) for sustainable construction proposed several actions in order to overcome these barriers. The barriers and the proposed actions for the time period of 2008-2011 are summarized in the Report from LSS, together with all main regulatory framework for the sector.

The sustainable consumption and production is a very challenging aspect of the European Strategy towards Sustainable Development, as it requires changes to the way products and services are designed, produced, used and disposed of, taking into account producer and

consumer behaviours. To reinforce the European effort for further sustainable consumption and production and promote its sustainable industrial policy, an Action Plan (COM(2008) 397 final) was introduced, in July 2008, which seeks to substantially change consumers and producers behaviours towards better products, a leaner and cleaner production and a smarter consumption. This Action Plan identifies priority issues falling into three broad categories: (i) smarter consumption and better products; (ii) leaner production; and (iii) global action. In regard of smarter consumption, current EU legislation dealing with eco-design and labelling will be revised. The leaner production category in the Action Plan focuses on developing tools to monitor, benchmark and promote resource efficiency through life-cycle thinking. Therefore, the Community Eco-Management and Audit System (EMAS) will be revised to increase the participation of companies and reduce the administrative burden and costs to SMEs.

2.2 Specific Challenges

In relation to Energy Efficient Materials for buildings the following challenges must be further highlighted.

Raw materials

Two major problems are highlighted with respect to availability and supply of raw materials:

- Supply of large quantities of relatively abundant materials.
- Supply of rare materials.

Earth has a limited source of supplies. The availability of some non-renewable resources, including many metals and construction materials, does not currently give cause for too much concern. However, the volumes of construction minerals consumed per year are very high, which make them environmental significant. The extraction of construction minerals, apart from emissions and energy consumption due to the processes of extraction and consequent processing, tends to be very damaging to landscapes, generate noise, and have negative impacts on biodiversity. Moreover, the increasing consumption of construction minerals is related to the transformation of land into built-up area, leading to significant losses of its basic natural functions. Some specific raw materials (rare earth, for example) present significant problems of availability. These constraints affect negatively the development of new high-performance, energy efficient compound materials for construction.

The EU generally has little natural resources and is therefore strongly dependent on raw material imports. The EU Raw Materials Initiative is intended to secure access to raw materials that are of critical importance for the EU economy. About 40-50% of the total flow of raw materials in the global economy are used in the manufacturing of building products and components. The main resources addressed for building and construction are cement, steel, aggregates, timber and oil for organic materials. The EU is to a high degree self-sufficient in the production of construction minerals. However, material supply pressure are increasingly felt in the building and construction industry for metals and for energy raw materials.

The EU is highly dependent on primary metal imports, some of which, especially high tech metals, are regarded as critical. Raw Materials Initiative expert group recently defined 14 critical raw mineral materials: Antimony, Beryllium, Cobalt, Fluorspar, Gallium, Germanium, Graphite, Indium, Magnesium, Niobium, PGMs (Platinum Group Metals), Rare earths, Tantalum and Tungsten. These resources are important for emerging green technologies for

renewable energy and GHG reduction (e.g. for production of solar cells, thin-film photovoltaics). For base metals such as zinc, copper, tin and aluminum shortages of ores are already beginning to influence the building and construction market. In the case of zinc, widely used since 30% of building and construction steel is zinc coated for corrosion protection, the ratio of reserves to current consumption is approximately 20 to 30 years. Although current recycling rates for metals are relatively high, high-quality metal grades still require primary production from ores.

In order to achieve a sustainable level of resource consumption in the EU building and construction sector, the consumption of non-renewable resources must gradually decline with a decline rate that is greater than or equal to the rate of depletion. Secondly, the consumption of renewable resources must be contained within the rate of natural replenishment. The EU building and construction industry will be increasingly confronted with rising pressures on the sustainable performance of building and construction materials. Measures to achieve a sustainable level of resource consumption are found to also reduce embodied energy and embodied carbon of materials. They include increased recycling and re-use; increased use of renewables (e.g. timber, hemp, sheep wool, recycled cotton,...); reduced and efficient use of primary raw materials; improvement of durability, technical performance and multi-functionality of building materials or components. These measures are further specified in following chapters.

Recommendation: to develop a deep analysis on raw material supply chain for most eco&energy friendly solutions for the different building materials → this should be an important topic for the starting European Innovation Partnership on “Non-Energy Raw Materials for a Modern Society”.

Processes and Supply chain

One of the major complexities of the construction sector is the difficulties of achieving efficient **industrialization**. This results from the concept of a unique building that is highly entrenched in the cultural values of many societies and the dependence on unique site characteristics and constraints. The size of building parts and components also plays a major role in the barriers to industrialization, leading in many situations to a high proportion of in-situ manufacturing. Industrial processes and an efficient supply chain are thus essential requirements for energy efficient buildings and strongly influence the development of energy efficient materials for buildings.

Conservatism of the industry

Conservatism is typical of the construction sector and can create difficulty to accept new materials (lack of long term performance data which goes against the requirement to give a very long guarantee of many years) or new techniques. New techniques might be badly needed for new materials, e.g. gluing.

Education to increase skills of workers

Workers have to be properly trained to use and install traditional and new materials. This is a critical topic, we talk e.g. about Passive Houses or thermal bridges in classical building/renovation.

Waste and emissions

A great share of construction and demolition waste (C&DW) that is produced annually may be further used and/or recycled. The recycling/reuse of C&DW enables to reduce the volume of landfills and contributes to the safeguard of raw materials. For instance, concrete is a very

popular construction material. It is estimated that approximately 25 billion tonnes of concrete are manufactured globally each year. At the same time, almost 900 million tonnes of Construction and Demolition Waste (C&DW) is created annually, in which, the concrete content varies from 20% to 80% (WBCSD, 2009). Except for a few countries, the demolition waste of a concrete structure is typically disposed in landfills. However, since environmental concerns are given special attention, concrete recycling is becoming increasingly popular. According to the US Construction Materials Recycling Association (WBCSD, 2009), in the US 140 million tons of concrete are recycled each year.

Recycling, deconstruction and reuse

Reuse of building components and materials tends to reduce the emissions due to recycling processes. However, the efficiency of reusing construction materials depends on the way the materials are accessed during the demolition stage. Design for Deconstruction aims to enable an easier dismantling of the building in order to further increase the potential for recycling and reuse of the materials.

Regulatory Framework.

The general framework for the activities including the construction business is given by different **European directives** and regulations initiatives, which have to be fully considered when dealing with material's specification targets.

The two most relevant European legal acts are:

- Construction Products Regulation (CPR) (Regulation (EU) N° 305/2011 of 9 March 2011)
- Energy Performance of Buildings Directive (EPBD)

Other relevant directives are:

- Waste Directive
- REACH Regulation
- SVHC Consultation (Substances of Very High Concern)
- RoHS Directive (exemption of lead as alloying element in steel)
- Procurement Directives

The proper implementation of these Regulations and Directives (fully described in the report from LSS) is important to promote the development and use of energy efficient materials for buildings, for renovation today mostly based on incentives.

Two main changes concerning the "Basic Requirements for Construction Works" (BRCW) and "essential characteristics" of construction products in the new CPR would be taken into account:

- Construction works must also be energy-efficient, using as little energy as possible during their construction and dismantling. (BRCW 6 "Energy economy and heat retention")
- The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable (BRCW 7 "Sustainable use of natural resources") and in particular ensure the following:
 - reuse or recyclability of the construction works, their materials and parts after demolition;
 - durability of the construction works;
 - use of environmentally compatible raw and secondary materials in the construction works

Two additional aspects should be taken into account:

- The case when investing more energy in the material leads to a better energetic performance of the system
- The use waste materials in the construction works

Further to these directives, **Standardization** issues must be taken into account, mainly involving (see report from LSS):

- CEN Committees, particularly CEN/TC 350 on “Sustainability of Construction Works”
- Structural Eurocodes
- Execution Standards
- Sustainable Construction (Lead Market Initiative, EPBD, etc. with related Technical Committee)
- Fire safety
- Labelling systems (e.g. Eco-Labelling, Labelling schemes may/should be used in tendering of construction works for the setting of criteria and for the verification of compliance with criteria; ISO standards provide three types of labels)
- Certification (e.g. Environmental Management Systems (EMS))

Section 3: On-going Research and Actors in the Field of Material Research for Energy Technology Applications and Challenges

At the EU level many programmes are devoted to materials in general (mainly in the NMP – Nanotechnologies, Materials and Production FP7 Programme, but also in ENVIRONMENT and ENERGY), but none of them is specifically focussed on building materials, which on the other side currently are the largest resource consumer. Some applicative projects in the field are developed in the CONCERTO Programme (co-ordinated by the DG Energy and Transport), EUREKA Programme (the European Construction Technology Platform has used EUREKA Umbrella mechanism for implementation of its Strategic Research Agenda with the title “Technologies for a Sustainable and Competitive Construction Sector”), the CIP-EIP ECO-INNOVATION Programme and in some COST actions. Also DG Enterprise has supported specific studies in the field. Research Fund for Coal and Steel (RFCS) supports research and development traditionally for constructional steelwork. It has in recent years supported a few projects that deal with energy-efficiency or sustainability of steel-framed buildings.

The most important activity in FP7 is surely the Public Private Partnership on Energy Efficient Buildings (one of the 3 launched in the 2009 Recovery Plan). This initiative is well developing new solutions for reducing the energy bills for citizens and should be further supported. Its Roadmap (see Figure 6), perfectly in line with the recommendations in this document, *has however limited room for specific material developments, which necessarily require research also on the material itself and its scale-up and production phase.*

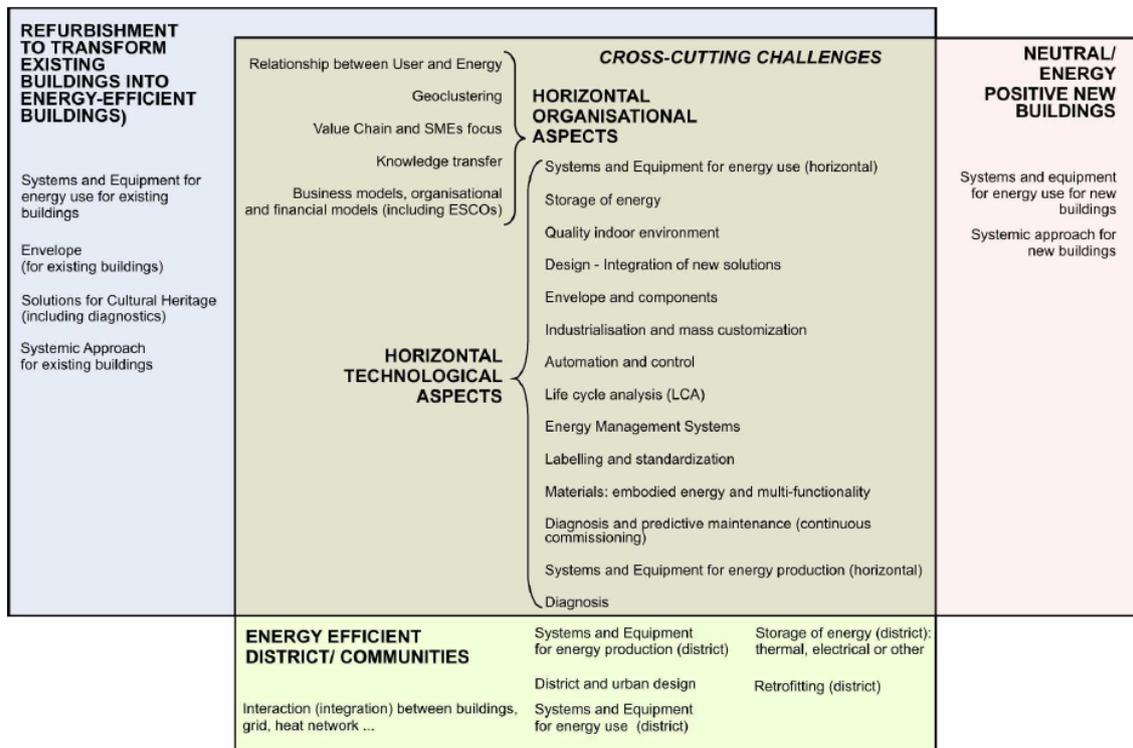


Figure 6. The overall view on the E2B Roadmap for energy-efficient buildings (E2B 2010).

A summary of the RTD Programmes in relation to various research phases is presented in Table 1.

| <i>Phase of R&D EU Programme</i> | <i>Basic</i> | <i>Applied</i> | <i>Development & Demonstration</i> | <i>Piloting and Marketing</i> |
|---|--------------|----------------|--|-----------------------------------|
| Research Programmes (FPs) Special: eco-calls | | | | |
| e.g. ECTP Umbrella | | | | |
| and Steel FCS | | | | |
| Competitive Innovation Programme CIP | | | | |
| | | | | |

Table 1. Coverage of EU RTD Programmes in relation to phases of R&D on the energy-efficient buildings.

(from the contribution of Heli Koukkari)

Several research institutions and industries are involved in research for energy efficient materials for buildings. Many of them (about 70) are grouped in the Focus Area MATERIALS of the European Construction Technology Platform, coordinated by Saint-Gobain and Università Politecnica delle Marche. They include research centres (e.g. SINTEF, VTT, TNO, CSTB, CNR, Instituto de Tecnologia Ceramica, Fraunhofer, Tecnalia (including former Labein), EMPA, etc.), Universities (Danish Technical University, Università di Bologna, Universidad Politecnica de Valencia, National Technical University of Athens, Chalmers University, etc.), material and construction Industries (Keraben, Bouygues, Elkem, Royal BAM Group, Uponor, Zueblin, Geocisa, etc.) and Associations (NANOCEM, SB Alliance, etc.).

It is important to remark that:

- most industries involved in building material research are large industries (only few are SMEs), this has to be considered in designing future R&D schemes (Calls targeted to SMEs are not appropriate in this field);
- there are many national and local programmes and groups focused on research on building materials, but their high fragmentation still makes the impact of the results in some cases not relevant (Dedicated Coordinated Actions can be used to monitor and create networks).

Other European Technology Platform to be mentioned in the field are mainly European Steel Technology Platform - ESTEP, Advanced Engineering Materials and Technologies - EUMAT, Sustainable Chemistry - SUSCHEM, Forrest based Tech. Platform - FORESTRY.

It is worthwhile to mention that in May 2011 the CSA project “Building-Up”, funded by the NMP Theme under DG Research and Innovation, will be kicked-off gathering all these material relevant Platforms with the overall goal to develop a long term roadmap for Energy-efficient Buildings which could leverage on synergies and multidisciplinary research.

The European Technology Platform for Sustainable Mineral Resources (SMR 2011) includes also aggregates and ornamental stones, and these sectors are important for the construction sector deals with the construction sector issues, too.

Initiatives and Programmes on Nanotechnologies (e.g. NANOFUTURES) are giving important inputs to new energy efficient materials, for examples on new surface functionalities.

Several building material producers (cement, steel, glass, ceramics) are working at setting up an Initiative on ENERGY INTENSIVE INDUSTRIES, which could give important inputs for reducing embodied energy in building materials, as well as looking for manners to fully exploit synergic potential energy savings..

Section 4: Material's Specification Targets for Market Implementation in 2020/2030 and in 2050

4.1 How to give Specifications for building materials

Specifications for new generation of building materials must first of all consider, further than the regulatory Framework (already discussed at Section 2); the current achievable performances.

If we consider, *for example*, the envelope, the values reported in Table 2 can be taken as optimal state-of-the-art energy efficiency measures (values currently required to improve the operational energy efficiency of new non-domestic buildings in UK).

| Energy efficiency measure | Notes |
|--|--|
| Improved envelope air-tightness | Depends on building type but 3 m ³ /h/m ² @50 pa readily achievable in most non-domestic new buildings |
| Reduced thermal bridging | Can be significant and of growing relative importance. A particular challenge for steel based systems |
| Increased roof insulation | U-value of 0.1W/m ² /k achievable |
| Increased ground floor insulation | U-value of 0.15W/m ² /k achievable |
| Increased external wall floor insulation | U-value of 0.1W/m ² /k achievable |
| Optimised glazed area | Can be significant and is very cost effective |
| Improved glazing U-value | U-value of 0.8W/m ² /k achievable |
| Solar shading | Louvers, brise soleil, double-skin facades, etc. Cost effective when integrated with solar LZCs |
| Solar control glazing | Climate dependent optimising emissivity and transmittance |
| Cool roof | High reflectance paint finish |

Table 2. Energy efficiency measures for new buildings in UK. (from the contribution of Michael Sansom)

The overwhelming importance of the envelope structures for the energy consumption of buildings due to heating demand has resulted to several kinds of activities aiming at high performance materials and products. A challenge for building scientists and materials scientists is, however, *the difficulty of assigning a quantitative energy savings value to any given materials improvement* (Judkoff 2008). The elements of a building are highly interactive in their energy performance and also dependent on the surrounding climate, building type, and usage patterns in the building.

Consequently, the building design and construction is developing toward an integrated process aiming at holistic fitness with technical, economic and well-being performance requirements. It is clearly acknowledged in several European R&D projects that the **performance-based approach is the way to realize all dimensions of sustainable construction**. The final outcome of construction processes can in matter of fact achieve in many material combinations. Also, the life-cycle targets can usually be achieved with many kinds of combinations of materials and systems.

For a product development process, *technical material characterization* may still offer a helpful tool. The same holds directing of research efforts like introduced in Table 3 that deals with high performance insulation materials and solutions. The figures given here are agreed

also by several insulation material producers who strive to nano-porous foams that would double the current thermal performance.

| <i>Property</i> | <i>Requirements</i> |
|---|---------------------------------------|
| Thermal conductivity – pristine | <4 mW/(mK) |
| Thermal conductivity – after 100 years | <5 mW/(mK) |
| Thermal conductivity – after modest perforation | <4 mW/(mK) |
| Perforation vulnerability | Not to be influenced significantly |
| Possible to cut for adaption at building site | Yes |
| Mechanical strength (e.g. compression and tensile) | May vary |
| Fire protection | May vary, depends on other protection |
| Fume emission during fire | Any toxic gases to be identified |
| Climate aging durability | Resistant |
| Freezing/thawing cycles | Resistant |
| Water | Resistant |
| Dynamic thermal insulation | Desirable as an ultimate goal |
| Costs vs other thermal insulation materials | Competitive |
| Environmental impact (including energy and material use in production, emission of polluting agents and recycling issues) | |

Table 3. Proposed requirements of the future high performance thermal insulation materials and solutions (Jelle, Gustavsen & Baetens 2010). (from the contribution of Heli Koukkari)

All various disaggregated factors are under development at the moment like window products. For them and for the external doors, minimum thermal performance values are tightening at the moment. Surface properties add complexity of the overall performance of facades and especially to that of windows.

Which is the **potential impact** of introducing large use of envelopes with higher technical specifications? As an example, the study of Uihlein & Eder (2010) only focused on windows and roofs can be used. They. concluded based on an extensive modelling of the European residential building stock that retrofitting of windows and roofs would be an additional cost-efficient way to improve the overall energy performance when the Energy Performance of Buildings Directive concerns major renovations (EU 2002, EU 2010). According to their cost-optimal scenario, the amount of greenhouse gas emissions would become smaller even faster than the EPBD evaluates (figure 7).

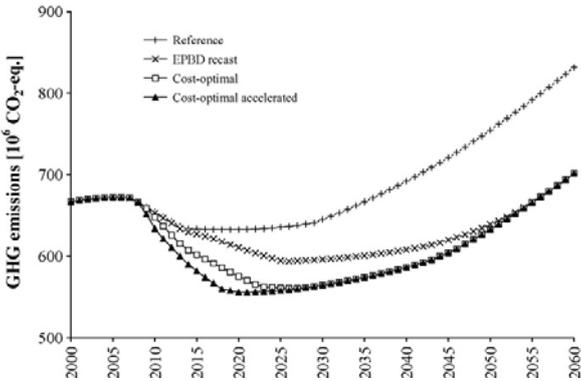


Figure 7. Impact of cost optimal renovation of windows and roofs on the greenhouse gas emissions from the European residential building stock (Uihlein & Eder 2010). (from the contribution of Heli Koukkari)

4.2 General Material's Specification Targets

Starting from similar considerations and analyses, future specifications can be derived.

In this Section 4, general Specification Targets for Energy Efficient Materials for Buildings are given. They represent general medium-long term objectives expressed in % improvements to be achieved from most of materials (given the wide variety of building materials, this is in first analysis the only possible approach). These targets are mainly derived from the the Strategic Research Agenda of Focus Area Materials of the European Construction Technology Platforms and the report from MVH.

On the contrary, **for the specific materials selected for this roadmapping exercise, specific Key Performance Indicators are given in the Table B of Section 6** of this Report.

Targets for Materials and embodied energy, production efficiency and environmental impact

- Reduction targets for raw material consumption for building and construction products of 20% by 2020. Leading to overall resource use reduction in absolute terms (absolute dematerialisation), and allowing a steep severing of reduction targets towards the “Factor 10” requirements, aiming for a 90% reduction in absolute terms by 2050.
- An increase is required in the share of materials reclaimed for re-use and recycling and in recycled content of building materials/components. The Waste Framework Directive specifies a 70% target by 2020. A 90% target by 2030 is considered achievable giving recycling and recovery rates about or above 90% reached in Flanders, the Netherlands, Denmark... today. 100 % must be achieved in 2050.
- 10 - 15 % specific reduction in CO2 emission of building materials production by 2020; 30 % by 2050
- Increasing the use of embodied energy calculations and LCA in product manufacturing, leading to EPD's (Environmental Product Declarations) compliant with CEN TC 350. Target: the large majority (>50%) of building products obtain EPD's compliant with CEN TC 350 (Sustainability of Construction Works) by 2020.
- Production time and costs reduced by 50 % through innovative, efficient and predictable manufacturing processes (long term)
- Improvement of production quality to almost 100 % of 1st choice products with high flexibility and reduced production batches tailor-made to the markets demands (long term)
- Materials suppliers are fully integrated in the construction processes
- New manufacturing processes are able to sustain the production of materials with new functionalities with low embodied energy
- Industrialised production which at the same time allows for individual design (mass customisation)
- Energy consumption for transport reduced by 30 % by optimised use of lighter materials and pavement materials

Targets for Materials and operational energy use

- Insulation and storage (thermal, acoustic, electro-magnetic) capabilities of the different envelope components increased by 30-40 % with respect to current best-performer building materials (performances specification can be measured also in terms of thermal transmittance of the building envelope, given a certain design;

example: U-value of a well-insulated wall decreased from 0.2 W/m²K to 0.12 W/m²K without increasing thickness and cost)

- Cost-effective materials (30-40 % performance improvement with no cost increase) for energy-positive new buildings
- Building materials capable to adapt 100 % indoor environmental conditions depending on changing use requirements (long term)
- Building materials are 100 % optimised for industrialised prefabrication
- Uptake of cost-effective solutions for energy renovations of buildings with optimized life cycle environmental impact and durability, by means of *integrated solutions* (materials specifically developed to fit into new products) and *energy upgrade contractors*. Target: 50% market share of *integrated solutions* and *energy upgrade contractors* in building renovation market by 2030.
- Total energy consumption reduced of 50 % by 2030 during the life cycle of new buildings: this corresponds to a mid-way between Low Scenario of penetration of SET-Plan technologies (which represents a low uptake of SET-Plan technologies, stems from the European energy outlook “*EU energy trends to 2030 — Update 2009*, DG-Energy (2010)”) and High Scenario of penetration of SET-Plan technologies, (which represents industry estimates for the uptake of SET-Plan technologies).

Section 5: Synergies with other Technologies

First of all it is worth stressing that there is a strong competition among the different building materials: **many of them can offer alternative but similar design solutions**, which in most cases are chosen by designers depending on local price and availability. So, it is not possible here to analyse synergies/competitions of all building materials among themselves, it would need a specific road-mapping exercise.

On the other side, the elements of a building are highly interactive in their energy performance and also dependent on the surrounding climate, building type, and usage patterns in the building. Therefore an **holistic approach** must be used to ensure improvement of overall performances.

In this context, material-based solutions have to be used in strong synergy mainly with:

- innovative design concepts;
- innovative construction paradigms/methods
- renewable sources;
- recycling-reuse methodologies and design concepts
- ICT tools for home automation;
- HVAC systems;
- Domestic water management systems;
- Lighting systems.

All these technologies have to be coordinated with new material solutions, but can also be somehow seen as competitive industrial technologies to approach the problem of energy efficiency. Durability/maintenance cost of solution will be a differentiating factor.

In additions, materials for construction are usually considered and classified as having traditional functionalities (structural, covering etc) and, as a consequence, they are used by builders only in a traditional way. This poses limitations to the development of new ideas and concepts in energy management of buildings. The challenge for the construction industry as a whole is to move towards knowledge-based approaches exploiting the possibility of the materials to introduce **multi-functionality**. Technology jumps can only be achieved when seeking inspiration from other, advanced fields (bio-medical, aerospace, electronics etc). The goal for the research can be summarised as “From design for the customer to design by the customer”. Service-oriented materials are therefore needed to drastically increase the range of utilisation. For example, new advanced materials and material combinations with intelligent advanced properties and intelligent functionalities, e.g. detection, regulation, control. This can be achieved by innovative nano-technologies (e.g. material sensitive to electrical pulses), but also by full integration of ICT tools (e.g. embedded micro-sensors) in traditional materials.

The main challenges in this process of synergy integration with other technologies are to develop:

- new functionalities which are potentially sustainable and which can guarantee an important socio-economic impact;
- tools to simulate, design and measure (from the basic phenomena) the materials with the new improved functionalities both at the product level and at the building level (improvement of building energy codes for low energy buildings is needed);

- cost-effective processes for the production, use and maintenance of these materials in the buildings of the future while respecting health and safety expectations of workers and users.
- awareness and dissemination actions to stimulate end users to purchase the newly developed multifunctional materials for its energy efficiency benefits.

Finally the potential interactions with industrial fields and markets where the same kind of materials are used have to be considered, particularly in terms of availability and thus costs and supply chain. This is the case e.g. for the steel use with respect to car industry or for some bio-based products with respect to food industry. In some cases replacement materials could be convenient.

Section 6: Needs and Recommendation of Activities addressing 2020 Market Implementation

In order to achieve the specified technical targets and objectives, considerable efforts are required in terms of R&D strategies, EU and Member States policies and market organization. Some general suggestions for programme implementation are hereafter given, divided in short-medium (2020) or long (2050) term actions. After that, specific roadmaps for most important materials (and product/systems based on such materials) are proposed.

6.1 Implementation suggestions

Short-Medium Term Implementation suggestions (2020)

- A critical point for establishing a EU strategy is that each material would require specific research and innovation Programme, as raw materials, production cycles and use are very different. *This has been a major problem in many FP6 and FP7 Calls, where approaches targeting more materials were required.* Therefore, even though in this SET-Plan Roadmapping exercise building materials are addressed together, an approach focused on “coherent or similar material families” is highly recommended for future R&D Programmes.
- The Public Private Partnership on Energy Efficient Buildings must be fully supported for continuation after FP7. This is in fact the major programme today promoting the development of new solutions for energy efficiency in buildings.
- It is recommended that in the future topics related to *Embodied Energy and Efficiency of Production Processes* of building materials would be more supported at the Commission level. These topics have always been considered at the edge between NMP, Energy and Environment Programmes. This caused in last years, a situation where none of these Programmes fully approached these issues and no coordinated Programme has never been launched. This caused a delay in the developments in these fields.
Also a coordination between the PPP on Energy Efficient Building and the PPP Factories of the Future would be highly recommended in this area.
- Durability evaluation is a main issue for all traditional and new building materials (e.g. for all nano-based surface functionalities), but it has never been developed in any dedicated Programme.
- As for many technology solutions for energy efficient buildings, also for materials a major problem for a competitive market development is the *demand side*. In most of the cases, the demand (e.g. local Public Authorities) is not commissioning Quality and Efficiency of building products as first requirement, whilst the “lower price” is always the main driver. This situation makes the introduction of innovations in the construction market very difficult, as Quality and Innovation are often not properly paid, i.e. have a low Return on Investment. Actions are necessary from both the Regulation side and the research side. These should be considered and developed within the *Smart Cities* Initiative under discussion at the Commission. Possible specific-material regulations could be studied (e.g. in terms of minimal energy performances of materials to be certified).
- This also concerns *Market organization*: manufacturers of innovative products, equipments, systems are rarely consulted when architects/specifiers define their construction projects. Consequently building services engineering and contractors are often working on traditional solutions. When tenders concerning products, equipments, systems are launched, it is too late to offer the innovative ones.

A condition of success in using new products, equipments, systems should be the organisation of information and/or training of architects/specifiers in order to help them to consider innovative products, equipments, systems in their projects from the beginning.

Furthermore dispositions should be proposed for facilitating experimental jobsites.

This new way to proceed would considerably speed up the innovation process in the Construction sector.

- Also the European Innovation Partnership on “Non-Energy Raw Materials for a Modern Society” is considered of interest for the building material producer.

Long Term Implementation suggestions (2050)

- At least *the target of 4 % of turnover in R&D investment should be achieved in building material industry* if a significant impact to energy efficiency must be guaranteed, combining private and public investments. In a realistic evaluation, mainly because of the world crisis, similar figures are not achievable in the short term.

- Identification and establishment of *Research Centres of Excellence* for specific (most critical) energy efficient materials for buildings. These centres should have high technical research skills unique in the world.

- Identification and establishment of strategies for a continuative full *International Coordination* of the research and its exploitation.

6.2 Specific Material R&D Recommendations, KPIs and Roadmaps

As previously stated, in order to have maximum achievable impact from material innovation, it has been decided to analyze and focus on “**materials and operational energy use**” and “**materials and embodied energy**”.

In addition, due to:

- relevance for energy efficiency of buildings;
- relevance for environmental impact;
- applicability on retrofitting;
- production volumes;
- relevance of industrial sectors in Europe;
- available skills and competences in Europe;

the Experts decided to focus and suggest to put effort on the following materials, product/systems based on such materials and their combination:

- **cement and concrete;**
- **steel;**
- **ceramics (bricks and tiles);**
- **glass (windows and frames);**
- **traditional and new insulation materials (including PCMs and insulation coatings).**

Expected impacts and targets (see Section 4) can be achieved by implementing research on these selected materials. Fibers, microfillers and nanoparticles are covered by this approach, as long as they can e.g. enhance ceramics, insulation and concrete at the same time. The same applies for e.g. adhesives and sealants for cost-effective installation, mainly in renovation works.

Other materials (as timber, composites, aluminium, plastics, etc.) can be important, but are not considered in this first roadmapping exercise and could be added in a second phase. Nevertheless, their efficiencies and accessibility (cost of production and large diffusion for the customers) must be encouraged.

Two series of Tables can be hereafter found:

TABLE A – R&D RECOMMENDATIONS: for each selected material, R&D suggestions are given for both Embodied Energy/Carbon and Operational Energy/Carbon. In particular consider the following notes as legenda:

B: Recommendations relating to reduced embodied energy/carbon

C: Recommendations relating to R&D to improve existing production of common/traditional construction materials

D: Identify new materials R&D - this could be a new cement or an entirely new material, include waste and by-product suggestions where appropriate

E: Recommendations relating to building operational energy/carbon savings as a consequence of finished product developments

F: Recommendations relating to building operational energy/carbon savings resulting from improvements to existing products and systems

G: Recommendations relating to building operational energy/carbon savings resulting from the development of new products and systems

TABLE B – KEY PERFORMANCE INDICATORS AND R&D ROADMAP: for each selected material, Key Performance Indicators are analysed and possible Roadmaps by 2020 are identified. These Roadmaps have not the ambition to be exhaustive, but can represent a starting point for implementation.

TABLE A – R&D RECOMMENDATIONS

| Material | Embodied energy/carbon (Note B) | | Operational energy/carbon (Note E) | |
|---------------------------------|--|--|--|---|
| | Traditional material production (Note C) | Alternative new materials (Note D) | Products and systems (improvements to existing) (Note F) | New products and systems (Note G) |
| KEY BUILDING MATERIALS | | | | |
| (CEMENT and) CONCRETE | Use of waste streams from other sectors to fuel cement kilns (Pozzolanic Fly Ash - PFA, Ground Granulated Blast Furnace Slab - GGBFS). Enhancing the safe carbonation of concrete during building life. Increase recycled aggregate fraction while maintaining/increasing technical properties. | Alternative energy replacements from waste PFA GGBFS recycled concrete. New cements are in development including, e.g. based on non-carbonate raw material as magnesium silicate, belite cements and geopolymers. CO2 neutral concrete (e.g. incorporating yeast - research at MIT) | Thermal concrete (e.g. distributed Styrofoam, Foam concrete) Thermally insulated products Thermal inertia (capacitance) of concrete To be further developed: light weight concrete with expanded clays as aggregates. Geopolymer precast concrete. Autoclaved aerated concrete. Cellular concrete. Concrete with stabilized PCM | Self-healing concrete; aerogels plus concrete; Nanoporous concrete |
| STEEL | R&D underway as part of the ULCOS (Ultra-Low Carbon dioxide(CO2) Steelmaking - www.ulcos.org) programme | Decarbonized fabrication with hydrogen (HE) - Development of systems and markets for the reuse of structural steel. Reducing steel use by using high strength steels | Thermally broken details: improved thermal breaks at penetrations. More advanced steel-based solar shading mechanisms with tracking capability and with integrated solar technologies. Integration of heating/cooling systems and phase change materials within lightweight structural steel systems. Development of visually acceptable exposed soffits. | Thermal studs; Systemised approach to construction including off-site, panelised and modular systems. Development of steel-based transpired solar collectors. Development of high/low solar reflectivity/absorptance coatings for steel envelope products. Development of composite products that include a steel component. Development of new steel cladding products, e.g. vacuum insulated panels, panels insulated with other (waste) streams, e.g. cellulose. |
| CERAMIC - Bricks - Tiles | Improvement of energy efficiency (large potentials in the area of new dryers, kilns, burners for kilns, dry-milling, not-firing production, alternative/waste/cleaner fuels) and performances (higher flexibility by innovative processes, new control systems) of production cycles for tiles and bricks. Increased recycled fraction in bricks, use of paperfibres for lightweight bricks. | Investigate innovative material formulations allowing reduced embodied energy by lower temperature cycles and by recycling. Bricks without mortar (click brick) easier to reclaim in case of demolition of a building. Bricks incorporating biotic renewables (e.g. hempcrete). Unfired bricks | Development of composite ceramic tiles with layers of insulating materials and higher thermal inertia - Ultra thin or elastic ceramic slabs for low-energy transport and/or prefabrication - Surface properties (e.g. infrared reflectivity for outdoor, humidity-buffering surfaces for indoor control, surface active materials, self-cleaning or with microbiological action, etc.) must be further developed and diffused - Low-cost bricks with advanced heat-storage or insulating materials | New systems for advanced facades with RES integrated (e.g. facades with solar thermal, ceramic PV tiles, etc.) - Materials with embedded sensor for life-long advanced monitoring and control New adhesives for cost-effective installations |
| GLASS - windows - frames | High limits already achieved (according to competitiveness studies - 30 to 40% energy savings have already be achieved during the last 30 years), but further improvement is still possible | Recycling content | Low-emissivity, reflection surfaces, vacuum glazing optimization of solar energy and daylight transmittance, insulated frames, passive frames, light directing elements, sun pipes, prismatic rooflights | Intelligent windows (integration to indoor and outdoor temperatures, monitoring) |

TABLE A – R&D RECOMMENDATIONS

| Material | Embodied energy/carbon (Note B) | | Operational energy/carbon (Note E) | |
|---|--|--|--|---|
| | Traditional material production (Note C) | Alternative new materials (Note D) | Products and systems (improvements to existing) (Note F) | New products and systems (Note G) |
| INSULATION MATERIALS (interesting projects in this area launched in 1st PPP EEB Call - to be monitored) | | | | |
| Traditional insulation materials | | | | |
| Fossil fuel based (Expanded Polystyrene - EPS, Extruded polystyrene - XPS, Polyurethane - PUR,...) | Increase recycling content, manufacturing efficiency and renewables in production. | Use of CO2 as a raw material substituting petroleum in polyurethane insulation (e.g. Bayer). Bio-based PUR | Nano-porous insulation (double efficient) Insulation with energy storage | Nanofoams (aerogels) - for EPS silica or carbonmatrix |
| Mineral (glass wool, stone wool, foamglass) | Increase recycling content, manufacturing efficiency and renewables in production. | Bio-based binders E.g. Ecosse glasswool (Knauf) with incorporation of biobased materials (starch-based resins). | | |
| Biotic renewables (sheep's wool, woodfibre insulation, hemp insulation...) | Renewable biotics are inherently low in embodied energy. | | | |
| Emerging insulation materials | | | | |
| Biopolymers (currently niche market, growth expected) | | High potential for substituting fossil fuel based products. E.g. biopolymer foam insulation (soy based) E.g. natural fibre insulation (with wood residue, hemp and flax fibre) with thermal bonding technology using bio-based polylactic acid (PLA). | | Nano-treated biofibres, regenerated fibers (e.g. from waste paper) |
| Nanotechnologies (e.g. insulation nanocoatings) Aerogel Vacuum Insulation Panel - VIP Nanocellular foams | | Optimization/research needed in embodied energy and life cycle impacts. | Nanotechnologies leading to high thermal performance (up to ten times higher than conventional materials) Importance of applied research e.g. on VIP for building practice or advanced sealants, particularly for low intrusive renovation works. | Potential of nanotechnologies for optimization of existing insulation materials (e.g. fossil fuel based,...) and of biobased insulation materials. E.g. Nanoporous insulation, nanotreated fibre insulations. Low emissive or high IR reflective nanocoating for building envelope components (ITO, ATO nanoparticles). |
| Materials combining structural properties and/or thermal resistance/inertia and/or lightweight - e.g. for thermal breaks | | | | |
| Foamglass, ... | Increase recycling content, manufacturing efficiency and renewables in production. | Recycling content | Constructive strength for heavy and pulling loads | Nano-foams Foam insulation with lower thermal conductivity (addition of storage capacity) Form-stables PCM with thermal conductivity improvement. |

TABLE B – KEY PERFORMANCE INDICATORS AND R&D ROADMAP

| Material | KPI target (Key Performance Indicator) | Comments | Basic research | Applied research | Pilot Actions | Reference Test facilities | Demonstration Actions | Market measures | Possible industrial implementation year | Other sectors for which synergies exist |
|---------------------------------------|--|---|---|--|---|--|--|--|---|--|
| KEY BUILDING MATERIALS | | | | | | | | | | |
| COMMON POINTS TO ALL MATERIALS | <p>NOTE: KPIs are very much dependent on design and installation on buildings, so % improvements with respect to state of the art are recommended to have realistic achievements</p> <p>Furthermore, in order to promote materials that reduce the CO₂ footprint of buildings without degrading energy performance, a notion of "TEP" (ton equivalent petroleum) related to the amount of CO₂ reduced can be introduced.</p> | <p>Materials for energy efficient buildings must be highly durable, non-toxic, aesthetically pleasing, and comfortable and safe for human interactions. It is recommended that also these properties should be considered in Programmes for Energy Efficient Materials for Buildings.</p> <p>In particular: DURABILITY evaluation is a main issue for all traditional and new building materials (e.g. for all nano-based surface functionalities), but it has never been developed in any dedicated Programme. Definition and application of common metrics. USABILITY: this would mean a good material is also characterized by handling and application questions, i.e. the user (construction worker) - material interaction.</p> <p>Standardisation of Embodied Energy</p> | <p>Generate fundamental understanding of mechanisms that influence the durability of the different properties of construction materials, products and components, including improved Life Cycle Analysis (LCA) tools and reliable, fast and robust ageing models. Develop processes to generate improved durability, including reliable test methods and inspection procedures.</p> <p>COMBINATION of materials has to be considered.</p> | <p>Development of reference test cases and advanced testing procedures to in-situ evaluate material performances</p> <p>In applied research COST is always a legislative driven issue that must be answered for each proposed step in the life cycle, This requires materials people to work together with subsystem developers and those all to work together with the total refurbishment system supplier and the final contractor of the refurbishment contract, which needs to collaborate with building owners.</p> | <p>For all selected materials, pilot actions should be focused on the most promising solutions arisen from previous basic and applied research step. (<i>WAVE approach</i>: the knowledge gained in first waves feeds into the successive projects at the design stage)</p> | <p>Prenormative research on durability evaluation procedures for new and advanced functionalities.</p> | <p>Demonstration Actions common to several materials and their combination should be implemented.</p> <p>Evaluation of the energy gain of the actions on different materials is possible only by extensive demonstration on several buildings in different Geoclusters (Coordinated Actions in the PPP EEB are running to properly define and implement Geoclusters).</p> <p>It is recommended that at least a demo case is realised in 3 different climates for each investigated technology.</p> <p>Synergies with Demo actions in the PPP EEB projects must be implemented.</p> | <p>Regulations and further Incentives to Green Solutions are necessary for the uptake of existing and advanced solutions. Construction companies (SMEs for the large part) are forced only to "lowest cost", with no incentives to offer tender solutions integrating quality, safety, environmental and life-cycle costs. Specific actions are needed to develop the Demand side, mainly from the Public side (Green Public Procurement, European eco-label, PPP...it could be further developed in the <i>Smart Cities</i> Initiative). See also Roadmap for Sustainable construction from Lead Market Initiative.</p> <p>Specific regulations for materials (e.g. minimal performances in terms of embodied energy, insulation, etc.) can be studied.</p> | <p>It can vary for different materials and products, depending on current technology level.</p> | <p>Material-based solutions have to be used in strong synergy with innovative design concepts, renewable sources, ICT tools for home automation, HVAC systems, domestic water management systems and lighting systems. Synergies with advanced ICT, nano-technologies and bio-technologies are required to achieve materials "multi-functionality". Technology jumps can only be achieved when seeking inspiration from other advanced fields (bio-medical, aerospace, electronics etc).</p> |

TABLE B – KEY PERFORMANCE INDICATORS AND R&D ROADMAP

| Material | KPI target (Key Performance Indicator) | Comments | Basic research | Applied research | Pilot Actions | Reference Test facilities | Demonstration Actions | Market measures | Possible industrial implementation year | Other sectors for which synergies exist |
|-------------------------------|--|--|--|---|---|---|---|--|---|--|
| KEY BUILDING MATERIALS | | | | | | | | | | |
| (CEMENT and) CONCRETE | Long-term target zero-emission cement; thermal energy consumption per ton of clinker from 3.8 GJ in average to 3.5 GJ; share of alternative fuel and biomass in cement production (up to 25% by 2020); Direct emissions reduced by 5 % in EU by 2020, even with a growing production trend; Clinker to cement ratio to 0.73 by 2020; CO ₂ captured in cement production up to 3-6 % by 2020, with potential means to reach 40-45 % reduction by 2050; waste content in cement or concrete (no realistic targets yet); total embodied energy per ton of concrete, CO ₂ emissions per ton of concrete, recycling content of concrete | Concrete is the second most consumed material in the World. Its embodied energy is mainly due to cement but also to aggregates. One ton of cement requires about the equivalent of 60-130 kg fuel oil or 110 kWh of electricity. Globally, due to increase in volumes, the CO ₂ emissions will grow from the current 2 billion tons to close 5 billion tons without changes in production. Over half of its targeted emissions cuts are expected to come from Carbon Capture Storage (CCS), and only one tenth from energy-efficiency by 2050. In Europe, industries are also aiming at reduction of embodied energy of concrete. | Alternative blends and their influence on concrete specifications and usability, including radical use of waste materials (even communal waste and sewage). 3 years CO ₂ capturing. 6 years Low carbon or negative carbon cements (starting from current developments).3 years The fluidised bed process. 3 years Application of nanotechnologies to improve insulation and thermal inertia properties of concrete or composite concrete structures 3 years | First production sample in industrial environment for most promising solutions investigated in first basic research step. 3 years Pre-competitive research to support international standardization on blended cements and concretes that uses a high recycling content. 3 years | Industrial Implementation of production pilots including all main developments from previous steps. 3 years | Cement industry is globally consolidated, and have own testing facilities and R&D units. In research organisations, e.g. modelling of processes at high level. Almost all building research organisations have laboratories for concrete material research. As a consequence there is no need for new test facilities, but it is suggested that a number of existing test facilities and procedures around Europe are standardised and used as references. Standardisation of production procedures. 2 years | Buildings assessed in design and monitored in use. 3 years See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | Specific actions are needed to develop the demand side, mainly from the Public side (Green Public Procurement, European eco-label, PPP...it could be further developed in the <i>Smart Cities Initiative</i>). See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | 2018-2020 | Other industries supplying with waste materials. Creation of material flows of recycling societies. Nanotechnologies |

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|--------------|--|--|---|--|--|---|--|---|--|--|
| STEEL | Reduced GHG emissions associated with steel production - ULCOS is targeting a 50% reduction relative to current Basic Oxygen Steelmaking (BOS) production. Reduced operational carbon emissions in steel framed and steel clad buildings. Greater reuse of structural steel. Greater uptake of steel-based integrated envelop products, such as pv and transpired solar collectors | In terms of steel production, ULCOS (www.ulcos.org) is the lead programme for carbon reduction. ULCOS has selected four process concepts that could lead to a reduction of Carbon dioxide(CO2) emissions by more than half compared to current best practice. The four breakthrough technologies identified are: <ul style="list-style-type: none"> • Top Gas Recycling Blast Furnace with CO2 Capture and Storage (CCS) • Hlsarna with CCS • ULCORED with CCS • Electrolysis For the Top Gas Recycling Blast Furnace, Hlsarna and ULCORED, the aim of a 50% reduction of Carbon dioxide(CO2) emissions can only be reached if each of these technologies is combined with Carbon Capture and Storage technology. Electrolysis requires the availability of Carbon dioxide(CO2)-free electricity in large quantities. Another option that might reduce the amount of Carbon dioxide(CO2) emissions in producing steel is the use of Carbon from Sustainable Biomass. <p>Work is needed however in the development of new steel-based envelope products and coatings to enable the benefits of steel construction to be realised but with reduced building operational carbon impacts.</p> | Basic research in most of the areas identified in TABLE A has already been carried out or is underway (see also previous comment on ULCOS). | Development of design with and design for reused structural steel products. 3 years Development of better thermally isolated products and details for steel construction systems. 3 years Development of transpired solar collectors and roof integrated pv. 3 years Development and testing of new advanced coatings for internal and external steel products. 3 years | ULCOS II is concerned with piloting promising technologies in the field of steel production. So these projects should be followed and supported. 5 years | Pre-normative research for the standardisation of the advanced steel-based products developed in the previous research steps. 2 years | ULCOS II is concerned with piloting promising technologies in the field of steel production. So these projects should be followed and supported. 3 years | It is important that long-term, whole life benefits of highly recyclable materials such as metals, are taken into account in the assessment and regulation of the embodied carbon impacts of buildings. Any such regulation, should be compatible with the EU's wider sustainable development objectives. Market measures to stimulate the greater reuse of structural steel would be beneficial. | This will be dependent upon the specific issue/products. | There are many synergies with other sectors. These include pv manufacturers (in terms of integrated pv products); insulation and plastics (in terms of advanced steel cladding products and thermally broken steel products); other material sectors notable timber, for more advanced and efficient composite and hybrid structures; large wind turbines (in terms of the steel used to manufacture them) |

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| Material | KPI target (Key Performance Indicator) | Comments | Basic research | Applied research | Pilot Actions | Reference Test facilities | Demonstration Actions | Market measures | Possible industrial implementation year | Other sectors for which synergies exist |
|---------------------------------------|--|---|--|--|--|---|---|---|--|--|
| KEY BUILDING MATERIALS | | | | | | | | | | |
| CERAMIC - Bricks - Tiles | 30 % specific reduction in embodied energy and CO2 emission - Production time and costs reduced by 50 % through innovative, efficient and predictable manufacturing processes • Improvement of production quality to almost 100 % of 1st choice products with high flexibility and reduced production batches tailor-made to the markets demands • Industrialised production which at the same time allows for individual design and flexibility • Insulation and storage (thermal, acoustic, electro-magnetic) capabilities increased by 30-40 % with respect to current best-performer building materials • Energy consumption for transport reduced by 30 % Long term • Ceramic products capable to adapt 100 % indoor environmental conditions depending on changing use requirements • Ceramic-based products are 100 % optimised for industrialised prefabrication | EU ceramic industry is world leader in terms of quality: State of the Art: Power Specific Electricity Consumption: 3.9 kWh/m2, Specific Gas Consumption: 31 kWh/m2. The combustion emissions are the 94% over the total manufacturing emissions. Best practice in production is already achieved and known in Europe, but improvement is possible in many areas - Many innovative functionalities are possible at the lab-scale, but are not yet cost-effective for industrial implementation - | Investigation on basics (e.g. new burners, new methods and material formulations for low temp. production, advanced dedicated control systems, etc.) – 5 years Durability Evaluation methods established for all traditional and new materials (durability for bulk and surface properties) 3 years - Investigate innovative material formulations allowing reduced embodied energy by lower temperature cycles and by recycling 3 years- Basic research for ceramic-based products capable of reducing operational energy ("composite" ceramics and bricks) - Materials with embedded sensors and devices 3 years - <i>NOTE: given the high level of competences in Europe in this field, a Centre of Excellence (also virtual, a sort of Network of Excellence) for energy-efficient ceramic materials could be very useful</i> | Investigation on new production technologies (lab-scale prototypes of production machineries embedding results from basic research) – 3 years Cost-effective industrial upscale of ceramic materials with new functionalities – 3 years Preliminary production and test of new ceramic products - Prototypes of new ceramic products and systems for advanced facades. 3 years New systems for advanced facades with RES integrated. New adhesives for cost-effective installations 4 years | Development of Pilot production lines with high efficiency and flexibility based on previous basic/applied research results. 5years Application of new materials and products in reference buildings for comparative evaluation (many reference test cases are being developed in PPP EEB projects and could be used to this aim --> this should be defined from now) 3 years | In ceramic industry some of the biggest machinery, tile or brick producers (in particular in Italy, Spain and Germany) have pilot plants where these technologies could be preliminary tested - It should be however pointed that the introduction of some of these technologies would require a complete re-design of the production processes and machines (e.g. kilns). This means that, even if these technologies are established, their improvement has large potential but requires real research effort and new reference test facilities (at least one large production pilot where different solutions can be tested) | Actions to support extensive demonstration and installation of new ceramic based products across Europe. 3 years See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | Specific actions are needed to develop the demand side, mainly from the Public side (Green Public Procurement, European eco-label, PPP...it could be further developed in the Smart Cities Initiative). Regulations for competitive materials from Far East. See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | Many industrial player of the sector are active in EU research projects and are looking for industrialization of such technologies in about 10 years (2020). So potentials for industrial implementation are high. High competition with China and Far East. | Nanotechnologies for coatings, industrial plants and burners, pv producers, etc. |

TABLE B – KEY PERFORMANCE INDICATORS AND R&D ROADMAP

| Material | KPI target (Key Performance Indicator) | Comments | Basic research | Applied research | Pilot Actions | Reference Test facilities | Demonstration Actions | Market measures | Possible industrial implementation year | Other sectors for which synergies exist |
|---------------------------------------|---|---|--|---|---|---|--|--|--|---|
| KEY BUILDING MATERIALS | | | | | | | | | | |
| GLASS - windows - frames | <p>KIPs: renewable energy in production; recycling content; overall U-value improved depending on the climatic region close to a wall.</p> <p>The average breakdown of the various sources of energy consumption in glass manufacturing processes is: 37 % of the enthalpy is required for the heating of the raw materials (20°C to 800°C) and then for melting them (800°C to 1500°C) 22 % of enthalpy is consumed by chemical reactions 27 % of enthalpy is consumed by gases heating 14 % in thermal loss (structures)</p> <p>Easier improvements have already been made during the last decennia's but the following objectives are realistic:</p> <ul style="list-style-type: none"> • >25% decrease in total energy demand. • Up to 100% reduction in CO2 emissions. • >50% reduction in NOx emissions. • Increase in demand for renewable, local energy sources by approximately 10 GWh/year. | <p>Today more than 40% of windows in the EU are still single-glazing, and another 40% are early uncoated double-glazing. In the newly published EU Energy-Efficiency Plan 2011, the market uptake of more efficient windows is presented as one action. The heat transfer through glass is large. In thermo windows the gaps are filled with gasses or vacuum that breaks the heat transfer. 30 % better with the same light transfer is probably possible.</p> | <p>Improved production processes by: use of alternative fuels (e.g. biomass) instead of fossil fuels, increase of recycled raw materials, use of new burner technologies (e.g. submerged). 5 years</p> <p>Glass with controlled light transfer, switchable properties of coatings (extention of life-cycle), energy-harvesting glasses; aerogel glazing to produce windows with a U-value of 0.1 W/m2K 5 years</p> | <p>Development, engineering includes mainstreaming the advanced solutions; Integration of glass in construction, new insulating frame materials, reducing of thermo-bridges. Applied research: uptake intelligence. 3 years</p> | <p>Cost-efficient renovation processes and products based on the advanced glass products developed in basic and applied research steps. 5 years</p> | <p>For new production processes, real scale pilots are needed to validate achievements.</p> | <p>Actions to support extensive demonstration and installation across Europe. 3 years</p> <p>See further comments on previous table "COMMON POINTS TO ALL MATERIALS"</p> | <p>Specific actions are needed to develop the demand side, mainly from the Public side (Green Public Procurement, European eco-label, PPP...it could be further developed in the Smart Cities Initiative)</p> <p>See further comments on previous table "COMMON POINTS TO ALL MATERIALS"</p> | <p>Several technologies are quite mature, industrialization can be achieved by 2016-2018</p> | <p>Nanotechnologies for coatings, Industrial plants and burners, pv producers,...</p> |

TABLE B – KEY PERFORMANCE INDICATORS AND R&D ROADMAP

| Material | KPI target (Key Performance Indicator) | Comments | Basic research | Applied research | Pilot Actions | Reference Test facilities | Demonstration Actions | Market measures | Possible industrial implementation year | Other sectors for which synergies exist |
|--|---|--|--|--|---|---|---|---|---|--|
| INSULATION MATERIALS (interesting projects in this area launched in 1st PPP EEB Call - to be monitored) | | | | | | | | | | |
| Traditional insulation materials | | | | | | | | | | |
| Fossil fuel based (Expanded Polystyrene - EPS, Extruded polystyrene - XPS, Polyurethane - PUR,...) | Material research for traditional insulation materials is to focus on enhancing thermal performance and lowering environmental impact (LCA-based measures): Lowering the use of non-renewable resources e.g. fossil energy carriers: - by increasing recycled content (e.g. use of paper fibres) up to 90 % (currently quite high) - shifting towards renewable resources (e.g. bio-based materials, being low in embodied energy, renewable and/or biodegradable). - increasing recycling potential for products with non renewables. - Increase efficiency and lowering environmental impacts of production processes - Nanotreatment enhancing thermal resistance and other product characteristics - Use of CO2 as a raw material replacing the use of fossil energy carriers. | Several major foam insulation producers claim to develop nano-porous materials (with an estimated breakthrough time up to 15 years). However currently few aerogel insulations are on the market. Timeline: basic research on nano-treatment (5-15 years) | Basic research on nano treatment: Nano-porous insulation double efficient in terms of thermal resistance. Nano-porosity chemistry; Modelling short term and long-term mechanics and physics of new materials Hybrid aerogels Use of CO2 as a raw material substituting petroleum in e.g. polyurethane insulation. Substitution towards/incorporation of biobased materials e.g. Ecosse glasswool (Knauf) with incorporation of starch-based resins. 4 years | Investigation on new production technologies (lab-scale prototypes of production machineries embedding results from basic research) - Cost-effective industrial upscale - Preliminary production and test of new products - Prototypes of new products and systems. Nano-porous insulation occupational health 3 years | Development of Pilot production lines, pilot applications of new products in buildings. 5 years | All global producers of insulation materials and chemicals have excellent laboratories; most of the building sector R&D organisations have testing facilities for products on markets. Dedicated test facilities and procedures (in particular those for nanotechnologies) needs to be standardised at the EU level. | Buildings assessed in design and monitored in use. 3 years See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | Specific actions are needed to develop the demand side, mainly from the Public side (Green Public Procurement, European eco-label, PPP...it could be further developed in the Smart Cities Initiative) See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | Nano-porous insulation EPS, PUR, etc. are fully used on the market by 2018-2020 | Chemical Industry, Nanotechnology |
| Mineral (glass wool, stone wool, foamglass) | | | | | | | | | | |
| Biotic renewables (sheep's wool, woodfibre insulation, hemp insulation...) | Significant improvement of industrial use For renewable such as hemp, miscanthus, bamboo a carbon-neutral cycle is considered possible, these biotic materials grow fast and have a favorable overall environmental performance. | Renewable biotics are inherently low in embodied energy. Hemp and miscanthus are used in bricks, concrete or in render composites. | Development of sustainable growth solutions in different fields (e.g. timber based). Particularly a shift to timber framed building constructions should be mentioned. 3 years | Sample productions developed. 3 years | Pilot applications of new products in buildings 3 years | | Buildings assessed in design and monitored in use. 3 years See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | | Industrialization possible in short times, if sustainable solutions are found. | Biologists, natural products industries. |

TABLE B – KEY PERFORMANCE INDICATORS AND R&D ROADMAP

| Material | KPI target (Key Performance Indicator) | Comments | Basic research | Applied research | Pilot Actions | Reference Test facilities | Demonstration Actions | Market measures | Possible industrial implementation year | Other sectors for which synergies exist |
|--|---|--|--|---|---|---|--|--|---|---|
| INSULATION MATERIALS (interesting projects in this area launched in 1st PPP EEB Call - to be monitored) | | | | | | | | | | |
| Emerging insulation materials | | | | | | | | | | |
| Biopolymers (currently niche market, growth expected) | - Emerging market of biobased materials: resources that are renewable in less than 10 years, low in embodied energy, carbon neutral and/or biodegradable. - approx. 1-4% market share for biopolymers by 2020 mentioned by JRC/IPTS (estimation dates from 2005). - Research is needed on potential gains in terms of embodied energy compared to conventional materials and on LCA of bio-based materials. - High efficiency manufacturing (lower costs, higher speed, reduced energy and process resource consumption) and growth in market share leading to cost competitiveness. | Biobased-polymers can technically replace up to 90% of petroleum-based polymers at a longer run but mainly due to problems in feedstock availability the growth is slower. Dependence on establishment of strategically important bio-refinery pilot plants and demonstrators in the EU (LMI). Dependent on gasification plants for new process as well. | Basic research on bio-based insulation materials as an alternative for fossil fuel based insulation materials. Chemistry and manufacture of nanotreated biopolymers and fibres from various sources; bio-based binders E.g. soy based biopolymer foam insulation; natural fibre insulation (with wood residue, hemp and flax fibre) with thermal bonding technology using bio-based PLA. Basic research on nano-treated biofibres. Basic research on raw materials and industrialization. 4 years | Investigation on new production technologies (lab-scale prototypes of production machineries embedding results from basic research) - Cost-effective industrial upscale - Preliminary production and test of new products - Prototypes of new products and systems. Transparent and dedicated LCA methodology 3 years | Development of Pilot production lines, pilot applications of new products in buildings. 4 years | All global producers of wooden materials have access to laboratories through partnerships; most of the building sector R&D organisations have testing facilities for products on markets. Dedicated test facilities and procedures (in particular those for nanotech.) needs to be standardised at the EU level. | Buildings assessed in design and monitored in use. 3 years See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | Specific actions are needed to develop the demand side, mainly from the Public side (Green Public Procurement, European eco-label, PPP...it could be further developed in the Smart Cities Initiative) See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | Nano-porous bio-based polymers are fully used on the market by 2020 | Bioenergy, agriculture |

TABLE B – KEY PERFORMANCE INDICATORS AND R&D ROADMAP

| Material | KPI target (Key Performance Indicator) | Comments | Basic research | Applied research | Pilot Actions | Reference Test facilities | Demonstration Actions | Market measures | Possible industrial implementation year | Other sectors for which synergies exist |
|--|--|---------------------------------------|--|--|---|---|---|---|--|---|
| INSULATION MATERIALS (interesting projects in this area launched in 1st PPP EEB Call - to be monitored) | | | | | | | | | | |
| Emerging insulation materials | | | | | | | | | | |
| Nanotechnologies (e.g. insulation nanocoatings) | Nanotechnologies play a key role in enhancing technical performance of building materials. | Many American products in the market. | Basic research for material development and optimization (e.g. on new aerogels) Potential of nanotechnologies for optimization of existing insulation materials (e.g. fossil fuel based,...) and of biobased insulation materials. E.g. Nanoporous insulation, nanotreated fibre insulations. Optimization/research needed in embodied energy and life cycle impacts. New generation VIPs. 4 years | Importance of applied research e.g. on VIP for building practice, advanced sealants or low emissive nanocoatings, particularly for low intrusive renovation works. Upscale and optimization needed to achieve cost competitiveness with conventional materials. Long term durability evaluation. Joining technologies. 3 years | Development of Pilot production lines, pilot applications of new products in buildings. 4 years | Many testing facilities already existing in many EU labs. Dedicated test facilities and procedures (in particular those for nanotech.) needs to be standardised at the EU level. 3 years | Buildings assessed in design and monitored in use. 3 years See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | Specific actions are needed to develop the demand side, mainly from the Public side (Green Public Procurement, European eco-label, PPP...it could be further developed in the Smart Cities Initiative) See further comments on previous table "COMMON POINTS TO ALL MATERIALS" | New generation VIPs potentially in the market by 2018. | Nanotechnologies play a key role, e.g. for enhancing performance of many building materials mentioned in this roadmapping exercise. Further synergies with advanced ICT, bio-technologies, aerospace, electronics etc). |
| Aerogel | Nanobased insulation materials (aerogels, VIP, nanocellular foams) have a high thermal performance (up to ten times higher than conventional materials). Main challenges; - Achieving cost competitiveness and increasing market share (currently niche market, partially due to high cost). | | | | | | | | | |
| Vacuum Insulation Panel - VIP | - Optimization/research needed in embodied energy and life cycle impacts. - Insulation material easy applicable for retrofitted buildings. | | | | | | | | | |
| Nanocellular foams | | | | | | | | | | |

TABLE B – KEY PERFORMANCE INDICATORS AND R&D ROADMAP

| Material | KPI target (Key Performance Indicator) | Comments | Basic research | Applied research | Pilot Actions | Reference Test facilities | Demonstration Actions | Market measures | Possible industrial implementation year | Other sectors for which synergies exist |
|---|---|----------|--|---|---|---------------------------|-----------------------|-----------------|---|---|
| INSULATION MATERIALS (interesting projects in this area launched in 1st PPP EEB Call - to be monitored) | | | | | | | | | | |
| Materials combining structural properties and/or thermal resistance/inertia and/or lightweight - e.g. for thermal breaks | | | | | | | | | | |
| Foamglass, ... | Breaking cold bridges between structure and surroundings. New construction material, combination between reinforcement and insulating material. (Raw materials are flexible). | | Basic Research for material optimization 3 years | Applied research to investigate new constructive solutions. 3 years | Buildings assessed in design and monitored in use. 2 years | | | | | |
| Light thermal inertia materials | Improvement of the thermal inertia in lightweight materials with the use of additives | | Production of form-stable PCM additives Incorporation in a huge range of new and ordinary construction materials 3 years | Specific test analysis in the final product characterization 2 years | Pilot scale of the additives Plant scale of the incorporation process 2 years | | | | | |
| OTHER (important, but not considered in this first approach) | | | | | | | | | | |
| Biobased plastics | | | | | | | | | | |
| Aluminium | | | | | | | | | | |
| Timber | | | | | | | | | | |

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Energy efficient materials for buildings

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Abstract

In the context of the SET-Plan road-mapping exercise on Materials, “Energy Efficient Materials for Buildings” have been identified as one of the challenging topics with potentials for relevant energy saving. The Experts have identified areas of possible improvements and decided to focus on reduction of i) Embodied Energy, ii) Energy in the Building Use, for some of the most important and energy-relevant building materials.

This report not only summarises main conclusions from the single Experts reports, but also includes common agreed recommendations for future research on energy efficient materials for buildings as discussed and defined during the Expert meeting (24/02/2011) and the Stakeholders meeting (31/03/2011). The Experts original reports are separately presented, as they include many detailed important information and suggestions. References are not included in this Summary Report, as they are widely addressed in single Experts report. The Reader should thus refer to single reports for literature.

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