Universidade de Aveiro Departamento de Química
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Materiais para Energia – Oportunidades em Transferência de Tecnologia

Materials for Energy – Opportunities for Technology Transfer

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Materials for Energy – Opportunities for Technology Transfer

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia Química, realizada sob a orientação científica de Doutora Ana Isabel Dias Daniel, Investigadora Auxiliar do Centro de Investigação em Materiais Cerâmicos e Compósitos da Universidade de Aveiro e sob co-orientação científica de Professor Doutor João Manuel da Costa e Araújo Pereira Coutinho, Professor Associado com Agregação do Departamento de Química da Universidade de Aveiro

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A toda a minha família, pelo carinho, paciência e incentivo. Este trabalho é dedicado a vocês.

palavras-chave Tecnologias da Energia, Investigação e Desenvolvimento, Materiais, Indústria, Transferência de Tecnologia

resumo

A energia é uma temática atual e, apesar das diferentes motivações (o aumento do consumo de combustíveis, as questões ambientais ou de segurança de abastecimento), os principais objetivos são comuns, reduzir o consumo de energia e encontrar formas de energia alternativas aos combustíveis fósseis.

Actualmente estão a ser desenvolvidos esforços significativos no sentido da implementação de tecnologias de energia sustentável, delineando para tal estratégias e prioridades, assim como desenvolvendo mecanismos de financiamento e projecção de cenários. Na Europa, estes esforços estão a ser desenvolvidos no sentido de cumprir com os objectivos ambiciosos estabelecidos para 2020, no que respeita a energia e às alterações climáticas.

Sob a forma de electricidade, calor, luz, mecânica, biológica ou química, a energia vai se tornar uma comodidade cada vez mais cara e, neste sentido, há uma grande necessidade de gerir este recurso de forma eficaz. Novos produtos resultantes do desenvolvimento de novos materiais avançados poderão ter um impacto significativo na área da energia.

Pretende-se com esta dissertação analisar a atual problemática energética, explorar a aplicabilidade da ciência dos materiais em tecnologias energéticas sustentáveis com potencial de comercialização e perceber de que forma o posicionamento do Laboratório Associado da Universidade de Aveiro, CICECO - Centro de Investigação em Materiais Cerâmicos e Compósitos, o maior instituto Português em matéria de engenharia e ciência dos materiais, vai ao encontro desses pressupostos.

Deste modo, a presente análise pretende reunir informação de forma a criar uma ferramenta de apoio à decisão em termos de desenvolvimento estratégico.

keywords

Energy Technologies, Research and Development, Materials, Industry, Technology Transfer

abstract

Energy is a current topic and although due to different motivations (rising fuel costs, environmental issues or supply security) the main goals are common, consume less energy and find alternatives to fossil fuel based technologies.
Nowadays, significant efforts towards the implementation of sustainable energy technologies, by delineating strategies and priorities, as well as through developing supporting mechanisms and building scenarios. In Europe this efforts are being taken in order to meet the ambitious and binding energy and climate change objectives for 2020.
In the form of electricity, heat, light, mechanical, biological or chemical, energy will become an always more expensive commodity, and therefore there is a great need to manage this resource effectively. New products made from new advanced materials can have a large impact on the energy field.
It is intended with this dissertation to better understand the energy problem nowadays, to explore applicability of materials science towards sustainable energy technologies with potential to commercial deployment and to understand in each way the positioning of the University of Aveiro associate laboratory CICECO – Centre for Research in Ceramics and Composites Materials, the largest Portuguese institute in the field of materials science and engineering, is fulfilling these assumptions.
Therefore, this analysis aims at gathering information in order to create a tool for strategic decision making.

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Definitions

Total primary energy supply – share of energy sources in the energy mix. It is calculated as primary production + recovered products + imports + stock changes + exports + bunkers (i.e. quantities supplied to sea-going ships).

Total final consumption – is the energy finally consumed in the transport, industrial, commercial, agricultural, public and household sectors. It excludes deliveries to the energy conversion sector and to the energy industries themselves.

Energy Intensity – calculated as final energy demand divided by value added at basic prices. It is an energy efficiency indicator that shows the effect of final energy consumption to GDP. The lower energy intensity, the greater the energy efficiency of an economy / product.

Reserves (according to the scheme of the World Energy Council - WEC) - *proved amount in place* is the resource remaining in known deposits that has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology and *proved recoverable reserves* are the tonnage within the proved amount in place that can be recovered in the future under present and expected local economic conditions with existing available technology.

Resources (according to the scheme of the World Energy Council - WEC) - *estimated additional amount in place* is the indicated and inferred tonnage additional to the proved amount in place that is of foreseeable interest (includes estimates of amounts that could exist in unexplored extensions of known deposits or in undiscovered deposits in known coal-bearing areas, as well as amounts inferred through knowledge of favourable geological conditions). Speculative amounts are not included and *estimated additional reserves recoverable* is the tonnage within the estimated additional amount in place that geological and engineering information indicates with reasonable certainty might be recovered in the future.

Energy Density - The amount of energy that can be supplied from a storage technology per unit weight (measured in Watt-hours per kg, Wh/kg). In combination with the physical size and weight of the storage device, this factor defines the quantity of energy that the device can take in and deliver.

Discharge Time - The period of time over which an energy storage technology releases its stored energy. This is in turn related to the power capability of the device i.e. its rating in kW or MW.

The **energy rating** (expressed in kWh or MWh) is important in determining how long a device can supply energy for. The power rating is important in determining how much energy can be released in a set time. As an example a 100kWh device rated at 20kW can supply 20kW of output for 5 hours (20x5 = 100kWh).

Costs of energy storage devices are usually quoted in terms of cost/kWh or costs/kW. These are usually related to the application the device is aimed to satisfy. Some devices will have a high cost per kWh but relatively lower cost/kW others will be the reverse. It will depend on the application as to whether a given device is potentially economic.

Efficiency of a light source is the light power out, not adjusted for the response of the human eye, divided by the electrical power in. Efficiency is dimensionless and is usually given as a percentage. The terms efficiency and efficacy are both widely used in lighting, and care must be taken not to confuse them.

Reserves-to-production (R/P) ratio – if the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.

Abbreviations

AFC – Alkaline Fuel Cell

CCS – Carbon Capture and Storage

CIGS – Copper indium gallium diselenide

CPV – Concentrating Photovoltaics

CSP – Concentrating Solar Power

DEFC/DMFC – Direct Ethanol/Methanol Fuel Cell

DSSC - Dye-sensitized Solar Cell

EC – European Commission

EII – European Industrial Initiative

EJ – Exajoules

EERA - European Energy Research Alliance

ETP – European Technology Platform

EU – European Union

EV – Electrical Vehicles

FCV – Fuel Cells Vehicles

GDP – Gross Domestic Product

GHG – Greenhouse gas

GW - Gigawatt

GWh – Gigawatt hour

HEV – Hybrid Electrical Vehicles

IEA – International Energy Agency

IGCC – Integrated Gasification Combined Cycle

ITER – International Thermonuclear Experimental Reactor

JTI – Joint Technology Initiative

KIC – Knowledge and Innovation Communities

LED – Light-emitting Diodes

LNG – Liquefied Natural Gas

M€ - Million Euros

MCFC – Molten Carbonate Fuel Cell

MOF – Metal Organic Framework

Mt - million tonnes

Mtoe – Million tonnes of oil equivalent

MtU – Metric tons of uranium

MW – Megawatt

MWe - Megawatt electrical

MWh – Megawatt hour

NP – Nanoparticle

OECD – Organisation for Economic Cooperation and Development

OLED – Organic Light-emitting Diodes

PAFC – Phosphoric Acid Fuel Cell

PCM – Phase Change Materials

PEMFC – Proton Exchange Membrane Fuel Cell

PHEV – Plug-in Hybrid Electrical Vehicles

PRD – Priority Research Directions

PV – Photovoltaics

R&D – Research and Development

RES – Renewable Energy Sources

SET Plan – Strategic Energy Technology Plan

SOFC – Solid-oxide Fuel Cell

SRA – Strategic Research Agenda

STE - Solar Thermal Electricity

TCO – Transparent Conductive Oxides

TFSC – Thin-film Solar Cells

TPV - Thermophotovoltaics

TTO – Technology Transfer Office

TWh – Terawatt hour

USA – United States of America

I - Introduction

Energy is a very actual topic and is in the centre of discussion. This is due to several problems, namely, the increasing of global energy demand, climate changes and environmental issues, the concentration of reserves in a few countries, scarcity and finite nature of fossil fuels, rising of oil and gas prices, and supply security.

European Commission adopted the Europe 2020 which is the EU's growth strategy for the coming decade. (EC, 2010b) In this case, Europe must reverse the situation of a deep economic crisis, reduce unemployment and poverty, while switching to a low-carbon economy.

These challenges are interconnected and, for instance, the need for clean sustainable energy represents an opportunity for employment growth and increases exportation of energy technologies. In spite of the different motivations which put energy in the centre of discussion, the main goals are common, consume less energy and find sustainable and environmental-friendly alternatives to fossil fuel based technologies.

Although, clean energy technology has great potential, achieving it is difficult. While traditional fossil fuel based technologies are well developed and mature, clean energy technologies have lack of maturity, operate below their potential, thus having many scientific and technological drawbacks to overcome.

In the form of electricity, heat, light, mechanical, biological or chemical, energy will become an always more expensive commodity, and therefore there is a great need to manage this resource effectively.

New products made from new advanced materials can have a large impact. For instance, photovoltaic solar cells convert sunlight into electricity. The most common material currently used is silicon and there are worldwide efforts to produce systems based on other semiconductors, like thin films or dye-sensitized, with better performance. For wind turbines new materials are needed for lighter and stronger blades and, also, for sensors incorporated in turbine blades to continuously monitor fatigue and damage and signal the need for repair. In order to decrease the pressure from the prime cropland, the development of biofuels focused on non-food feedstocks are needed. New materials that can adsorb carbon dioxide or other pollutants can be used to help clean up the products of combustion from a fossil-fuel power plant. Nuclear power has its own unique technical challenges on materials which are related to material and fuel handling, fusion, fission and radiation damage as well as decommissioning and storage. New materials for rechargeable batteries and supercapacitors are under development and, in the case of batteries, lithium has drawn more attention. For the use of hydrogen in transportation, an efficient storing system, for instance, in a vehicle is needed and materials for hydrogen-storage should be based on light elements that combine and release hydrogen under conditions that do not cause instability. Fuel cells produce electricity through electrochemical oxidation of, for instance, hydrogen, alcohols or hydrocarbons. The performance of the cell depends on its main components and many new materials are being designed for decrease cost and improve efficiency.

As a transversal science, Nanotechnology, the science and technology at the scale of nanometers, has the potential to intervene in all of these areas in order to create new materials and devices to transform the way energy is managed. Nanotechnology advancements can play a key role in the energy production and efficient consumption providing, also, new ways to obtain energy from clean renewable sources.

In order to explore solutions and chose strategies to solve the energy problem, it is important to analyse the strategy defined by EU. The objectives for 2020, namely to reduce greenhouse gas emissions, to increase the share of renewable energy and to decrease energy consumption, set by the European Council in 2007 (EC, 2007a) are also objectives supported by Europe 2020 Strategy (EC, 2010b) along with achieving the target of increase investment in R&D in particular by improving the investment conditions for private sector.

Also, the Strategic Energy Technology Plan (EC, 2009a) reinforces EU policy for low carbon technologies and the setting up of strategic alliances with industry to share R&D and, following this it was created the European Industrial Initiatives which among others Europe approaches, namely, European Technology Platforms and Knowledge and Innovation Communities exist for engagement of basic scientists with industry in the energy field.

Common strategic framework is also aligned with the priorities of these strategies and there are many funding sources available to support energy-related research activities. Due to multidisciplinary in materials and because they are probably the most important element for the development of the new technologies to provide clean and reliable supply of efficient energy, several European funding initiatives support materials research within the structure of the EU 7th Framework Programme.

The development of clean energy technologies, the re-establishment of economic growth and employment creation are, therefore, challenges on which industry plays an important role in the proposal of innovative solutions to achieve a new generation and sustainable renewables, along with low-carbon energy technologies.

These are also challenges for the research centres and innovation also relies on their contribution to overpass gaps in understanding the appliance of materials for sustainable energy technologies. The universities have five fundamental roles to society which are teaching, basic research (the oldest ones) knowledge transfer, policy development and economic initiatives (the newest ones). Although, these institutions must become leaders in providing curriculum and guidance for the next generation of energy scientists and engineers they also have an important role in stimulating the transfer of knowledge and technology to industry.

Therefore, reinforcing this link between materials research institutions and industry can be an important strategy towards renewable, sustainable, and low-carbon energy technologies.

The University of Aveiro associate laboratory CICECO – Centre for Research in Ceramics and Composites Materials is the largest Portuguese institute in the field of materials science and engineering and, although it has several successful examples of technology transfer activities, most of the research is more fundamental. CICECO with its broad research base in the materials field, it is well positioned to address some of the main technical challenges regarding energy field.

The work in this dissertation intends to better understand the energy problem nowadays, to explore strategies towards sustainable energy technologies commercial deployment and to understand in each way the positioning of the University of Aveiro associate laboratory CICECO is fulfilling this purposes, in the development of new materials or improvement of existing ones towards the progress of sustainable energy technologies.

The dissertation is divided in three major chapters: the analysis of the Energy problem, the analysis of strategies in order to solve the Energy problem and the characterization of CICECO in order to understand its positioning regarding to material research for Energy technologies applications and its mechanisms of technology transfer.

In order to pursue the proposed goals, the study in this dissertation is carried out following the methodology presented in the next section.

The analysis carried out has some limitations since the information gathered by CICECO is organized by competencies and not by effective and/or possible applications. Thus, the matching presented may not be complete since some of the challenges presented in this work are related to applications. Also, there are some competencies in CICECO where it has not yet been identified the relation with energy field.

Therefore, it is not in the scope of this work to propose areas in which CICECO should make efforts to create or improve competencies. The goal of this dissertation is to gather information in order to create a tool for this decision making.

1. Methodology

The present study was carried out in three steps. The first one, through bibliographic analysis, intended to better understand the energy problem and the strategies proposed to its resolution, mainly, throughout the analysis of technological developments in the materials science field in order to make those technologies more accessible. The second step consisted in the characterization of the associated laboratory CICECO – Centre for Research in Ceramics and Composite Materials (University of Aveiro), which is the largest Portuguese institute in the field of materials science and engineering. Finally it was carried out the matching between the results obtained from in the first part of this work regarding the main R&D challenges in materials science and main competencies of CICECO in the Energy field.

For the study on the sources of the energy problem, all characterization and analysis was performed based on the energy scheme represented in Figure 1.

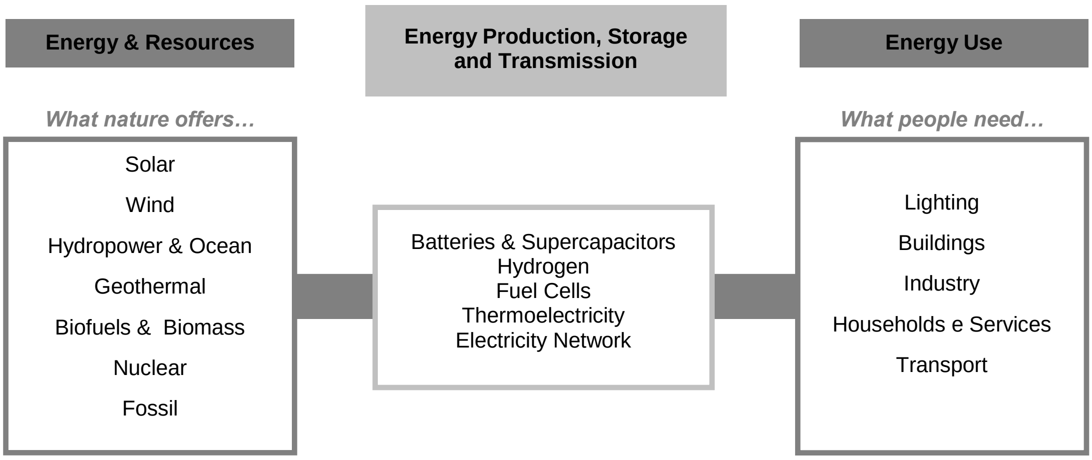


Figure 1 - Energy scheme (EIA, 2009b)

The analysis was carried out through the study of documents related to energy topic, mainly working documents, from EC, OCDE and world status reports, as well as, political and strategic documents from sector associations. Additionally, scientific reviews and books were also studied. The analysis of statistic data, was done by using common indicators for energy policy (IEA, 2009a) The criterion used for ranking the sources of primary energy analysis was their availability which constitutes a major factor when it comes to choose sources of energy.

The main purpose is to analyse each one of the topics presented in Figure 1 in order to understand their main benefits and main problems, and to be able to identify the main future trends in the area of materials for energy.

When it comes to the solution analysis, there are several strategies to overcome the main barriers of the energy problem. This dissertation gives emphasis to the role of Materials Science in the Energy field and the main R&D challenges towards market deployment. In order to do so, the themes discussed were chosen based on European Union strategies.

Therefore, also in this part of the work, an analysis was carried out on the role of universities regarding the need to strengthen the link between research centres and industry, along with the study of some example of energy related structures within Europe, created for the gathering of the various intervenient in this area in order to define common strategies. Complementarily to this information, data on European funding in the energy field is also explored.

The strategy for bibliographic analysis, in order to explore the role of materials sciences, was to study documents which have resulted from the input information of several stakeholders including, at the same time, research institutions and industry, resulting in energy technologies targeted to industrial needs and towards market deployment.

As a result the following thematics were analysed, regarding innovation and R&D on Materials for Energy: Solar Energy, Wind Energy, Bioenergy, Nuclear Energy, Carbon Capture and Storage (CCS), Energy Efficiency: Lighting, Buildings, Industry and Transport, Electricity Grid, Energy Storage: Batteries, Supercapacitors and Hydrogen, and Fuel Cells. Figure 35 summarizes the strategy to present main challenges for Materials Science, concerning each one of these themes.

Among the documents analysed are the Strategic Research Agendas from European Technology Platforms, which describe a common vision for Europe based on a consultation made to stakeholders (Industry and public researcher centres and national government representatives) related to energy, and, the SET plan roadmap (EC, 2009c). This last one was important since it presents the technology roadmaps for the implementation of European Industrial Initiatives and Joint Technology Initiative.

Another source of information was a report from the USA Department of Energy which proposes basic science PRD most urgently needed to accelerate the innovation of clean energy technologies and industrial deployment, as a result of a series of workshops which gathered members from the international scientific community, including researchers and laboratory experts, universities and industry. (DOE, 2010). To harmonize some of this information, was, also, analysed a set of articles from a special volume of MRS Bulletin on energy and other review articles.

Having identified the role of materials science in the main energy areas and technologies, the following step of this dissertation was to analyse the structure of the associated laboratory CICECO – Centre for Research in Ceramics and Composite Materials (University of Aveiro).

The characterization of the laboratory was carried out through a general presentation of its structure, scientific and technical, followed by a description of how CICECO manages its contacts with industry and, finally, it is analysed the positioning of CICECO towards the Energy technologies challenges. CICECO has many scientific competences in the field of Materials for Energy, but only recently these competencies have been analysed and structured to provide a more integrated and complemented offer on Energy technologies.

The information used for this characterization was based on data available on the CICECO website, annual reports and to have more recent statistical data, some presentations from CICECO were also consulted. The information used, regarding the analysis of CICECO competencies in the Materials for Energy field, has a form of four matrices and was gathered and compiled by CICECO. This information was provided by CICECO in order to carry out the analysis proposed in this work.

The following step was to analyse and discuss CICECO competencies and its comparison with the strategy on materials for energy, outlined from the bibliographic analysis. This is carried out by matching both results, in order to be able to conclude on the alignment of the information and understand in which way CICECO competencies are in line with the challenges for the energy problem.

II – The Energy Problem

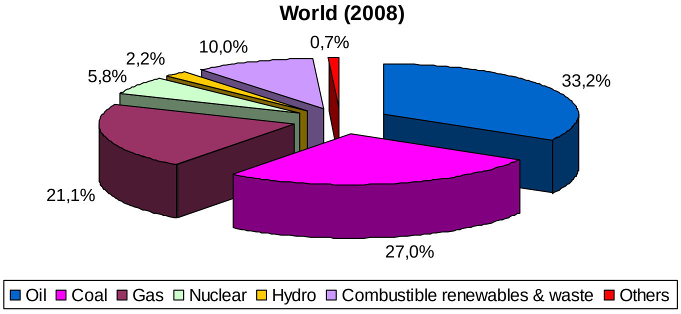
1. Energy Consumptions

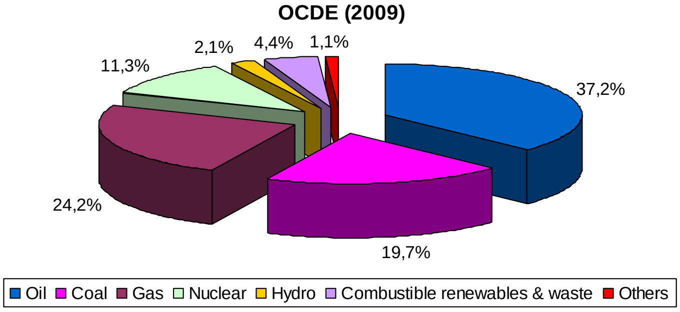
Europe has entered into a new energetic period, as stated in the Green Paper "European strategy for sustainable, competitive and secure energy". The global demand for energy is increasing and it is foreseeable that demand for energy and CO_2 emissions raise about 60% until the end of 2030 (EC, 2006a). Additionally, to this scenery is one of high and volatile oil and gas prices, being these reserves concentrated on a few countries. The price of electricity is also catching up this trend.

Within this scenario, it is imperative that EU and the rest of the world quickly respond by increasing the low carbon technology and enhance energy efficiency.

The definition of strategies related to the energy topic has been guided by the availability and accessibility of its sources, by its economic viability and the convenience it offers. Progressive moves have been taken place towards the clean fuels from coal, oils and natural gas. Given its availability, coal is an important energy source, although it cannot be considered that there is only one global fuel for energy production (IEA, 2010c).

As shown in Figure 1, in 2009 about 80% of the total primary energy supply was dependent on fossil fuels. (IEA, 2010c) The economic growth together with prosperity, have been built around oil, gas and coal, which makes non-producer countries very vulnerable to its external interruption in its supply and price volatility.





Others include geothermal, solar, wind, thermal, etc

Figure 2 - Total primary energy supply (excluding electricity trade) (IEA, 2010c)

Portugal is one of these examples, it is a country short in its own energetic resources, namely, those that ensure the general energetic needs in most developed countries (such as oil, coal and gas). Such situation leads to a high external energetic dependence (81,2% in 2009) and a high primary fossil sources imports. In this case, oil plays an essential part in the supply structure, representing 48,7% of primary energy total consumption in 2009, natural gas was 17,5% and coal represented 11,8%. (DGEG, 2011)

One interesting indicator regarding primary energy is the origin of consumption by country. Comparing, for instance, EU with two developed countries (USA and Canada) and with two developing countries (China and India) (Figure 2) it is possible to conclude that all of those depend mostly on the fossil fuels. Nevertheless, oil does not play an important part in China and India, where it is supplanted by coal due to the reserves of this fuel in these countries. (BP, 2010)

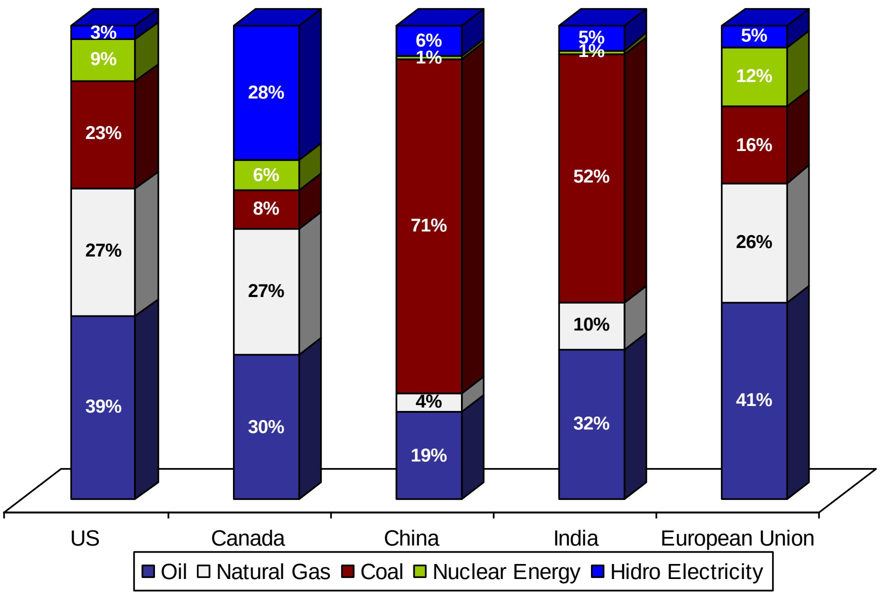


Figure 3 - Primary Energy Consumption, by country and by fuel share, 2009 (BP, 2010)

In terms of consumption of primary energy per country, industrialization is a factor that increases significantly the demand for energy and currently, developed countries consume much more primary energy comparing to the developing countries. For instance, in 2009 USA, with a population of about 4,5% of the world's population, consumed 19,5% of the primary energy consumed worldwide and India, with a population of about 17% of the world's population, consumed 4,2%. (PRB, 2009) (UNFPA, 2009) (BP, 2010)

Also, comparing developing countries with developed ones is interesting to evaluate the contribution of energy consumption from each country to the total energy consumption worldwide. For instance, China where consumption has been increasing during the last decade, will be, until 2035, responsible for more than 24% of the world consumption of energy, more than the 15,8%, of 2007. As shown in Figure 3, by 2035, USA will still be the second biggest consumer in the world right after China and well ahead from India. (EIA, 2010)

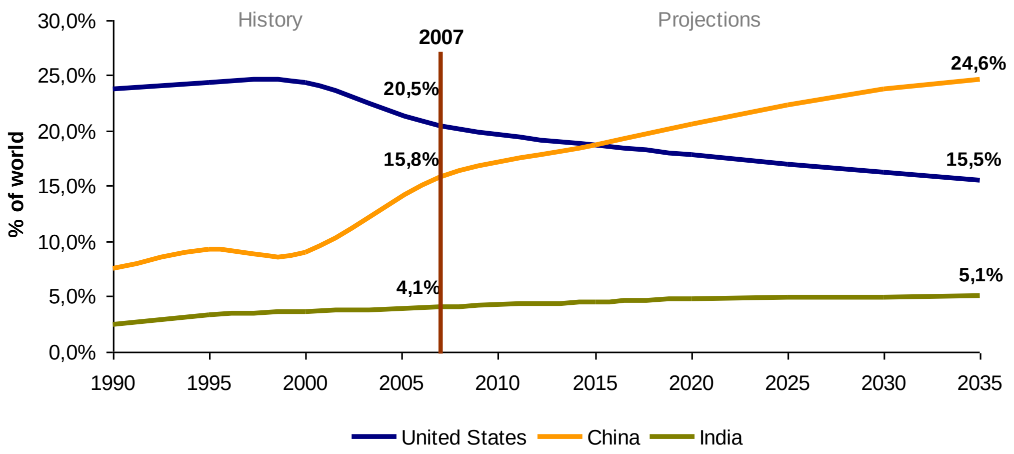
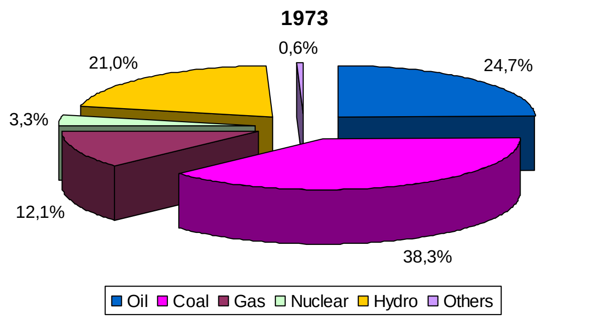
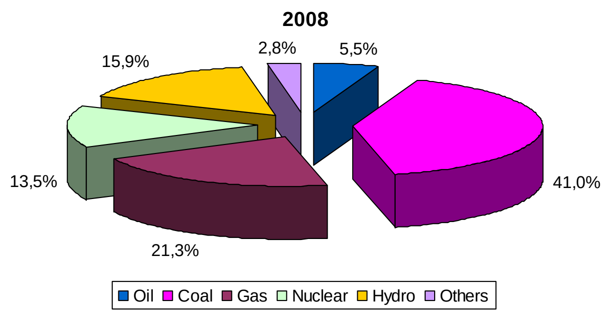


Figure 4 - Shares of world energy consumption: History and Projections for 2035

World final energy consumption greatly depends as well on the fossil fuels. Figure 8 shows that in 2008 the fossil fuels contributed with about 78% of the total final consumption, as well as for electricity generation which registered in 2008 a dependence of around 68% (Figure 5). (IEA, 2010c)





Other includes geothermal, solar, wind, combustible renewables and waste, and heat.

Figure 5 - World fuel share of electricity generation (IEA, 2010c)

One common indicator for understanding evolution of final energy consumption is the *energy intensity.* The less the *energy intensity* is, the more is the energy efficiency of a product/economy. (IEA, 2009b) There is a positive correspondence between a country GDP and the amount of energy consumed. Developed countries consume more energy than developing countries, but over time, the energy intensity tends to decrease since developed countries produce and use energy in a more efficiently way (Figure 6). Since 1990, this indicator has shown a constant decline on the global scale, revealing an improvement in the way energy is used. (IEA, 2009b)

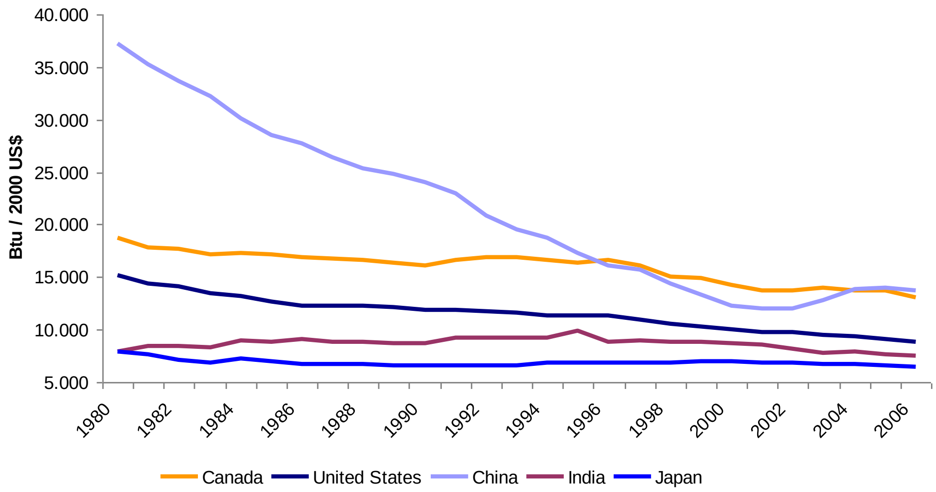


Figure 6 - Energy Intensity – (Btu / 2000 US$) - Product Using Purchasing Power Parities, 1980-2006 (EIA, 2009a)

Figure 7 compares Portugal to the EU average and shows that for Portugal the energy intensity has been decreasing much faster than the EU average. In Portugal it diminished 11,4% whereas in Europe it was only 9,4%, however Portuguese average is still higher than European average (EUROSTAT, 2009)

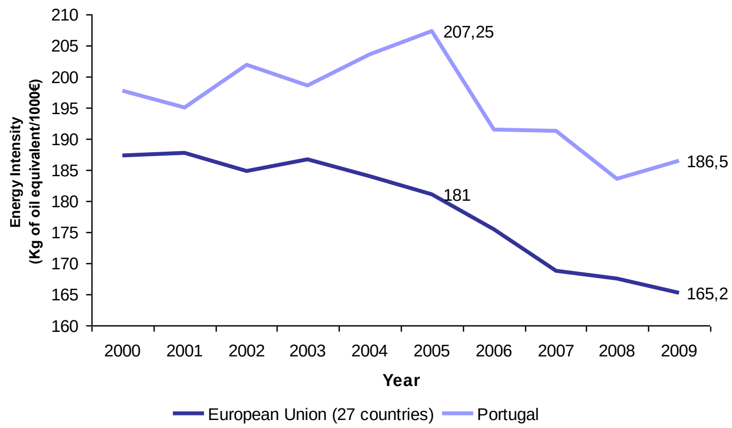


Figure 7 - Comparison of Portuguese and EU (27) Energy Intensity (Kg oil equivalent/1000€) (EUROSTAT, 2009)

Renewable energy supplies 19% of global final energy consumption (Figure 8), of which traditional biomass represents approximately 13% and is used primarily for cooking and heating. Hydropower represents 3.2% and is growing moderately. Other renewables represent 2.7% with a very rapid growing in developed countries and in some developing countries. (REPN, 2010)

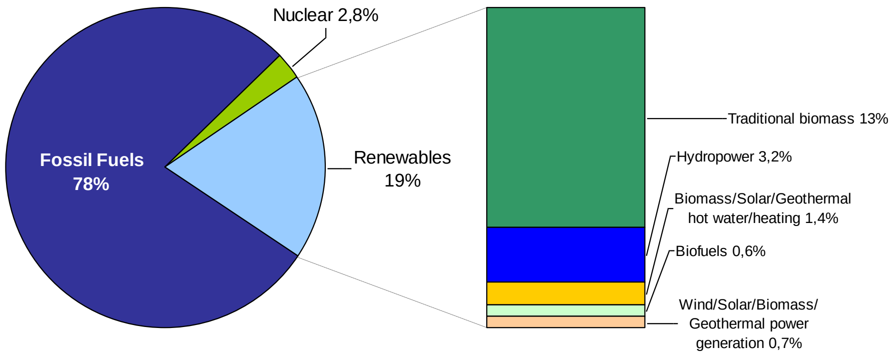


Figure 8 - Renewable Energy share of Global Final Energy Consumption, 2008 (REPN, 2010)

Although the percentage of energy from renewable energies is still low comparing to the energy generated from fossil sources, the goal for 2020 in EU-27 is to increase to 20% the share of renewable energies over the final energetic consumption (EC, 2010a). Portugal is one of the states with the most ambitious targets for the incorporation of renewable energies until 2020, with a 31% goal, surpassing in 11%, the minimum stipulated by the EU. (REPN, 2010)

Certain indicators show that the necessary changes in the domain of electricity generation from renewable sources are now starting to emerge. Wind energy and solar energy (PV) have been dominating the investment in renewable energies and a record amount was reached in 2008, having stayed in the identical levels in 2009. (REPN, 2010) In 2009, wind energy systems were the most technology of electricity generation added in Europe and, regarding to installed capacity of renewable energies, similar progress have been verified worldwide. (IEA, 2010b)

2. Primary Energy Sources

The availability of resources for energy production has an enormous impact on the energy mix consumed nowadays and future consumption. Fossil energy sources - oil, gas, coal - and sources of fissile energy - uranium and thorium (a source of fissile uranium) - have in common that they are exhaustible. They are generally categorised in terms of proved reserves and resources. (ERCN, 2005)

The definition of reserves is complex. There are various definitions differing for various world regions and institutions which have evolved over many decades and there is still no universal agreement on definitions or a universally applied method of reserve reporting. (EWG, 2008)

At the end of 2007, oil had a reserves-to-production ratio (R/P ratio) of about 55 with the Middle East being the dominant oil province. The gas reserves are distributed around the globe mainly in the Middle East and in Russia and at the end of 2007 it had a R/P ratio of 64. Coal reserves are rather evenly spread around the globe being dominated by USA, Russia and China, as shown in Figure 17. The R/P ratio was of 150 in the end of 2007. (ERCN, 2005) (BGR, 2009)

Regarding to nuclear sources, total potential of uranium is regionally distributed quite uniformly and during the past years the source which has thorium as a by-product was produced in particular in India, Malaysia and Sri Lanka and at the end of 2007, the R/P ratio of uranium was 29. (BGR, 2009)

The resources of the non-renewable energy resources were estimated at approximately 571 700 EJ, by the end of 2007 and the dominant position of coal amongst the resources is even more significant than for the reserves with, approximately, 76% (BGR, 2009), with its resources being several times larger than the reserves, but some of them may be low-grade and/or hardly mineable. (ERCN, 2005) At approximately 20% the aggregated resources of conventional and unconventional natural gas range second, with 1.6 % and 18.5 % respectively. The unconventional gas resources are huge, but it is uncertain the extent to which they would be producible. Crude oil follows at near the 4% ahead of nuclear fuel at a little more than 1%. (BGR, 2009)

Renewable energy sources are by definition infinite therefore their development is not restricted by availability and, although their potential is huge as it is shown in Figure 9, their development relies on geographical constraints.

The term *renewable energies*, in the context of this document refers to a vast range of technologies resulting from renewable sources which can make energy services available in the shape of electricity, heating and cooling and, also transport solution. Wind, hydro and ocean energy are used for electricity generation, whereas solar and geothermal, besides electricity, are also used for heating and cooling. Bioenergy is the source of energy available for electricity, heating, cooling and, also, transport. (EREC, 2010)

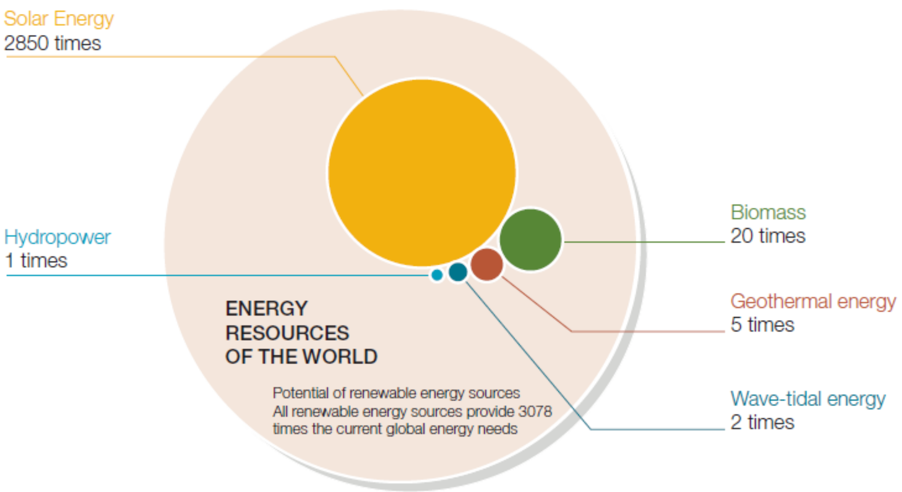


Figure 9 - Renewable Energy Resources (EREC, 2010)

Worldwide existing renewable power capacity reached about 1,230 GW in 2009, up 7% from 2008, approximately a quarter of global power-generating capacity, estimated at 4,800 GW in 2009 and supplies about 18% of global electricity production. (EREC, 2010) For solar hot, solar thermal and wind power renewable technologies, 2009 represented a faster growth, comparing to previous four years (Figure 10). The fastest of all renewables technologies in the 2004-2009 period, was solar PV. Also, biofuels grew rapidly, with a 20% for ethanol and a 51% for biodiesel (reflecting its lower production levels). Other technologies like hydropower, biomass power and heat, and geothermal power are growing at more moderated rates of 3–6%, making them comparable with global growth rates for fossil fuels (3–5%). (REPN, 2010)

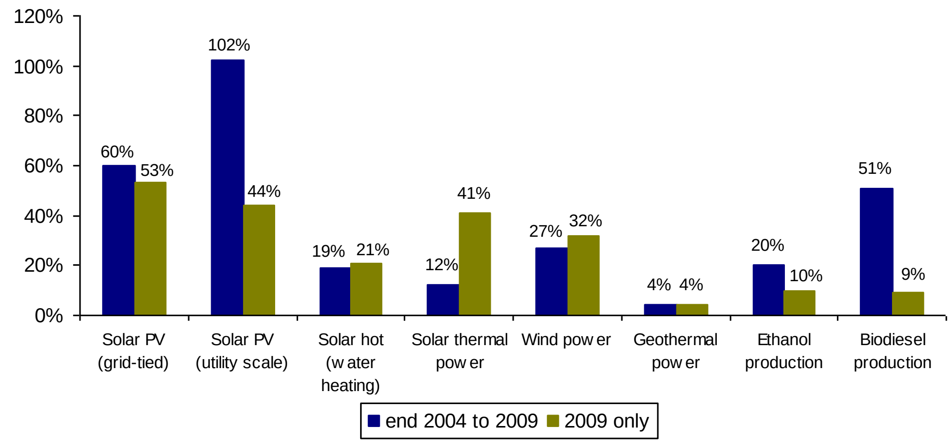


Figure 10 - Average Annual Growth Rates of Renewable Energy Capacity, end-2004 to 2009 (REPN, 2010)

In [*www.ren21.net*](http://www.ren21.net), "*Renewables Interactive Map*" allows access to updated information worldwide about advancements on renewable energies, with a browsing by country or world region, offering an updated, interactive, and user friendly picture of the global status of renewables. (REPN, 2010)

The share of renewables in global electricity generation is expected to increase to almost one-third from 2008 to 2035. Electricity produced from solar PV will continue to increase very rapidly, although its share is expected to reach only about 2% in 2035. The share of modern renewable, in heat production in industry and buildings will increase from 10% to 16%, coming primarily from wind and hydropower. The use of biofuels will grow more than four-fold between 2008 and 2035, meeting 8% of road fuel demand by 2035 (up from 3% now). (IEA, 2010e)

Due to financial crisis and reduction in credit the investments in clean energy worldwide in 2009 were down 6.6% compared with 2008, nevertheless, it reached an impressive value. On the other hand, oil and gas industry experienced investment declines of 19%. Clean energy investments have increased 300% globally since 2004 and an average of $32 billion was invested each quarter in the past two years (Figure 11).

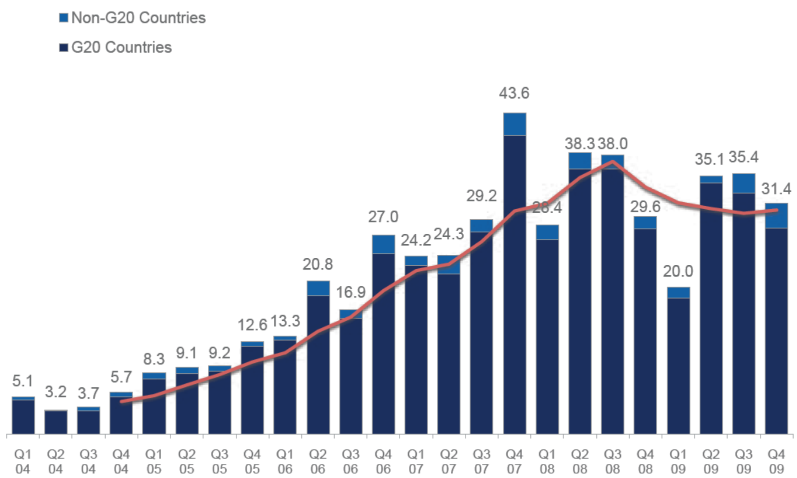


Figure 11 - Financial investment in clean energy: global trends by quarter ($ in billions) (BLOOMBERG, 2010)

Analysing investments by sector Figure 12 shows that China is the leader among the G-20 nations and for the first time. The United States comes in second in the G-20, although it continues to control the venture capital/private equity investments associated with technology innovation. United Kingdom comes in third place among the G-20 with large offshore wind deals being backed by the government. In Spain, on the other hand, the investments in 2009 were mainly on solar energy, with more than $10 billion. Brazil, which is prepared for significant growth in wind energy investments, constitutes an important clean energy investment destination. Germany continues strong on clean energy in terms of manufacturing and installed capacity. (BLOOMBERG, 2010)

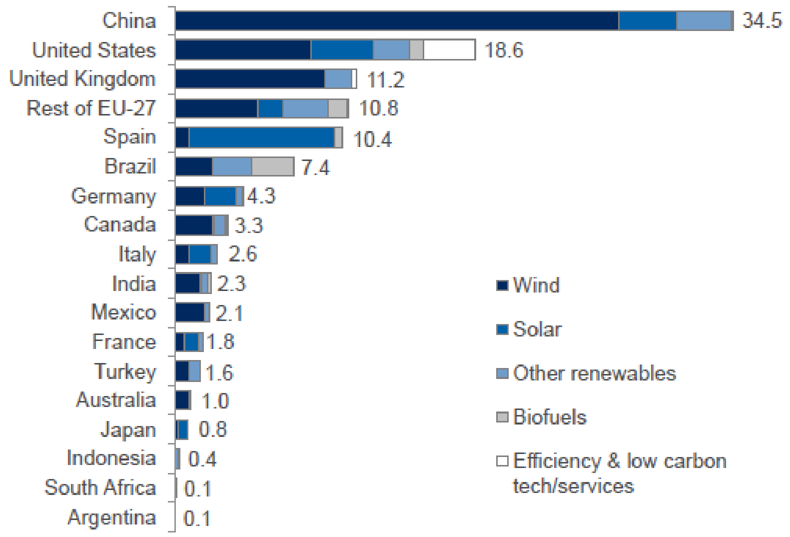


Figure 12 - G-20 investment by sector, 2009 ($ in billions) (BLOOMBERG, 2010)

A Renewable Energy Sources (RES) market overview for EU shows an increase of 200.000 jobs to 550.000, from 2004 to 2010 and an increase in turnover from €10bn to €70bn. (EREC, 2010) By the end of the year 2012, the number of jobs is expected to reach one million (EC, 2009a). Therefore, it is legitimate to say that renewable energy industry in Europe is a major responsible for the development of a sustainable economy, not only contributes to a more sustainable supply system but, also, it manufactures equipment, exports technology and, thus creates added value. (EREC, 2010)

Renewable energy offers great promise also because they represent an important help in the decrease of CO_2 emissions which has put pressure into the shift to low carbon technologies for electricity generation. Along with renewables, nuclear power and other low carbon technologies are projected to reduce the amount of CO_2 emitted per unit of electricity generated by one third between 2008 and 2035. (IEA, 2010e) This shift calls for cost effective technologies and materials science plays an important role, for instance in lighter, stronger materials for the blades of wind turbines and better, cheaper materials for photovoltaics.

In the following subsections it will be discussed in more detail the different sources of primary energy, their availability, their associated technologies and main challenges and, also, what is the role of materials science in overcoming these challenges in order to provide sustainable supply of energy.

2.1 Solar Energy

In a study promoted by the US National Academy of Engineering, aiming at identify the most promising emerging-energy technologies and develop a plan for the United States and the world for energy, Ray Kurzweil and Larry Page (Google cofounder and entrepreneur in the energy field) stated that solar energy is the most interesting and promissory of all. (MQ, 2011) This shows the raising interest solar energy has gained over time.

Although it reaches the Earth in a little concentrated way (RAMAGE, 2003) sunlight is the largest potential source of carbon-free electricity (Figure 9). More energy from the sun hits the surface of the Earth in one hour than that currently consumed by humans in a year. (DOE, 2010) Nevertheless, currently solar energy has a tiny contribution in the world total primary energy supply of less than 1‰. (ERCN, 2005)

Solar thermal approach is one of the routs for solar energy generation. In this case, the sun's radiation is converted into heat that is either used directly or concentrated, known more commonly as concentrating solar power (CSP). CSP uses reflectors to concentrate sunlight to generate high temperatures to heat fluids that drive steam turbines to produce utility-scale electric power. Three main CSP types are parabolic trough, dish and power tower systems. Each makes use of reflective mirrors to focus sunlight on fluid such as oil, water, gas or molten salt. (MRS, 2010) CSP plants efficiency is around 15–20% but, on the other hand, the installation and generation involves high costs, almost five times those of coal. (ARUNACHALAM et al., 2008)

Other route to recover energy from the sun is solar photovoltaic (PV) where materials with special features (semi-conductor materials) are used to convert solar radiation into electric energy. These, can be either used locally in autonomous systems or connected to central power grids. (ARUNACHALAM et al., 2008) The most commonly used semi-conductor material is silicon which is second most abundant material on Earth. (EUPV, 2010)

2.1.1 Solar Photovoltaic (PV)

PV can be used in many fields. For instance, on-grid applications are delivering either only the surplus energy (electricity not consumed by the producer) or all the produced electricity into the grid. Typical on-grid applications are roof top systems on private houses (average size 3 kilowatt). Other on-grid applications are larger plants with capacities of several megawatts. On the other hand, off-grid systems have no connection to an electricity grid and are contributing to rural electrification in many developing countries. PV is also used for many industrial applications where grid connection is not possible (e.g. telecommunication). Consumer goods are another application where PV can be used (e.g. pocket calculators). (EUPV, 2010)

Solar PV show advantages towards other energy sources for energy generation, namely (DOE, 2010):

- enables electricity production during the day (highest rates and strongest demand);
- there are no carbon emissions production and no noxious gases (oxides of nitrogen or sulphur) or particulate emissions;
- PV systems can last at least 30 years, and potentially a hundred years, if designed for that duration;
- it operates simply, and most systems do not need elaborate on-site monitoring;
- PV operating cost, once capital investment is paid off, is about 1 ¢/kWh;
- PV reduces homeowner electricity bills, hedge against fluctuations in energy prices, and avoids high retail rates in some locations.

Nevertheless, the initial cost of PV remains the biggest barrier to their broad use. Incentives defray part of the high installation cost of carbon-free energy sources, and PV join wind, solar thermal electric, nuclear, wave, and geothermal electricity in this market. But to achieve transformative impact, PV must compete effectively without a subsidy on a commercial basis. (DOE, 2010)

Progress in photovoltaic R&D has achieved a well-documented reduction of about 97% of the original prices in the 1970s (DOE, 2010), but PV must becomes more cost effective and this is possible by decreasing manufacturing costs using polycrystalline materials and thin films technologies applicable to production at large-scale. (ARUNACHALAM et al., 2008)

Existing types of solar cells have one fundamental problem: limited absorption range and, consequently, limited overlap with the solar spectrum. Commercial silicon solar cells can absorb only about 45% of this spectral range, limiting overall efficiency to about 15% and no material has yet been shown to absorb light over a broad enough wavelength range, covering the visible and infrared regions. More advanced solar cell with demonstrated efficiencies of about 30% have been developed in laboratory, based on silicon and other semiconductors, but the production cost are too high for commercial applications. (ASL, 2011)

At present, crystalline silicon solar (c-Si) cells in their different forms (mono-crystalline, multi-crystalline, ribbon) have a market share of almost 90%. The rest is provided by thin film technologies (amorphous Si (a-Si), microcrystalline Si (μc-Si) CIGS, CdTe). Thin film technologies are the fastest growing technologies. (EUPV, 2010)

Producers along the value chain of PV (silicon, wafers, cells, modules) can be found all over the world. About €25bn of sales were generated by the Photovoltaic (PV) industry in 2008. Asian companies dominate the cell production for PV, nevertheless, European companies are gaining market share. The global PV market is currently dominated by Germany, USA and Japan. Many countries are establishing new markets like Italy, Spain, Greece, France, Portugal and Czech Republic. Increasing employment and industrial growth are key indicators when looking at the PV industry. (EUPV, 2010) Solar PV generates electricity in well over 100 countries and, as previously said, continues to be the fastest growing power-generation technology in the world. (ERCN, 2005) Cumulative global PV installations are now nearly six times what they were at the end of 2004 and analysts expect even higher growth in the next four to five years. (REPN, 2010)

2.1.2 Concentrating Solar Power (CSP)

Concentrating solar power (CSP) technologies use mirrors to reflect and concentrate sunlight onto receivers that collect the solar energy and convert it to heat which can be used to produce electricity via a steam turbine or heat engine driving a generator. (DOE, 2011) It provides clean and reliable power in units ranging from 10 kW to 300 MW. The first commercial solar thermal power plants were built in the 80s and in 2008 around 500 MW were commercially operated in the world. (ESTELA, 2009)

There are four main Solar Thermal Electricity (STE) technologies: Parabolic Trough Plants, Central Receiver Plants, Dish Stirling Systems and Linear Fresnel Systems. Each technology will progress thanks to a favourable policy framework and to its capacity to reduce generation costs and satisfy the specific needs of the power market. New generation plants, in operation and under construction, are located mainly in Europe (Spain), in the USA and in the MENA (Middle East and North Africa) countries. (ESTELA, 2009)

2.1.3 Solar Thermal

About 49% of final energy demand in Europe is used for heating and cooling requirements, mainly in buildings. Solar thermal is a matured technology, however today solar thermal energy is only used in a small percentage of European buildings and the main reason is the low price for fossil fuels. (ESTTP, 2006)

Solar thermal technology in buildings is usually for domestic hot water heating in private houses. Some large solar thermal systems are installed, to provide domestic hot water for multi-family buildings, hotels, hospitals and similar buildings. There are also some demonstration systems installed to produce high temperature heat for industry or to assist cooling machines. (ESTTP, 2006)

By 2030, solar thermal can cover 50% of the total heat demand, if the heat demand is first reduced by energy saving measures. To reach this goal new applications have to be developed and deployed. The main ones are the active solar building, the active solar renovation, industrial applications up to 250°C, solar heat for district heating and cooling. Therefore an industrial and technological approach should be done, looking mainly single components such as collectors, thermal storages, cooling machines, multifunctional components and control systems. (ESTTP, 2008)

2.2 Wind Energy

The year 2009 brought new records for wind energy utilisation around the world. The wind capacity worldwide reached 159.213 Megawatt, after 120.903 MW in 2008, 93.930 MW in 2007, 74.123 MW in 2006, and 59.012 MW in 2005 (Figure 13).

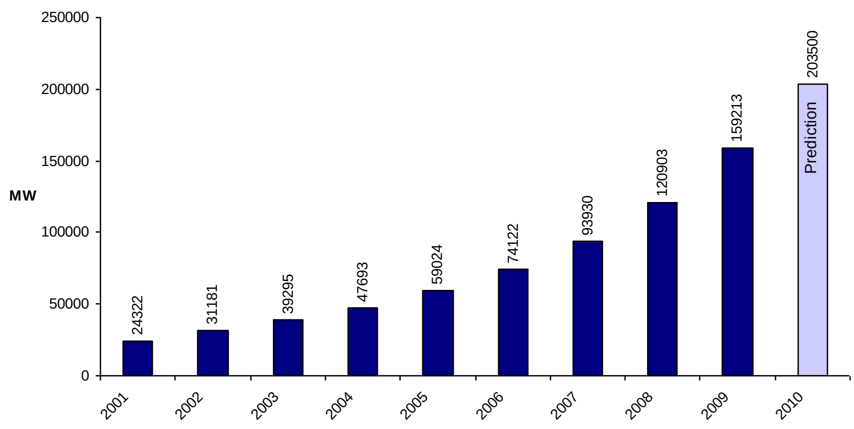


Figure 13 - World Total Wind Installed Capacity (WWEA, 2010)

Also in 2009, the wind sector worldwide was a major job generator (WWEA, 2010), with 82 countries using wind energy on a commercial basis, out of which 49 countries increased their installed capacity. USA and China together represented 38,4% of the global wind capacity. The top five countries (USA, China, Germany, Spain and India) represented 72,9% of the worldwide wind capacity, slightly more than 72,4% in the year 2008 (Figure 14). All wind turbines installed globally by the end of the year 2009 contribute 340 TWh to the worldwide electricity supply which represents 2% of the global electricity demand. In some countries and regions wind has become one of the largest electricity sources, being the highest shares from: Denmark: 20%, Portugal: 15%, Spain: 14% and Germany: 9%. (WWEA, 2010)

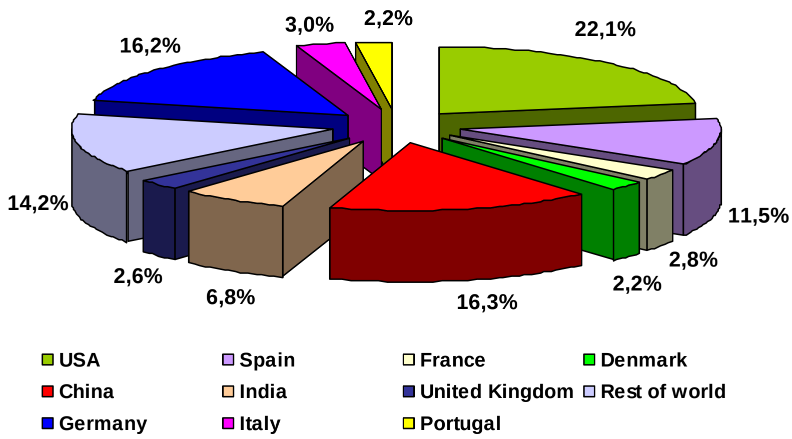


Figure 14 - Country Share of Wind Total Capacity 2009 (WWEA, 2010)

The wind shares with other renewable sources a certain number of advantages for the environment. A wind farm does not generate unpleasant residues, it does not pollute groundwater, it does not produce carbon dioxide and it does not affect negatively the flora. (RAMAGE, 2003) Also, wind turbines are built in short periods of time, they are small units relative to other types of electrical generators and therefore provide greater adaptability in responding to electrical demand, as well as being tailored to specific uses and locations. Another advantage to wind power, especially for residential use, is that it is a fine complement to radiant solar: days with little sun are usually those days of better-than-average winds. (HINRICHS, 2002)

Nevertheless, there are some features which prevent wind energy to fulfil its potential. There are host community concerns with potential changes in quality of life and well-being, more specifically caused by visual or landscape impacts, nuisance (e.g., noise or shadow flicker) impacts, and fear of property value loss. (IEA, 2010d) Also, the dependence on wind speed leads to the limitation on locations for installation of wind power generators (ARUNACHALAM et al., 2008)

One suggested solution to solve these issues is the development of offshore wind farms. (RAMAGE, 2003) The onshore technology already has a great level of development and collected great experience, the offshore technology, on the other hand, is still underdeveloped. (IEA, 2010d) The efficiency of wind power is about 20% and offshore turbines may be an option (ARUNACHALAM et al., 2008) nevertheless only less than 2% of wind power is produced offshore because of higher cost. (DOE, 2010)

2.3 Hydropower and Ocean Energy

The natural flows of river waters were used to move machines for thousands of years. Around a hundred years ago, it was the source of energy to some of the first power plants in the world and, currently, the hydropower energy represents around one fifth of the world electrical energy. It is now a highly developed technology. (RAMAGE, 2003)

Global hydropower capacity reached an estimated 980 GW by the end of 2009, including 60 GW of small hydro. Hydropower supplied 15% of global electricity production in 2008. Significant increases in hydropower capacity are in the project pipeline for 2011, namely in Brazil, China, India, Malaysia, Russia, Turkey, and Vietnam. Hydropower expansion is expected in developed countries as well. (REPN, 2010)

Ocean energy is the least mature of the renewable energy technologies, but interest is growing since a wide range of possible technologies could be used for energy production, like electricity, using this source. Ocean energy technologies for generating electricity include wave, tidal (barrages and turbines), and ocean thermal energy conversion (OTEC) systems. No commercial OTEC plants are currently in operation. (REPN, 2010)

The use of tides for ocean energy production was very limited for many decades (REPN, 2010), which as first sight seems to be odd, because tidal energy uses the same technology as conventional hydropower energy. (RAMAGE, 2003) Currently, there are several modern commercial projects for generating power, and numerous other projects are in development or under contract, from the coast of Ireland to Australia. Additionally, an estimated 6 MW is operational or being tested in European waters (off the coasts of Denmark, Italy, the Netherlands, Norway, Spain, and the United Kingdom), with additional projects off the shores of Canada, India, Japan, South Korea and the USA. A 2.5 MW commercial wave plant was installed in Portuguese waters in 2008, with plans to expand total capacity up to 250 MW by 2020. (REPN, 2010) The system first generated electricity in July 2008 but the three converters were taken offline in November 2008, due to technical problems and financial difficulties of one of the promoters, the asset manager Babcock & Brown. (NYT, 2009) Currently, at least 25 countries are involved in ocean energy development activities. (REPN, 2010)

Regarding the technological challenges faced by ocean tides, the waves can generate energy but they are not true water flows by themselves. It requires very different techniques to use and to control the wave energy, which need to be strongly developed and the most important aspect for success is reliability. These are structures which will face for ever hard weather conditions and could be inaccessible for weeks due to storms, making it difficult for regular maintenance. (RAMAGE, 2003)

Another technology for ocean energy production is implementation of thermal facilities in the middle of the ocean. This technology is based on a very simple idea: in the tropics the water temperature to the surface can be reasonably warm, around 25ºC (80ºF), while for hundreds of meters deep the temperatures do not exceed 5ºC. The permanent difference of temperature, almost stable, is enough for a thermal facility to generate energy. Although it is not possible to generate steam at high pressure at 25ºC, there are liquids which reach the boiling point at low temperatures. Several experiments were made in the 70s and some small ocean thermal energy converting devices were installed, but there are still many technical problems to be solved, one of which is ultimately the transport of energy to land. (RAMAGE, 2003)

2.4 Geothermal Energy

Geothermal energy is the energy that can be generated from the heat inside the earth's surface. Geothermal heating and cooling is currently produced in two different ways: the first one (very low temperature (enthalpy) up to 30°C) is based on the relatively stable groundwater and ground temperatures at typically shallow depths (up to 500m) – and therefore also near structural elements of buildings; the second one (low and medium temperature-enthalpy) extracts the heat from ground and groundwater at higher depths and temperature varying between 25/30°C and 150°C. (RHC, 2009)

Electricity generation is the most important form of utilization of high-temperature geothermal resources (> 150 °C). The medium-to-low temperature resources (< 150°C) are suited to many different types of application. (REPN, 2010) Direct applications are found in agriculture (horticulture, drying, fish-breeding...), industrial process, and balneology. (RHC, 2009)

By the end of 2009, geothermal power plants operated in 24 countries and totalled approximately 10.7 GW of capacity, generating more than 67 TWh of electricity annually. Nearly 88 percent of that capacity is located in seven countries: United States (3,150 MW), Philippines (2,030 MW), Indonesia (1,200 MW), Mexico (960 MW), Italy (840 MW), New Zealand (630 MW), and Iceland (at 580 MW, the leader on a per capita basis). Iceland generates about 25 percent of its electricity with geothermal power, and the Philippines approximately 18 percent. (REPN, 2010)

The key challenge for the widespread direct use of geothermal heat will be the ability to reliably engineer the subsurface heat exchangers (EGS) in a reproducible way to harvest the heat flux at the required temperature. (RHC, 2009) There exists many geothermal prospects enjoying high temperatures but lacking sufficient rock permeability to allow fluid circulation. In this tight rock, poorly conductive, systems could be turned into technically and commercially exploitable reservoirs, by providing enhancement of their permeability by engineering adequate stimulation procedures, such as hydraulic fracturing and acidizing. (GEOELEC, 2010) Development of new hard materials for drilling hard rock for deep geothermal wells and new piping materials that resist the extreme hot corrosion conditions of fluids used to transfer heat in geothermal systems will make it possible to access geothermal potential. (MRS, 2010)

2.5 Bioenergy

Bioenergy refers to renewable energy produced from biomass, which is organic material derived from forestry, agricultural, and municipal residues as well as from a small share of crops grown specifically as fuel. It is available in solid, liquid (e.g., vegetable oils and animal slurries that can be converted to biogas), and gaseous (biogas) forms. It is commonly used to generate both power and heat, generally through combustion, and some biomass can be converted to biofuels for transport. Biogas, a by-product of fermenting solid and liquid biomass, can be converted by a combustion engine to heat, power, and transport. (REPN, 2010) The bioenergy landscape is composed of a complex set of energy sources, technologies, and products, as illustrated in Figure 15.

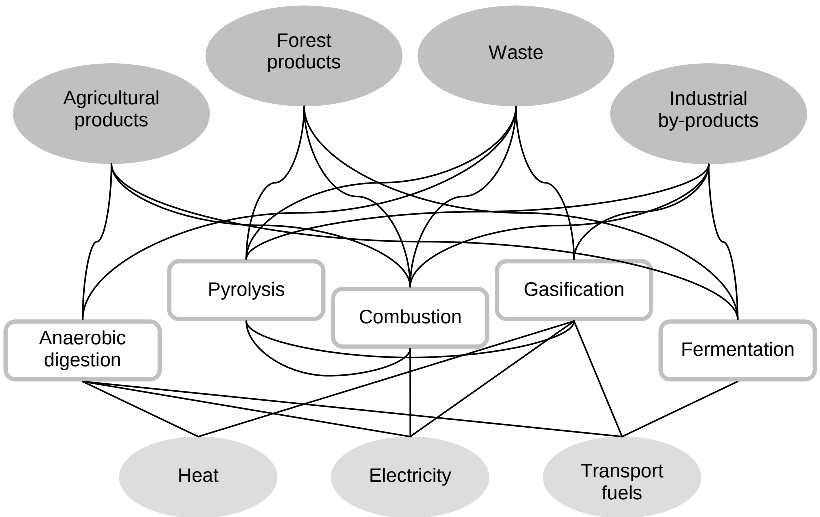


Figure 15 - Bioenergy matrix (IEA, 2006)

Currently, 61 Mtoe of biomass is used as final heat, main raw material fire wood, chips, pellets and other by-products, 9 Mtoe as electricity and 8 Mtoe as biofuel. (EREC, 2010) Biomass power plants exist in over 50 countries around the world and supply a growing share of electricity. Several European countries are expanding their total share of power from biomass, including Austria (7%), Finland (20%), and Germany (5%). (REPN, 2010)

Biofuels are fuels (often for transportation) made from biomass or its derivatives after processing. Examples of commercially available biofuels include ethanol, made primarily from corn and sugar cane, and biodiesel, produced from vegetable oils. Corn accounts for more than half of global ethanol production, and sugar cane for more than one third. (REPN, 2010) (IEA, 2010e)

USA is the world's largest producer of biofuels, followed by Brazil and EU. Together USA and Brazil accounted for almost 90 percent of global ethanol production. (REPN, 2010)

In 2009, worldwide production of fuel ethanol increased by 10 percent over 2008 (Figure 16). Most of the increased production occurred in the USA, with significant increases also in Canada, Germany, and France while production in Brazil declined. Both Belgium and the United Kingdom saw significant expansions, although their totals remained relatively low. (REPN, 2010)

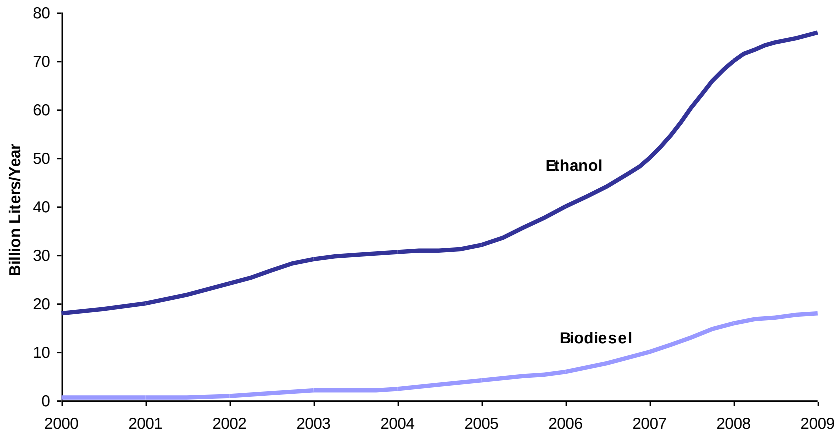


Figure 16 - Ethanol and biodiesel worldwide production (2000-2009) (REPN, 2010)

Although the production in Brazil is declining, this country was the first one to commercially produce large amounts of ethanol from sugarcane as a substitute for gasoline. A variety of grades of fuel ranging from 5% ethanol in gasoline to nearly 100% ethanol are now in production and use being, also, manufactured fuel-flexible vehicles that can run on gasoline, ethanol, or any mixture of the two. Due to the corrosion resulting from the use of ethanol as a fuel, engines resistant to such deterioration have been produced. (ARUNACHALAM et al., 2008)

Biodiesel production is far less concentrated than ethanol, with the top 10 countries accounting for just fewer than 77 % of total production in 2009. The EU remains the centre of biodiesel production worldwide, representing nearly 50 percent of total output in 2009, and biodiesel still accounts for the vast fraction of biofuels consumed in Europe. But growth in the region has slowed considerably over the past few years and, despite continued increases in production, growth rates for both ethanol and biodiesel have slowed considerably in 2009. (REPN, 2010) Nevertheless, the use of biofuels is expected to continue to increase rapidly over the period of 2008-2035, due to rising oil prices and government support. USA, Brazil and EU are expected to remain the world's largest producers and consumers of biofuels. (IEA, 2010e) The decline in asset investment in biofuels relegated the sector to fourth place among the renewable energy sectors in 2009. (REPN, 2010)

Conventional biofuel technologies include well-established processes that are already producing biofuels on a commercial scale. These biofuels, commonly referred to as first-generation, include sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion. Typical feedstocks used in these processes include sugarcane and sugar beet, starch-bearing grains like corn and wheat, oil crops like rape (canola), soybean and oil palm, and in some cases animal fats and used cooking oils. (IEA, 2011c)

Advanced biofuel technologies are conversion technologies which are still in the R&D, pilot or demonstration phase, commonly referred to as second- or third-generation. This category includes hydrotreated vegetable oil (HVO), which is based on animal fat and plant oil, as well as biofuels based on lignocellulosic biomass, such as cellulosic-ethanol, biomass-to-liquids (BtL)-diesel and bio-synthetic gas (bio-SG). The category also includes novel technologies that are mainly in the R&D and pilot stage, such as algae-based biofuels and the conversion of sugar into diesel-type biofuels using biological or chemical catalysts. (IEA, 2011c)

First-generation processes and infrastructure are currently in place producing biofuels, mostly ethanol. However, since these operations use feedstocks from readily convertible sources of biomass, which are also food sources, this puts pressure on the food supply. In addition, food as a feedstock has an unfavourable net energy content compared to non-foods. The next-generation biofuels development (also named second generation biofuels) will focus on non-food feedstocks like lignocellulosic materials. (DOE, 2010) The production of lignocellulosic feedstocks commonly requires less fuel, fertilizers and other inputs also it enables higher greenhouse gas (GHG) savings than when biofuels are produced from conventional crops such as cereals and sugar beet. (IEA, 2011b)

The cost of producing biofuels today is often higher than the current cost of imported oil, so strong government incentives are usually needed to make them competitive with oil based fuels. (IEA, 2010e) In the case of lignocellulose it is not only Earth’s most abundant carbon source but also highly renewable and provides ample material to generate bio fuels. However, lignocellulosics are highly recalcitrant to conversion into biofuels. (DOE, 2010)

A move to lignocellulosic feedstocks for bioenergy will be one promising way to reduce emissions from land use change since this can decrease the pressure on prime cropland. However, if bioenergy is to provide energy for both transport and for heat and electricity production, a mix of lignocellulosic material and conventional food/feed crops is likely to be used as bio energy feedstock during the coming decades. (IEA, 2011b) Breaking down cellulose is one of the challenges for materials science since it requires aggressive chemical processes and catalysts, and to contain and manipulate these corrosive chemistries, materials with long lifetimes are needed. (MRS, 2010) A few large-scale experiments on the production of cellulosic ethanol have been reported. (ARUNACHALAM et al., 2008)

Algal biofuels and the associated processing technologies had special attention on the 2010 annual report from IEA Bioenergy. In this report, it was recognised that the conversion of algal biomass to biofuels still requires ongoing R&D support. Nevertheless, questions have also been raised about what might constitute the minimum economic scale of the inherent types of conversion processes. (IEA, 2011a) One challenge in materials science for the production of algal biofuels might be catalytic materials for conversion since the cellular membranes of algae are rich in the raw materials for production of hydrocarbon chains of gasoline and diesel fuel, but need their own special chemical routes. (MRS, 2010)

The leading principles for the further development of bioenergy in future energy systems are sustainability criteria, efficiency and competitiveness. Bioenergy has to bring to commercial maturity the most promising technologies that fit these principles. The topics that will affect R&D are the integration of bioenergy into supply structures with new conversion technologies, monitoring conversion technologies, monitoring biogas plants, modelling of the whole biogas chain, the development of digestion technologies and the development of both consulting and training programmes. (EREC, 2010)

2.6 Nuclear Energy

At the beginning of 2011, 56 countries operate 250 civil research reactors, and 30 host some 440 commercial nuclear power reactors with a total installed capacity of over 375,000 MWe They produce about 14% of the total electricity generation. At the same time, there are 61 reactors under construction worldwide with net electrical capacity of 64,1 MWe gross. (WNA, 2011) Until 2012 the world nuclear capacity will rather decline than increase due to aging reactors and too few new reactors under construction. In the long term beyond 2030 uranium shortages will limit the expansion of nuclear power plants. However, even to meet the demand until 2030 the present uranium production capacities must be increased by at least 30%. (EWG, 2006)

More recently, the attention on nuclear energy has shifted to its role as a non-CO_2-emitting source of clean energy, particularly when large-scale baseload generation is required, and also as a means ("load following") to offset generation variability in regions where there is substantial diffusion of renewables like solar and wind. A number of studies have concluded that the USA will not be able to reach the targets for CO_2 reduction without a full portfolio of non-emitting forms of energy generation, including nuclear. (DOE, 2010)

Nuclear electricity is attractive from the economic perspective since generation costs are relatively stable and predictable. The price of uranium can fluctuate but since it represents less than 10% of the final generation cost, electricity prices are only marginally affected. This is not the case for fossil fuels. (SNETP, 2011) Nevertheless, aspects related with plants security and the problems of radioactive wastes are still unsolved (RAMAGE, 2003)

Recent disaster in Fukushima plant has raised fear regarding nuclear energy. It has also brought to memory the consequences of other disasters like the Three Mile Island (1979) and Chernobyl (1986). Consequently, safety is an important factor in nuclear power plant development, along with issues concerning nuclear waste disposal and cost. Compared to conventional coal generation, nuclear power plants tend to be at least 15–30% costlier and are also capital intensive. (ARUNACHALAM et al., 2008)

In recent years, many breakthroughs have been made and a number of major projects are under development that may bring research to the point where fusion power can be commercialised. Several tokamaks have been built, including the Joint European Torus (JET) in the UK and the tokamak fusion test reactor (TFTR) at Princeton in the USA. The ITER (International Thermonuclear Experimental Reactor) project currently under construction in Cadarache, France will be the largest tokomak. (WNA, 2011) The ITER project is a next step toward determining the materials that would be needed to contain such a reaction, although results from this project are not expected for decades.

2.7 Fossil Energy

2.7.1 Coal

By the end of 2009, 85% of the existing coal reserves were concentrated on seven countries (in descending order of reserves): USA, Russia, China, Australia, India, Ukraine and South Africa, as shown in Figure 17. USA has 29% of all reserves alone and is second in production. China is by far the greatest coal producer has only approximately half the reserves of the USA. Thus, we can state that scenery of coal production in these two countries will dominate the future global production. (EWG, 2007) (BP, 2010)

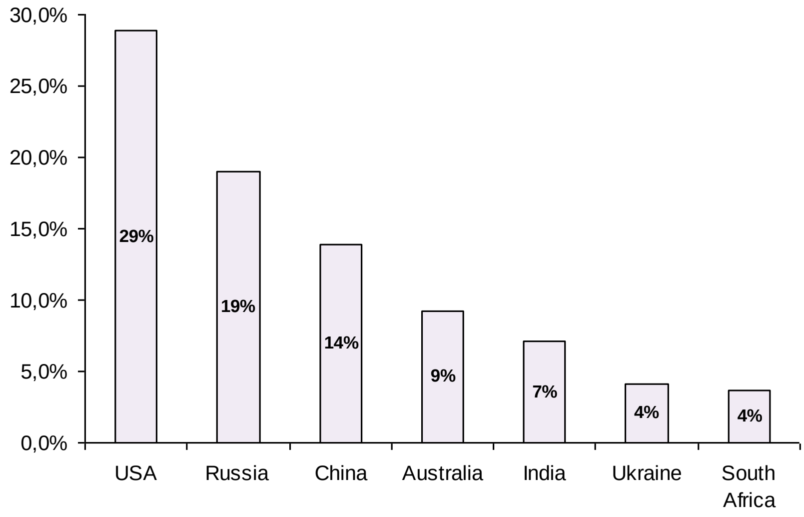


Figure 17 - Proved reserves of Coal at end 2009 (BP, 2010)

Coal accounted for about 29% of the global primary energy consumption in 2009 (hard coal 27%, lignite nearly 2%), only surpassed by oil (Figure 18). Coal is the fuel most widely used in power plants for electricity generation, accounting for 41% of the global share (Figure 5). (BGR, 2011) (BP, 2010)

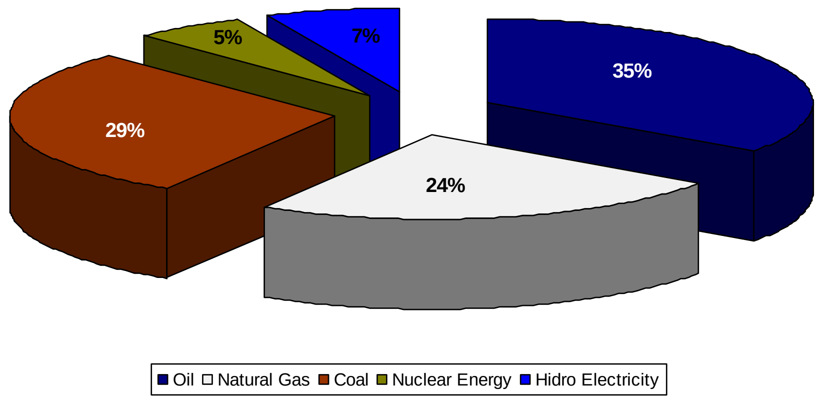


Figure 18 - Primary Energy Consumption by fuel at end 2009 (BP, 2010)

Around 5.9 billion tones of hard coal were used worldwide last year and 909 million tones of brown coal. Since 2000, global coal consumption has grown faster than any other fuel. (WCA, 2011) Coal has many important uses worldwide. The most significant uses are in electricity generation, steel production, cement manufacturing and as a liquid fuel, with 78,5% for industry. (WCA, 2011) Coal-fired electricity can help support the growth of renewable energy by balancing out their intermittencies in power supply. Coal can provide convenient, cheap base-load power while renewables can be used to meet peak demand. The economics and efficiency of biomass renewables can also be improved by co-firing with coal. (WCI, 2005)

Also, coal might contribute for producing substitutes of petroleum through methods of coal liquefaction. This conversion may become important if petroleum prices keep rising in the mid-term and long-term perspective (Figure 19). Methods for converting coal into liquid hydrocarbons (Coal-to-Liquid, CTL) have been known since the early 20th century. (BGR, 2009)

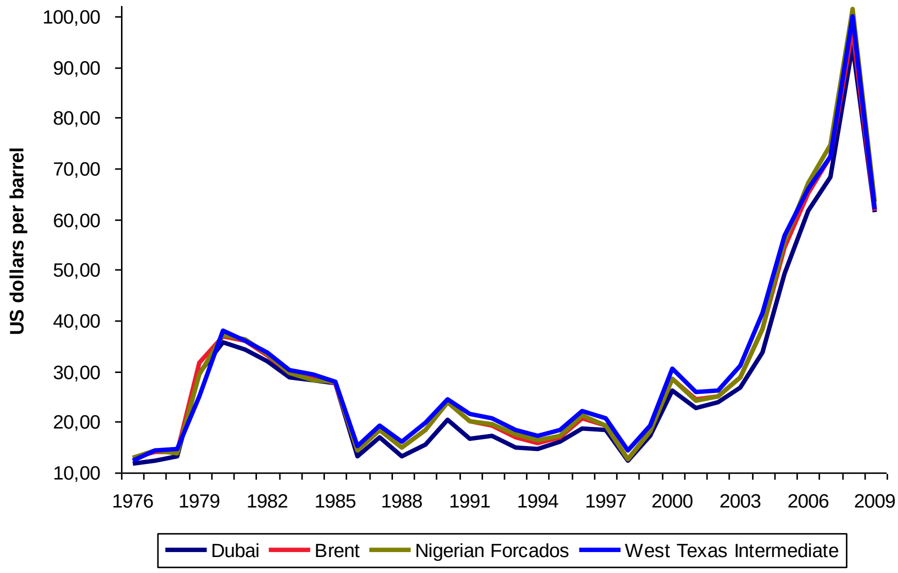


Figure 19 - Oil prices at end 2009 (BP, 2010)

There are two key methods of liquefaction: direct coal liquefaction – where coal is converted to liquid fuel in a single process and indirect coal liquefaction – where coal is first gasified and then converted to liquid. The cost effectiveness of coal liquefaction depends to a large extent on the world oil price with which, in an open market economy, it has to compete. If the oil price is high, coal liquefaction becomes more competitive. (WCI, 2005) This was the case when oil was cheap after the World War II and it allowed the eventual development of this process to become anti-economic, and its production was stopped everywhere. However, South Africa, which had relatively cheap coal and a sensitive dependence on imported oil, continued to develop its plant SASOL, which currently consumes thirty million tons of coal in order to produce a an amount of liquid fuel that avoids the import of five million tons of oil. (RAMAGE, 2003) Currently this power plant supplies about a third of South Africa domestic liquid fuel requirements from coal. (WCI, 2005)

Nevertheless, coal mining raises a number of environmental challenges, including soil erosion, dust, noise and water pollution, and impacts on local biodiversity. Viable, highly effective technologies have been developed to tackle the release of pollutants - such as oxides of sulphur (SO_x) and nitrogen (NO_x) - and particulate and trace elements, such as mercury. More recently, GHG emissions, including carbon dioxide (CO_2) and methane (CH_4) have become a concern because of their link to climate change. (WCA, 2011) Coal produces twice as much amount of carbon dioxide in comparison with oil and gas, in order to get the same amount of useful heat. Also, its transport, storage and use is more complicated. Thus a major future challenge is using coal, as one of the most important fossil energy carriers in the world, while minimizing carbon dioxide emissions. (BGR, 2011) Much has been done to achieve this, such as the improvements in efficiency levels, and implementation of technologies for carbon capture and storage (CCS). (WCI, 2005) This topic will be discussed in more detailed ahead in this document.

2.7.2 Oil

The invention of the combustion engine by the end of the 19th century was the basis for the success of petroleum. In the second half of the 20th century, petroleum was the most important energy source and ensured growth and prosperity. Today, petroleum is of major importance for transportation, with a share of 61,4 % (IEA, 2010c), heat generation and the chemical industry. Nevertheless, oil is a finite natural resource. The consumption of these resources has reached a considerable dimension by now. To form the amount of oil and natural gas consumed annually nature took about one million years. (BGR, 2009) Remaining world oil reserves are estimated to amount to 1,255 Gb according to the industry database. Production will start to decline at a rate of several percent per year. By 2020, and even more by 2030, global oil supply will be dramatically lower. This will create a supply gap which can hardly be closed by growing contributions from other fossil, nuclear or alternative energy sources in this time frame. (EWG, 2008)

Energy used for transport will continue to be dominated by oil, but should see its share of global energy utilization decline as other sectors grow more rapidly. The growth of oil in transport slows even more dramatically, largely because of displacement of oil by biofuels and it is likely to plateau in the mid-2020s. (BP, 2011)

2.7.3 Natural Gas

Around a fifth of final energy consumption around the world comes from natural gas (IEA, 2010c). Composed primarily of methane, the main products of the combustion of natural gas are carbon dioxide and water steam. (NGSA, 2010) It emits 40% less carbon dioxide than coal and 30% less than oil for the same amount of energy. (EWG, 2009) The combustion of natural gas, in contrast with oil and coal, releases very small amounts of sulphur dioxide and nitrogen oxides, virtually no ash or particulate matter, and lower levels of carbon dioxide, carbon monoxide, and other reactive hydrocarbons. (NGSA, 2010) Thus, gas is considered to be more environmentally friendly than other fossil fuels.

Of the natural gas reserves available on current estimates, over half lie in Russia, Iran and Qatar. (BP, 2010) Estimates on the available gas reserves there are highly questionable and are probably much too high. When the southern part was discovered back in 1971, the reserves were projected for an area of several thousand square kilometres based on just a few test boreholes and later these came up negative. Sceptics believe that in the end no more than one third of the originally expected natural gas reserves will be extracted. (EWG, 2009)

Natural gas entered as an attractive alternative fuel and has replaced oil for many applications. The cost of liquefying natural gas (LNG) has come down significantly in recent years, and transportation of LNG aboard large ocean-going tankers has extended the availability of natural gas beyond the limits of pipelines. (ARUNACHALAM et al., 2008) Besides transportation, natural gas has applications, commercially, in our home and in industry. The industrial sector accounts for the greatest proportion of natural gas use, with 35,1%. (IEA, 2010c)

One of the technologies that are revolutionizing the natural gas industry includes natural gas fuel cells. Fuel cells powered by natural gas are an extremely exciting and promising new technology for the clean and efficient generation of electricity. Fuel cells have the ability to generate electricity using electrochemical reactions as opposed to combustion of fossil fuels to generate electricity. (NGSA, 2010)

Other type of natural gas is shale gas - unconventional natural gas. Shale gas is defined as natural gas from shale formations. Its deposits are difficult to characterize overall, but in general are often lower in resource concentration, more dispersed over large areas, and require well stimulation or some other extraction or conversion technology. (API, 2010)

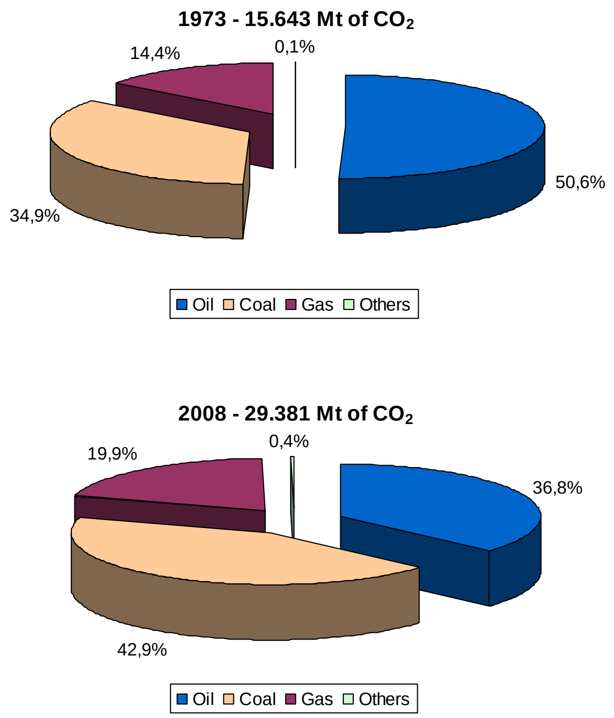
In order to take advantage of unconventional gas reserves, materials are needed for development of improved supporting agents that can survive extremely high stresses and are corrosion resistant; wear resistant coatings on drills to allow deeper wells; and the development of high strength, corrosion resistant alloys for use in well casings and deep well drill pipe. (MRS, 2010)

Natural gas is certainly set to play a central role in meeting the world's energy needs for at least the next two and a half decades. Global natural gas demand, which fell in 2009 with the economic downturn, is set to resume its long term upward trajectory from 2010. It is the only fossil fuel for which demand is higher in 2035 than in 2008 in all scenarios, though it grows at markedly different rates. (IEA, 2010e)

2.7.4 Carbon Emissions

Electricity generation is entering a period of transformation as investment shifts to low carbon technologies. Fossil fuels – mainly coal and natural gas – remain dominant, but their shape of total generation drops from 68% in 2008 to 55% in 2035, as nuclear and renewable sources expand. Globally, coal remains the leading source of electricity generation in 2035, although its share of electricity generation declines from 41% now to 32%. (IEA, 2010e)

The reduction on CO_2 and CH_4 emissions would be an important step towards a cleaner environment since they have a negative impact on planet's environment. Fossil fuels will continue to be the predominant source of energy, for much of this century and, to prevent or at least mitigate global climate change, it will have to be found ways to capture and store the CO_2 produced (Figure 20).



*Other includes industrial waste and non-renewable municipal waste.

Figure 20 - World fuel shares of CO_2 emissions (IEA, 2010c)

CO_2 is the natural left over after combustion of fossil fuel and the industrial CO_2 emissions are suspected to be responsible for climate change. Amongst the spectrum of measures that need to be urgently implemented to mitigate climate change and ocean acidification, CCS can play a decisive role as it could contribute 33% of the CO_2 reduction needed by 2050. Potential impacts on the ecosystems would vary depending on whether the storage site is located offshore or onshore. (CO2GEONET, 2008)

For factories and electricity generation plants, one approach is finding materials that will absorb the CO_2 in the flue gas and then release it during regeneration so that the CO_2 can be sequestered underground. (LAVE, 2008)

Technologies for carbon capture have reached the stage of prototype demonstration, and initial trials of geologic carbon sequestration have been completed. Nonetheless, the vast potential of this technology is just beginning to be tapped. (DOE, 2010)

The technical maturity of specific CCS system components varies greatly. Some technologies are extensively deployed in mature markets, primarily in the oil and gas industry, while others are still in the research, development or demonstration phase. The Special Report on CCS from IPCC provides an overview of the current status of all CCS components and, also, presents the category of materials, current and emerging, for each capture technology (IPCC, 2005) and this topic will be further discussed in this document.

Estimated additional costs for generating electricity from a coal-fired power plant with CCS, range from \$20 to \$70/tonne of CO_2 avoided, depending mainly on the capture technology and concentration of CO_2 in the stream from which it is captured. At these rates, electricity-generating costs would increase from 50% to 100% over those of plants with CO_2 capture. Capture and compression typically account for over 75% of the costs of CCS. The R&D efforts are underway to reduce the cost of capture and compression, making widespread deployment of CCS more viable. (BENSON et al., 2008)

Given the scale of sequestration needed to mitigate climate change and the short time frame required for GHG stabilization at acceptable levels, the basic science needs for this energy-related technology should be pursued with urgency. (DOE, 2010) CCS technologies have to be widely commercialised if the EU wants to achieve almost zero carbon power generation by 2050 and if the likely continued use of the vast global coal reserves is not to exacerbate climate change. (EC, 2009a)

3. Secondary Energy Production, Storage, Transmission and Distribution

Primary energy sources, as described in the previous section, are usually transformed into more convenient forms of energy, such as electrical energy, hydrogen or synthetic fuels. And its efficient use is dependent of storage and transmission systems.

Electricity is one of the fundamental enabling clean energy technologies of the 21st century, due to its versatility in providing energy services, the opportunities for electrification of transportation and the need for transmission of abundant renewable power resources to distant load centres. Traditional forms of electricity generation store energy on site in the form of a stock of (e.g.) coal, oil, gas, nuclear fuel or water behind a dam. An Alternating Current (A.C.) electricity grid, as used in all developed and developing countries, requires that supply and demand is always matched on a second by second basis, since electricity, with minor exceptions, can not be stored. The key role of electricity network and transmission system operators is to have arrangements in place to ensure this requirement is always met. The two prevalent forms of low and zero carbon generation are based around renewable and nuclear fuels. The former is in many cases (wind and solar being the prime examples) intermittent or variable while the latter is generally designed to operate at a constant output. Electrical energy storage offers the potential to store electrical energy once generated from low and zero carbon sources and to subsequently match supply and demand as required. (EC, 2008b)

Therefore, the change on demand profile and or electrical generation requires changes in terms of conception, operation and implementation of electrical networks (grid). (IEA, 2010b) Thus, the grid faces huge challenges, many of which require fundamental scientific understanding and breakthroughs in basic materials and in system-level integration. (DOE, 2010) One of the most exciting developments in recent times has been the discovery of “high-temperature” superconductors. Much of the excitement is resulting of the many applications, which includes magnetically levitated trains, high voltage transmission lines with no electrical resistance and high-speed, miniaturized electronic computer chips. Another possible utility application is the use of superconducting coils to store electricity which would be charged during off peak hours by using power from base load generators, and then discharged during times in the day when demand was largest. (HINRICHS, 2002)

Besides electrical power transmission, the importance of energy storage has grown over the past decades and has reached an unprecedented level as the world electrifies transportation and integrates alternative energy, especially intermittent wind and solar energy, into electrical utility grid, and as consumer use of portable, wireless electronic devices increases. New materials are a key to improved performance at lower cost. New architecture or processes are also needed to go beyond incremental improvements in existing materials. Fundamental understanding of interfaces and the electrochemistry at those interfaces will accelerate the research into improved performance at a lowest cost. (DOE, 2010)

In summary, energy storage offers many benefits in grid and transmission applications, including: i) improved fuel utilization and reduced consumption of fossil fuels; ii) reduced CO_2 and other greenhouse gas emissions; iii) a greater diversity of energy sources, increasing energy security and decreasing dependence on foreign sources of energy; iv) easier integration of renewable sources of energy, such as wind and solar, thus allowing a higher penetration of renewables; v) more efficient delivery of services needed for grid operation; vi) increased asset utilization of existing power generation and delivery infrastructure; vii) deferral of asset acquisition or upgrading; viii) improved reliability, power quality, and security of the grid. (DOE, 2010)

The document “Outlook of Energy Storage Technologies” provides an overview of the current status and outlook for energy storage technologies, discussing some of the potential applications of the different technologies, and reviewing some of the economic and environmental issues arising from their deployment. Additionally it sets an inventory of energy storage technologies and reviewing the most promising technologies for the main potential applications. (EC, 2008b)

One last challenge for electricity storage is “plug-in” hybrid or all-electric vehicles. A battery that could power a vehicle for 48–64 km and be recharged from an electricity outlet would save about two-thirds of gasoline use. If all automobiles and light trucks were plug-in hybrids, more than one-half of oil imports could be eliminated and if a battery was capable of powering the vehicle for 240 km and could be recharged from an outlet in 5–10 min, it might be possible to eliminate the use of gasoline in cars and light trucks. These vehicle batteries pose an extreme challenge for materials scientists. (Lave, 2008) The barriers to wider penetration of energy storage in transportation and grid applications are cost, life (durability), safety, and efficiency. The two biggest cost drivers in an electrochemical storage system are the materials costs and the processing/production costs. (DOE, 2010)

Fuel cells and hydrogen have great potential in the contribution to overcome energy challenges. Fuel cells because they constitute a technology that efficiently converts energy and hydrogen as a clean energy carrier. In several energy end-use sectors, for instance, in electric vehicles and power plants, fuel cells and hydrogen will play an important role. Thermoelectricity, also, will play an important role on power generation and its applications are broad. Thermoelectric materials were primarily used in niche applications but, with the arrival of broader automotive applications and the effort to utilize waste-heat-recovery technologies thermoelectric devices are becoming more prominent. (TRITT et al., 2008)

Due to their importance to transportation using plug-in electric vehicles and for utility-scale storage to overcome the obstacle on intermittency of renewable energy sources, the focus in this document will be on storing and energy converters like batteries and supercapacitors, as well as fuel cells, hydrogen and thermoelectricity.

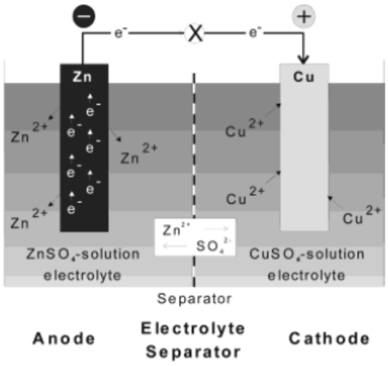
3.1 Batteries and Supercapacitors

Batteries represent the most common form of storing electrical energy. They are efficient storage devices, with output energy typically exceeding 90% of the input, except at the highest power densities. (WHITTINGHAM, 2008) R&D activities have been active in this field, which enabled the development of batteries that are lightweight, inexpensive and capable of thousands of recharges. Nevertheless, commercial products reach the market slowly. Technologies as nickel metal hydrides (NiMH), NiCd, zinc, sodium-sulphur and lithium batteries are possible replacements for the lead acid battery. (HINRICHS, 2002) Today, NiMH technology is the principal battery used in hybrid electric vehicles. (WHITTINGHAM, 2008) but it will soon be eclipsed by lithium-ion (Li-ion) batteries. Many automotive researchers believe that lithium-ion batteries are the choice for electric drive applications for the next 10–15 years, so the focus is on improving their low-temperature performance and safety. PHEVs and HEVs are starting to become commercially available, although the present high cost of such batteries and vehicles will likely limit widespread adoption. (DOE, 2010)

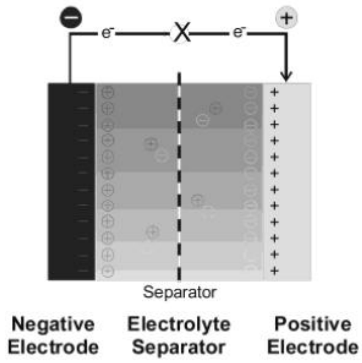
Sodium-sulphur batteries have achieved commercial status in Japan with over 50 operational examples. Whilst the technology has been available for several years, recent improvements in efficiency means that it now has one of the best energy densities of all technologies. A major drawback environmentally is that NaS batteries have a limited number of charge/discharge cycles and hence a finite lifetime dependent on the number and depth of charge and discharge cycles and how frequently they occur or are required. (EC, 2008b)

On the other hand, sodium sulfur batteries could be used for taming the variability of wind and solar power. In this case, these batteries are well-suited for storing electricity made from renewable energy when it is in surplus and use it during peak demand periods. This technology has been in development for several years. For instance, EaglePicher Technologies, began developing a battery for space applications in the mid-1980s that used sodium and sulfur components. By then, the focus for military and space batteries had shifted to lithium-ion models in the US and the impetus for a sodium sulfur battery vanished. While the technology was pioneered in USA, but then abandoned, Japan saw the promise and picked it up. Tokyo Electric Power Co. and NGK Insulators pushed sodium sulfur development in the 1990s, and today, NGK is the primary commercial manufacturer. (BEHR, 2011)

Other important storage devices are supercapacitors that were discovered in the mid 20th century and have been marketed since the 1980s. (EC, 2008b) Traditionally, capacitors differ from batteries by storing energy as charge on the surface of the electrodes, rather than by chemical reaction of the bulk material (Figure 21) and therefore the electrode does not have to undergo structural change. As a result, capacitors have much longer lifetimes, essentially unlimited under perfect conditions. They thus also tend to have much higher rate capabilities than batteries, being almost instantaneously charged or discharged. Consequently, they are suitable for repetitive fast applications, such as regenerative braking and subsequent acceleration. However, because capacitors use only the surface of the material for charge storage, they are very limited in energy storage capability, compared to lithium batteries. In addition, they provide a rather low quality of energy. (WHITTINGHAM, 2008)



Battery



Supercapacitor

Figure 21 - Representation of a battery and of a supercapacitor (WINTER et al., 2004)

Supercapacitors found their first application in military projects. Common applications today include starting diesel trucks and railroad locomotives, actuators, and in electric/hybrid-electric vehicles for transient load levelling and regenerating the energy of braking. NASA has used 30 large supercapacitors in its turbo-electric city bus. Interest has grown as their energy storage capacity has increased. (WHITTINGHAM, 2008)

Batteries and supercapacitors have low energy density and high cost compared to gasoline and diesel, when used for transportation. (DOE, 2010) Table 1 presents a summary on relevant aspects of the storage technologies presented above.

Table 1 - Summary of characteristics on some storage technologies (EC, 2008b)

Technology Type	Efficiency of recovery	Development	Deployment	Advantages	Disadvantages	Suitable for		
						Energy Management	Power Quality	Transport
Supercapacitors	85-98%	Developing	Widespread (small scale)	Long life cycle High efficiency High power density	Low energy density Toxic and corrosive compounds	Partially suitable	Suitable	Suitable
Nickel Batteries	60-91%	Available	Limited	High energy density Good efficiency	Low power density NiCd: Cadmium highly toxic NiZn, NiMH and $NaNiCl_2$ require recycling	Partially suitable	Suitable	Suitable
Lithium Batteries	90-100%	Available	Growing for small scale applications	High energy density High efficiency	Low power density High cost Lithium oxides and salt require recycling Polymer solvents and carbon must be made inert	Limited suitability	Suitable	Suitable
Sodium-Sulfur Batteries	> 86%	Available	Mainly in Japan	High energy density Good efficiency	Low power density High production costs Na requires recycling	Suitable	Partially suitable	Limited suitability

A number of scientific challenges and opportunities face both batteries and capacitors. Transformational changes in both battery and capacitor science and technology will be required to allow higher and faster energy storage at the lower cost and longer lifetime necessary for major market enlargement. Most of these changes require new materials with larger redox capacities that react more rapidly and reversibly with cations such as lithium. (WHITTINGHAM, 2008) Future development will most likely see supercapacitors become integral parts of a wide variety of hybrid energy-storage/power-delivery systems. (HALL et al., 2008)

3.2 Hydrogen

Hydrogen is abundant in chemical compounds such as water and the organic compounds of biomass, and its combustion produces only heat and water with no offensive pollutants or carbon dioxide. (CRABTREE et al., 2008) Although hydrogen is the most abundant element in the universe, it does not naturally exist in its elemental form on Earth. Pure hydrogen must be produced from other hydrogen-containing compounds, such as fossil fuels, biomass, or water. Each production method requires a source of energy, i.e., thermal (heat), electrolytic (electricity), or photolytic (light) energy. (DOE, 2007) One point to note is that hydrogen cannot be seen as a fuel. Like electricity, hydrogen is a means to deal with energy, carrying it from one place to another, and not a means to, firstly, generate it. We have to consume energy in order to remove the hydrogen from the water, and then the hydrogen, like electricity, carries the energy to the consumer. Thus, the economic system is based on the hydrogen is an alternative to the economic system based on electricity. (RAMAGE, 2003) Figure 22 shows that water–hydrogen cycle is closed, unlike the fossil fuel energy chain that operates on a “once-through” basis.

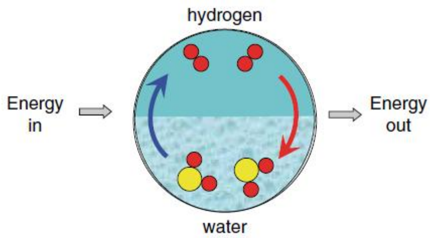


Figure 22 - Water - hydrogen cycle (CRABTREE et al., 2008)

Hydrogen can be combined with oxygen in the electrochemical reactions of a fuel cell to produce electricity, a clean, versatile carrier of energy enabling many end uses including lighting, refrigeration, communication, information processing, and transportation. (CRABTREE et al., 2008) Currently, hydrogen is a widely used industrial gas. Hydrogen from coal or biomass gasification offers high efficiency (up to 60%) electricity production for the grid. (MRS, 2010)

The “Critical path” technology barriers are: i) reducing the cost of hydrogen, which includes the cost of production and delivery that must be competitive with conventional fuels; ii) improving hydrogen storage technology, the low volumetric energy density of hydrogen makes storage a challenge (no current hydrogen storage technology enables a hydrogen fuel cell vehicle to travel the desired 300 miles or more per fill while meeting vehicular packaging, cost, and performance requirements); iii) reducing fuel cell cost and improving durability, the cost of fuel cell power systems must be reduced and durability must be improved for fuel cells to compete with conventional technologies. (DOE, 2007)

Hydrogen-based energy storage systems are receiving considerable attention presently due to the long timescale over which hydrogen can be stored and because of the potential hydrogen holds for replacing petroleum products as the energy carrier for the transport sector. When coupled with a renewable energy source or low carbon energy technology, hydrogen energy storage has the potential to reduce greenhouse gas emissions. The essential elements of a hydrogen storage system comprise an electrolyser unit, to convert electrical input to hydrogen during off-peak periods, the storage component and an energy conversion component to convert the stored chemical energy into electrical energy when demand is high or for use in transportation systems. (WHITTINGHAM, 2008)

For hydrogen to be an attractive energy carrier, better materials must be found for pipelines to transport the gas without losses and for its storage. These materials must be inexpensive and long-lived. Better materials must be found for storage tanks on cars, with several specific features like lightweight and capable of storing large enough quantities to power the vehicle for several hundred miles. Because vehicles are typically garaged in enclosed spaces, the storage tanks can have little or no leakage, as hydrogen is explosive. (LAVE, 2008)

Storing hydrogen in materials can occur via absorption, adsorption, or chemical reaction. Materials used for hydrogen storage can employ one or more of these mechanisms and may be grouped into four general categories (DOE, 2007), which will be further explored in this document.

A number of hydrogen-fuelled passenger cars and buses are already in circulation, but increasing their number to a commercial scale requires lowering the price through technological development and mass market production processes. Commercialisation depends also largely on the development of infrastructure for the production, storage, and distribution of hydrogen and special refuelling stations. Currently, only a small number of hydrogen refuelling stations exist worldwide, and refuelling station costs need to be reduced to make them commercially viable. (EC, 2011e)

3.3 Fuel Cells

Low emissions, quiet performance and high energy efficiency are the biggest assets of fuel cells, currently used mostly in transportation. These cells are becoming an optimum way to gear ourselves to a more environmentally friendly world. The Fuel Cell is a unique power converter that combines a fuel (usual natural gas or hydrogen) with oxygen by an electrochemical process to produce electricity. (HINRICHS, 2002) Fuel cells converting hydrogen and oxygen to electricity and water are an appealing alternative to fossil fuel combustion engines for their efficiency, versatility, and environmental friendliness. (CRABTREE et al., 2008)

Essentially, a fuel cell works by passing streams of fuel (usually hydrogen) and oxidants over electrodes that are separated by an electrolyte, as shown in Figure 23. This produces a chemical reaction that generates electricity without requiring the combustion of fuel, or the addition of heat as is common in the traditional generation of electricity.

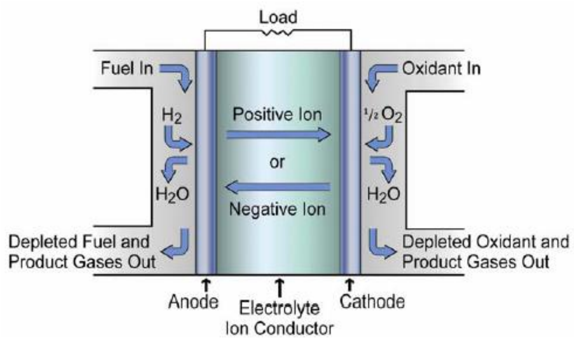


Figure 23 - General schematic of a single fuel cell (DOE, 2010)

The fuel cell is similar to a battery, providing direct current through an electrochemical process. However, a battery uses the materials that are stored at the electrodes (Pb and PbO_2 for a storage battery), while in a fuel cell the chemical reactants are fed to the electrodes on demand. (HINRICHS, 2002) When pure hydrogen is used as fuel, and pure oxygen is used as the oxidant, the reaction that takes place within a fuel cell produces only water, heat, and electricity, resulting in very low emission of harmful pollutants, and in the generation of high-quality, reliable electricity. (NGSA, 2010)

The high conversion efficiency of hydrogen fuel cells, up to 60%, makes them attractive compared to other electrical generation alternatives based on fossil fuels, which are about 34% efficient on average. (CRABTREE et al., 2008)

There are several types of fuel cells that are defined by the type of electrolyte used to convert the chemical energy into electrical energy, the kind of fuel involved and their operating temperature. The most relevant are: polymer electrolyte / proton exchange membrane fuel cell (PEMFC), molten carbonate fuel cell (MCFC), direct ethanol/methanol fuel cells (DEFC/DMFC), phosphoric acid fuel cell (PAFC), alkaline fuel cell (AFC), solid-oxide fuel cell (SOFC). (BTI, 2011)

PEMFC, SOFC and MCFC are still in the demonstration stage. PEMFC have a solid polymer membrane as an electrolyte. Due to membrane limitations, PEMFC usually operate at low temperatures (60-100°C). (DOE, 2007) Also this type of fuel cell has high power density and may be applicable for light-duty vehicles, and for smaller applications such as replacements for rechargeable batteries in video cameras and cell phones. (HINRICHS, 2002)

DMFC differ from PEMFC because they use liquid methanol fuel rather than hydrogen. DMFC operate at slightly higher temperatures than PEMFC (50-120°C) and achieve around 40% efficiency. Since they are refuelable and do not run down, DMFC are directed toward small mobile power applications such as laptops and cell phones. (BTI, 2011)

MCFC use molten sodium carbonate as the electrolyte. They have the ability to use coal-based fuels which make them suitable for large-scale electricity generating facilities. (HINRICHS, 2002) It operates at 600-750°C with an electrical efficiency of 50-60%, and a total efficiency of 80-85% with cogeneration of waste heat. To date, MCFC have operated on hydrogen, carbon monoxide, natural gas, propane, landfill gas, marine diesel, and simulated coal gasification products. (BTI, 2011)

SOFC are one of the high temperature fuel cells, operating at 800-1000°C. High temperature operation eliminates the need for precious metal catalysts and can reduce cost by recycling the waste heat from internal steam reformation of hydrocarbon fuels. SOFC are tolerant to CO poisoning, allowing CO derived from coal gas to also be employed as source of fuel. These fuel cells use a solid ceramic electrolyte and demonstrated electrical efficiencies are 45-55%, with total efficiencies of 80-85% with cogeneration of waste heat. (BTI, 2011)

The most critical issues on SOFC includes: i) poor thermal cycling resistance; ii) starting time; iii) electrode degradation at high temperatures (chemical reactivity); iv) cost of the interconnecting materials (chromite); v) sealing problems and vi) necessity of reducing the operating temperature. (BTI, 2011)

PAFC use liquid phosphoric acid as an electrolyte with a platinum catalyst. Anode and cathode reactions are similar to PEMFC, but operating temperatures are slightly higher (150-200°C) (BTI, 2011) and they are more tolerant of impurities within the influx gases than PEMFC cells, which are easily poisoned by carbon monoxide (CO). (EC, 2008b) PAFCs use hydrocarbon sources such as natural gas, propane or waste methane. (BTI, 2011) PAFC Is the most mature and commercially developed type of fuel cell, typically used for stationary power generation and has been operated in a commercial size of 200 kW and tested with an 11 MW unit. (HINRICHS, 2002)

AFC operate in an electrolyte solution of potassium hydroxide and can use a variety of non-precious metal catalysts at operating temperatures of 23-250°C. Fuelled by hydrogen gas, AFC have a high chemical reaction rate and offer an electrical efficiency of 60-70%. However, AFCs are poisoned easily by small quantities of carbon dioxide. (BTI, 2011)

The electrolyser and fuel cell components can be dedicated or ”reversible”, capable of electrochemically producing hydrogen or operating in fuel cell mode and converting the hydrogen back to electricity. PEMFC technology has been most extensively explored for reversible electrolyser operation, but SOFC and AFC technologies can also be applied reversibly. (EC, 2008b)

There are many uses for fuel cells especially on major automobile manufacturers that are working to commercialize a fuel cell car. Fuel cells do not, strictly speaking, constitute electricity energy storage, but compete with batteries, supercapacitors, and flywheels in some applications. They have the advantage of using hydrogen, a fuel that can be quickly pumped into the vehicle, allowing for fast charge. But they are very costly and pose challenges for storing hydrogen onboard the vehicle, in addition to the infrastructure challenge of an adequately supportive hydrogen economy. (DOE, 2010)

Fuel cells for Stationary Applications include MCFCs and SOFCs high-temperature fuel cell technologies, which are most attractive for industrial, commercial, and residential building sectors. Their high quality (high temperature) waste heat can produce electricity by generating steam to run a turbine, resulting in overall chemical-to-electricity conversion efficiencies greater than 80%. Lower-temperature fuel cells can be employed in stationary applications, PAFCs can achieve efficiencies of 60% to 80% when integrated with a building in which the waste heat can be used for space heating.

In case of fuel cells for automotive applications, PEMFC are more adequate. These fuel cells achieve hydrogen-tank-to-wheel efficiencies of 50% to 60% in midsize passenger cars, compared to less than 25% for gasoline-tank-to-wheel efficiencies in internal combustion applications. (DOE, 2010)

3.4 Thermoelectricity

High-efficiency thermoelectric (TE) materials are important for power-generation devices that are designed to convert waste heat into electrical energy. They can also be used in solid-state refrigeration devices. The conversion of waste heat into electrical energy may play an important role in our current challenge to develop alternative energy technologies to reduce our dependence on fossil fuels and reduce greenhouse gas emissions. (TRITT et al., 2006)

The thermal-to-electric energy conversion is a solid-state conversion process that is quiet, has no mechanical parts, and provides long-term stability. Thermoelectric devices can be used either for cooling (Peltier effect) or for power generation (Seebeck effect). Thus, heat (typically waste heat) can be converted directly into useful electrical energy. (TRITT et al., 2008)

The fundamental problem in creating efficient thermoelectric materials is that they need to be good at conducting electricity, but not at conducting thermal energy. That way, one side can get hot while the other gets cold, instead of the material quickly equalizing the temperature. (GASCOIN, 2011)

Energy-related research will grow rapidly over the next few years, and higher-performance thermoelectric materials and devices are urgently needed. To date, none of the new materials has displaced the current state-of-the-art materials (Bi_2Te_3, PbTe, or SiGe) in a commercial TE device. These materials have held that distinction for more than 30 years. (TRITT et al., 2006)

The future expansion of thermoelectric energy conversion technologies is tied primarily to enhanced materials performance along with better thermal management design. Nowadays most of the undergoing research is focused on systems that use the Peltier-Seebeck effect to harvest waste heat, for everything from electronic devices to cars and powerplants, in order to produce usable electricity and thus improve overall efficiency. (GASCOIN, 2011)

3.5 Electricity Grid

The costs of transport of electricity can be very high which, in financial terms, correspond to an amount up to half of the cost that we pay as consumers and, in terms of energy, the loss varies from 10% to more than 40% of energy off the power plant. (DOE, 2010)

On one hand, the implementation of smart grids (which integrate both electricity and thermal storage technologies) appears to support balancing of variable generation and demand, better management of peak loads and delivery of energy efficiency programmes, although system-scale demonstration is still needed. Additionally, smart grids can contribute to reducing CO2 emissions from both electricity generation and use. In developing countries, smart grids will facilitate expansion of electricity services, and show significant potential to reduce transmission and distribution losses. (IEA, 2010b)

On the other hand, the improvement of materials for energy transportation it's another challenge. The standard material for overhead conductors in transmission systems is aluminium conductor steel reinforced (ACSR), which consists of fibres of aluminium twisted around a core of steel fibres. The steel core provides the mechanical strength, and the aluminium provides the electrical conductivity. A number of alternative composite cable materials have been developed over the past several years. (AMIN et al., 2008)

Today, ceramic superconductors at temperatures up to 135 K have been achieved and the loss of resistance at temperatures below the critical temperature leads to numerous applications. One possible use of superconductors in electrical power systems could be for underground high voltage transmission lines. At this time, about 10% of the electricity carried by transmission lines is lost as heat because of the wire's resistance. These heating loses would be eliminated if superconducting cables were used. Because of the refrigeration required for superconductivity, the cables would have to be underground however they are presently 10 to 20 times more expensive than overhead lines. (HINRICHS, 2002)

The electricity grid faces (at least) three looming challenges: its organization, its technical ability to meet 25 to 50 year electricity needs, and its capacity to increase efficiency without diminishing reliability and security. The technical aspects of the challenges that will be posed by this rapid growth include both improving existing technology through engineering and inventing new technologies requiring new materials. Some materials advances will improve present technology (e.g., stronger, higher current overhead lines), some will enable emerging technology (e.g., superconducting cables, fault current limiters, and transformers), and some will anticipate technologies that are still conceptual (e.g., storage for extensive solar or wind energy generation). (AMIN et al., 2008)

4. Energy Efficiency

In previous sections of this document, the focus was on the topics related to the chain of energy supply – energy generation, its transformation and distribution. Nevertheless, it is also important to analyse the demand side, since it contributes to the increase of energy availability, mainly through energy efficiency practices.

Energy efficiency is the simplest and cheapest way to secure CO_2 reductions. In transportation, buildings and industry, available technology opportunities must be turned into business opportunities. (EC, 2009a) It is at the heart of the EU's Europe 2020 "Strategy for smart, sustainable and inclusive growth" and of the transition to a resource efficient economy, being one of the most cost effective ways to enhance security of energy supply, and to reduce emissions of greenhouse gases and other pollutants. This is why the EU has set itself a target for 2020 of 20 %

increase in energy efficiency (EC, 2010b), and why this objective was identified in the Commission's Communication on Energy 2020 as a key step towards achieving our long-term energy and climate goals. (EC, 2010a)

This can be achieved with greater electrification of transports and of heating in buildings and industry, with electrical energy requirements being estimated to increase by 80% in 2050 against 2005 levels. Energy efficiency across the economy, including more efficient electric vehicles, a buildings retrofit programme and other measures, can off-set the demand created by the move away from fossil-fuels towards electricity in other sectors. (ECF, 2010)

4.1 Lighting

Electricity generation is the main source of energy-related greenhouse gas emissions and lighting uses one-fifth of its output. Solid-state lighting using light-emitting diodes (LEDs) is poised to reduce this value by at least 50%, so that lighting will then use less than one-tenth of all electricity generated. Not only does lighting consume a significant amount of energy, it is also extremely inefficient. Incandescent light bulbs convert about 5% of the electricity they use into visible light. Even energy-saving compact fluorescent lamps are only about 20% efficient. These low efficiencies contrast starkly with the efficiencies of most of the household appliances. Therefore, there is much more potential for large energy savings from lighting than from most other appliances. (HUMPHREYS, 2008)

LEDs are semiconductor devices, while incandescent, fluorescent, and high-intensity discharge (HID) lamps are all based on glass enclosures containing a filament or electrodes, with fill gases and coatings of various types. LED lighting starts with a tiny chip (most commonly about 1 mm^2) comprising layers of semi-conducting material. LED packages may contain just one chip or multiple chips, mounted on heat-conducting material and usually enclosed in a lens or encapsulate. The resulting device, typically around 7 to 9 mm on a side, can produce 30 to 150 lumens each, and can be used separately or in arrays. (DOE, 2008)

The lumen is the unit of light intensity perceived by the human eye. The sensitivity of human vision is taking into account when talking about efficacy of a light source and, since the maximum sensitivity of the human eye is to green light with a wavelength of 555 nm, green light contributes more strongly to efficacy than blue or red light and ultraviolet and infrared wavelengths do not contribute at all. It is important to note that efficacy is different from efficiency. (HUMPHREYS, 2008)

The small size and inherent directionality of white LEDs make them a promising option for a number of general illumination applications. (DOE, 2008) White LEDs are already widely used, for example, as backlighting in cell phones; as interior lighting in aircraft, cars, and buses; and as bulbs in flash lights. They are also being fitted on airport runways. LED lighting should last for 10 years, giving significant operational savings. Although existing markets for LEDs are large, the real prize is home and office lighting, but their widespread use in our homes and offices is being prevented by, mainly, five factors: efficiency, heat management, colour rendering, lifetime, and cost. (HUMPHREYS, 2008)

4.2 Buildings

The direct emissions from buildings are responsible for about 10% of global CO_2 emissions; if the direct emissions from electricity use in this sector are included, that percentage increases approximately 30%. Most buildings have long-term lives, which means that more than a half of the existing buildings are still standing in 2050. The low rate of rebuilding in ODCE countries and those in transition, combines with a relatively poor growth, means that most energy savings and potential

CO2 emissions lays in the configuration and acquisition of new technologies to the current buildings. (IEA, 2010b)

Construction materials have an important role in sustainable development through their energy performance and durability, as this determines the energy demand of buildings through the lifetime. (ECTP, 2007) Many opportunities are available for materials advances to reduce the energy use and atmospheric emissions associated with the building sector. The energy and cost performance of walls, roofs, windows, mechanical systems, and on-site renewable electrical and thermal systems can all be improved through advances in materials. (JUDKOFF, 2008)

The drivers and methodologies for the construction materials require innovation in the composition and functionality of materials and products used in construction. Examples include improving process efficiency; fostering reduction, recycling, and substitution; employing natural materials; and developing better phase change materials. (BONFIELD, 2008)

In the building envelope, it would be beneficial to have materials with high thermal resistance, good moisture management, and variable opaque surface properties. High thermal mass can also be beneficial when used correctly in the right climates. For windows, advances in materials science related to low-emissivity coatings, electrochromic materials, and high thermal- resistance windows would be desirable. (JUDKOFF, 2008)

New technologies, concepts and high-tech materials for efficient and clean buildings are priorities on the Strategic Research Agenda for the European Construction Technology Platform. (ECTP, 2007) Recent advances in nanotechnology, modelling, analytical techniques and other technologies have the potential of creating breakthroughs in the production, properties and use of building materials. Any strategy to achieve economic, ecologic and social objectives within Europe must include measures to improve functionality, durability and efficiency of materials used for construction. (ECTP, 2007)

4.3 Energy Use

It is possible to achieve electricity generation with minimum carbon emissions therefore, if energy consumption based on fossil fuels is transformed into this type of electricity, this constitutes an opportunity to reduce CO_2 emissions in all final users sectors. For instance, instead of cars running with diesel or gasoline motors, we could have electric or hybrid vehicles, or replacing the heating based on fossil fuels for efficient heat bombs. (IEA, 2010b) This analysis is not very exhaustive, since some of the issues were already discussed previously.

The pattern of energy consumption in Portugal, in terms of energy final use, is similar to EU-27 one. The greatest consumption is shown in transport, with percentages of around 32% in Europe and 38% in Portugal, followed by industry and households, as shown in Figure 24. (EUROSTAT, 2011)

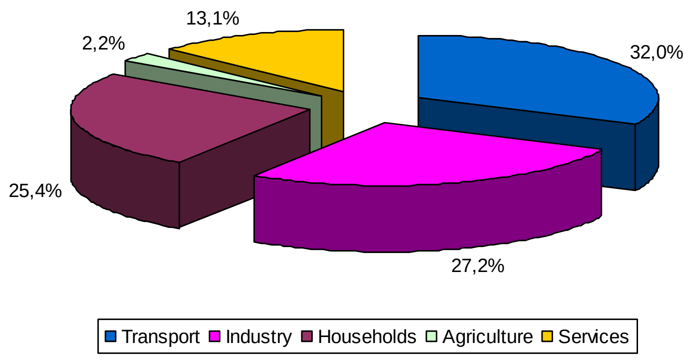


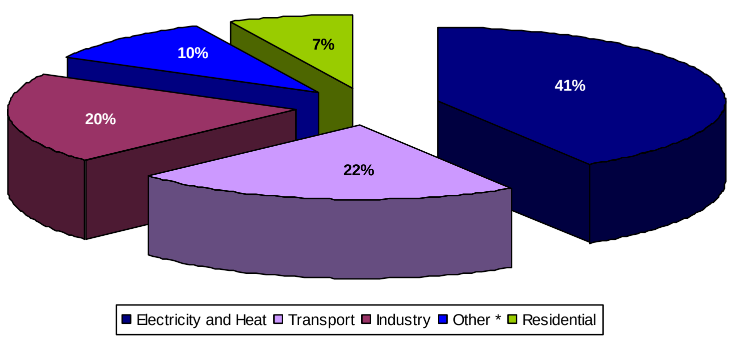
Figure 24 - EU27 Final Energy Consumption by sector (EUROSTAT, 2011)

It can be considered 4 groups of energy consumers: Industry, Households, Services and Transport.

5.3.1 Industry

Most industrial energy consumption occurs in industries that produce raw materials: chemicals and petrochemicals, iron and steel, nonmetallic minerals, and nonferrous metals. Together, these industrial sectors consumed 69.9 EJ of final energy in 2004 (62% of total final industrial energy use). The chemicals and petrochemical industry alone accounts for 30% of industrial energy use, followed by the iron and steel industry with 19%; the production of nonmetallic minerals is responsible for 10% and that of nonferrous metals for nearly another 4%. The food, tobacco, and machinery industries, along with a large category of unspecified industrial energy users, account for the remaining 37% of total final industrial energy use. (GIELEN et al., 2008)

The direct emissions from industry are responsible for about 20% of CO_2 current emissions (Figure 25). To reduce the CO_2 emissions considerably, it will be necessary to adopt in a large scale the best currently available technologies, as well as to develop and to implement a set of new technologies (such as coal exploitation and storage, reduction of fine particles, membrane separation and gasification of black liqueur). (IEA, 2010b)



* Other includes commercial/public services, agriculture/forestry, fishing, energy industries other than electricity and heat generation, and other emissions not specified elsewhere.

Figure 25 - World CO_2 emissions by sector in 2008 (IEA, 2010a)

The successful application of coal exploitation and storage technologies in several sectors of intensive energy industries (for instance iron and steel, concrete, chemical and petrochemical, and paper pulp and paper), could reduce dramatically direct emissions in industry. A decarbonised energetic sector will provide new opportunities to reduce the CO_2 intensity the electrification of the industrial processes. (IEA, 2010b)

In the utility industry, energy storage for the grid is just starting to be deployed more widely. Several companies are pursuing utility-scale energy storage now. Demonstration projects using various technologies have shown the potential of flow batteries, flywheels, and other battery technologies. (DOE, 2010)

Increasing the efficiency of industrial processes and the flows of materials through the economy is a slow transformation process that will take decades. In the short and medium term, it is important that new plants be built with the best available technology. Materials sciences will play a key role in the further development of emerging solutions for increased energy efficiency and reduced CO_2 emissions. (GIELEN et al., 2008)

5.3.2 Households and Services

Taking into account the way energy is used in these two groups, we can classify residential and services use together. Both of them use energy in a similar way, heating and cooling, lighting and equipment (appliances). They both consume more than one third of the energy used in Europe. (EUROSTAT, 2011)

Regarding the residential sector, the main obstacles to change energy use are those of higher initial costs, consumer's lack of knowledge on technologies and the low priority given to energetic efficiency. In order to overpass these obstacles, there is a need for consistent measure packages. Such measures should take into account the financial constraints, to develop the industrial capacity and investments in R&D. (IEA, 2010b)

Regarding the services sector, there is a need for policies involving the improvement of building structures for the new buildings, as well as heating, highly efficient cooling and ventilation systems. Bearing in mind its greatest final use percentage (compared to the residential sector); political measures will be needed to improve efficiency in energy use concerning lighting and other electric applications such as office equipment, information technology equipment and cooling. (IEA, 2010b)

5.3.3 Transport

According to what was previously mentioned, transportation is responsible for most energy consumed both in Portugal and in Europe Union. The transport sector worldwide is currently responsible for 22% of CO_2 emissions. To drastically reduce the CO_2 emissions until 2050, it will be necessary to diminish the rhythm of growth in the use of fuel in transports, through higher energy efficiency and the use of technologies with low carbon generation. (IEA, 2010b)

Most studies indicate that 70–80% of the energy usage in the lifecycle of a road transportation vehicle is in the use phase. The remainder is energy usage in the production of the vehicles, including the production of the materials, supply of the fuel, and disposing of the vehicles. Thus, advances in many materials and processes will be required in efforts to increase the energy efficiency of motorized vehicles for road transportation. (CARPENTER et al., 2008)

Electric vehicles are the least polluting mode of transportation available today. They also can operate very economically while using little or no petroleum fuel. (DOE, 2003) Electrical-Powered vehicles (EVs) have been built for many years. They were even as popular as gasoline powered cars at the turn of the century. In 1914, there were 20.000 EVs on the road. (HINRICHS, 2002) There are four kinds of electric vehicles currently in use: Hybrid Electric Vehicles (HEVs), Plug-in

Hybrid Electric Vehicles (PHEVs), Electric Vehicles (EVs), and Fuel Cell Vehicles (FCVs). (DOE, 2003) The development of materials plays an essential part concerning energy storage, already mentioned in section 2 of this work.

For new technologies to become commercially successful, the properties and cost of materials must compete with other technologies. One important example is developing lighter materials for the frame, body, and drive train of an automobile. (LAVE, 2008) Lightweighting and hybridization will play key roles in improving fuel economy. (CARPENTER et al., 2008) But the lighter materials must satisfy rigorous safety, durability, manufacturing, and cost criteria. (LAVE, 2008) In addition to new and improved designs, new materials or improvements in existing materials for vehicle structures, powertrains, energy storage systems, motors, power electronics, and tires will make lower fuel consumption and pollution possible. (CARPENTER et al., 2008)

In spite of the encouraging signs of introduction of measures by the governments to reduce CO_2 emissions in the transports area, it will be needed much more efforts to increase funding and coordination regarding investigation, development, demonstration and dissemination. (IEA, 2010b)

III – Strategies for Addressing the Energy Challenges

1. European Energy Strategy

Energy is crucial for the EU, with its economy and lifestyle being dependent on sustainable availability of electricity, heating, cooling and transport fuels. In the last years the definition of EU energy policies based on competitiveness, sustainability and security of supply have been significant. The first step in the process of addressing needs for this competitive, sustainable and secure energy supply was the Commission's Green Paper "A European Strategy for Sustainable, Competitive and Secure Energy", where several priority areas were identified in order to promote an European Energy policy and address the main challenges Europe faces in this area. (EC, 2006a)

The energy and climate change objectives for 2020 – to reduce greenhouse gas emissions by 20%, to increase the share of renewable energy to 20% and to save 20% of energy consumption - set by the European Council in 2007 (EC, 2007a) are main drivers of the EU energy policy with these objectives being also supported by the Europe 2020 Strategy. (EC, 2010b) The EU needs to save energy, invest in low carbon alternatives, build intelligent and diversified energy networks, produce more of its own energy which will sustain Europe's competitiveness in growth and job-creating new industries and contribute to its security of supply.

EC proposes three priorities guided by five measurable EU targets for 2020 that will steer the process and be translated into national targets regarding employment, research and innovation, climate change and energy, education, and reduce poverty. In the scope of the present dissertation it will be given emphasis to: i) achieve the target of investing 3% of GDP in R&D in particular by improving the conditions for R&D investment by the private sector, and develop a new indicator to track innovation and ii) Reduce greenhouse gas emissions by at least 20% compared to 1990 levels or by 30% if the conditions are right, increase the share of renewable energy in our final energy consumption to 20%, and achieve a 20% increase in energy efficiency. (EC, 2010b)

It is crucial to act at a European level with harmonized measures for the development of policies to achieve the improvement of energy efficiency and the coherent development of renewable energy. Thus, important documents concerning low carbon technologies and innovation have been launched, in order to bring new technologies to market and allow renewables and other energies with low-carbon emissions to compete with conventional sources of energy.

The Strategic Energy Technology (SET) Plan, presented by the Commission in November 2007 and agreed in March 2008, introduced priorities for future energy technologies. (EC, 2007c) It was agreed that EU must act with determination and ambition on a policy for low carbon technologies. In a carbon constrained world, the mastery of technology will increasingly determine prosperity and competitiveness. Also, setting up strategic alliances is necessary for industry to share the burden and benefits of research and demonstration. There is room for better exploiting the synergies between technologies (e.g. in the automotive sector, between hybrid vehicles, fuel cells, biofuels and gas).

In 2009 the Commission had drawn up the Technology Roadmaps 2010-2020 for the implementation of the SET-Plan. Its implementation has started and is currently working towards the establishment of large scale programmes such as the European Industrial Initiatives (EIIs).

This SET Plan also includes The Fuel Cells and Hydrogen (FCH) Joint Technology Initiative, The Smart Cities Initiative - Energy Efficiency and the European Energy Research Alliance (EERA), which brings together key European research organisations, to align their individual R&D activities to the needs of the SET-Plan priorities and to establish a joint programming framework at the EU level. (EC, 2009a)

By their turn, the SET-Plan Technology Roadmaps (EC, 2009c) presents the technology roadmaps for the implementation of the six first EII, the Initiative on Smart Cities and the EERA during the next 10 years. Seven roadmaps were proposed, built around a vision for the European energy system that by 2020 will have already embarked on a transition to a low carbon economy. These roadmaps put forward concrete action plans aimed at raising the maturity of the technologies to a level that will enable them to achieve large market shares during the period up to 2050. The main targets were: (EC, 2009a)

- Up to 20% of the EU electricity will be produced by wind energy technologies by 2020;
- Up to 15% of the EU electricity will be generated by solar energy in 2020;
- The electricity grid in Europe will be able to integrate up to 35% renewable electricity in a seamless way and operate along the "smart" principle, effectively matching supply and demand by 2020;
- At least 14% of the EU energy mix will be from cost-competitive, sustainable bioenergy by 2020;
- Carbon capture and storage technologies will become cost-competitive within a carbon pricing environment by 2020-2025;
- While existing nuclear technologies will continue to provide around 30% of EU electricity in the next decades, the first Generation-IV nuclear reactor prototypes will be in operation by 2020, allowing commercial deployment by 2040;
- 25 to 30 European cities will be at the forefront of the transition to a low carbon economy by 2020.

These roadmaps are essentially focused on research, development and demonstration programme at a European level and they include specific R&D programmes in several areas, namely, on materials science. Also, they promote the support of research infrastructures, as well as comprehensive demonstration programmes, that is to say, demonstrators for all technologies, to bridge the gap and accelerate the transfer of technologies from research to market deployment.

In Portugal, the Ministry Council approved, in 2008, the National Action Plan for Energy Efficiency (PNAEE) (RCM, 2008), which comprises a vast series of programmes and measures fundamental to be able to succeed in the objectives fixed within Directive of the European Parliament and Council which focuses on the efficiency in final energy use and energy services. (EC, 2006b) In 2010 and in the frame of the Directive on the promotion of the use of energy from renewable sources (EC, 2009b), the National Renewable Energy Action Plan (PNAER) was approved and establishes Portuguese goals regarding the 2020 share of renewable sources in final energy consumptions as well as measures and actions planned for transports, electricity, heating and cooling sectors.

Also, in 2010, the Portuguese government established the National Energy Strategy with the horizon of 2020, focusing on renewable energy and integrated promotion of energy efficiency (ENE 2020). (RCM, 2010) The specific objectives are the following: i) by 2020 60% of electricity production and 31% of final energy consumption are derived from renewable resources and a reduction of 20% in final energy consumption under the Energy-Climate Package 20 -20 -20; ii) promoting of an energy cluster in the renewable energy sector in Portugal and iii) developing an industrial cluster for the promotion of energy efficiency.

ENE 2020 is split into five main areas, with one axis entirely dedicated to renewable energy targets and strategies for development and promotion on the various technologies that make up the mix of renewable for 2020 (Axis 2 – Biomass; Biofuels; Waves, Geothermal and Hydrogen; Hydro; Wind; Solar). On Axis 3 ENE 2020 promotes energy efficiency consolidating the reduction target of 20% of consumption final energy in 2020, via investment in innovative projects including electric vehicles and intelligent networks, decentralized production of renewable basis and optimization models and lighting management energy for public buildings, and residential services. (RCM, 2010)

Despite the importance of energy policy objectives, there are serious gaps in delivery. The output of developed by Member States since 2008, are distressing since the move towards renewable energy use and greater energy efficiency in transport is happening too slowly. As shown in Figures 26 and 27, while EU is broadly on track for the 20% targets for renewable and GHG decrease compared with 1990, it is a long way from achieving the objective set for energy efficiency. (EC, 2010a) Recent Commission estimative suggests that the EU is on course to achieve only half of the 20% objective. (EC, 2011b)

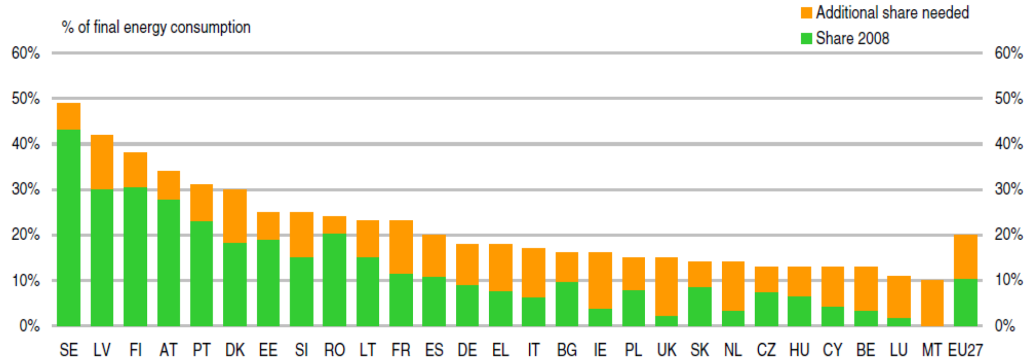


Figure 26 - Share of renewable energy in final energy consumption, 2008 and increase needed to meet the 20% target (EC, 2010e)

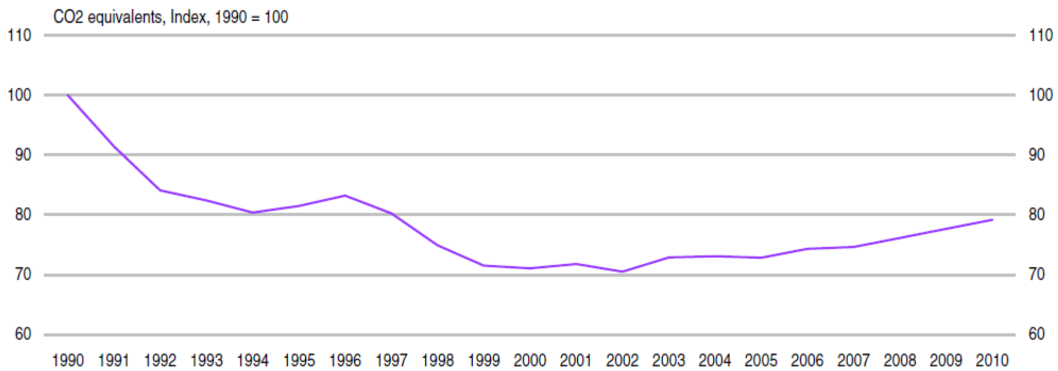


Figure 27 - Total greenhouse gas emission, EU-12, 1990-2012 (EC, 2010e)

Buildings account for 40% of total energy consumption in EU and the sector is expanding, which is suggestive of increase on its energy consumption. Therefore, energy performance in the buildings sector represents an important aspect to reduce the EU's energy dependency and greenhouse gas emissions and the EU Energy Performance of Buildings Directive (EPBD), introduced in 2002 and recast in 2010 (EC, 2010d), is the main legislative instrument for improving the energy performance of buildings.

On March 8, 2011 the Commission published the Energy Efficiency Plan. (EC, 2011b) This Plan was designed to contribute towards the European Union meeting its indicative energy savings target of 20% by 2020. (EC, 2010b) It covers all sectors except transport, which will be dealt with in an upcoming White Paper. The Plan proposes actions on the Public Sector, on buildings, on Energy Supply Obligations, on Co-generation and on Industry. (EC, 2011b)

Aligned with the initiative “Resource efficient Europe” set up in the Europe 2020 Strategy (EC, 2010b) and the new Energy Efficiency Plan 2011 (EC, 2011b), the goals of European transport policy are, in practice, to use less and cleaner energy, better exploit modern infrastructure and reduce its negative impact on the environment and key natural assets like water, land and ecosystems. (EC, 2011c)

In the Energy Roadmap 2050 (ECF, 2010) a new energy strategy towards 2050 is proposed. Various scenarios in terms of energy mix are presented, which describes ways of achieving Europe’s long-term decarbonisation goal and their implications for energy policy decisions. The roadmap examines several decarbonisation scenarios for the power sector and sets out the near-term implications of this long-term commitment.

The Roadmap 2050 finds that in each of the low/zero-carbon pathways, using 40%, 60%, 80% or 100% renewable energy sources, the future cost of electricity is comparable to the future cost of electricity under the current carbon-intensive infrastructure. Roadmap 2050 also shows that with the necessary investments in energy efficiency and Europe’s power network infrastructure, a decarbonised power sector using available technologies can provide the same high level of reliability that consumers enjoy today, in all low/zero carbon pathways.

The key finding of the Roadmap 2050 project is that the challenge is basically the same in either a high-carbon, low-carbon or zero-carbon energy scenario, in terms of overall cost to consumers or the European economy. What does change significantly is the required level of investment early in the cycle. Capital expenditure on energy infrastructure will need to increase by 50-100% in the next 15 years to deliver a zero-carbon power sector by 2050. But in that scenario, the overall energy bill for the economy will be heading downward by 2020, and the day-to-day running costs fall fast throughout the period. (ECF, 2010)

In order to Europe 2020 target of 20% energy consumption from renewables it will required more investment in solar energy, particularly in southern Europe where there is most potential, and in wind energy, especially along the Atlantic and North Sea coasts. The target of reducing greenhouse gas emissions by 20% is ambitious and will require investment by both the private and the public sector. Increasing energy efficiency will require investing in buildings, lighting, transport and perhaps promoting urban living and more compact cities. (EC, 2010e)

Energy Technology Perspectives 2010 highlights the investment in renewable energy, led by wind and solar, the building of new nuclear power stations, the starting of acceleration of the rate of energy efficiency improvement in OECD countries and, in transport, major car companies are adding hybrid and full-electric vehicles to their product lines and many governments have launched plans to encourage consumers to buy these vehicles. The most vital message of Energy Technology Perspectives 2010 is that an energy technology revolution is within reach. Achieving it will stretch the capacities of all energy-sector stakeholders and entail substantial upfront costs, but over the long term these will be more than offset by the benefits. (IEA, 2010b)

1.1 Universities role

The five fundamental roles of the university to society are teaching, basic research (the oldest ones) knowledge transfer, policy development and economic initiatives (the newest ones). (BREZNITZ et al., 2010) These institutions must become leaders in providing curriculum and guidance for the next generation of energy scientists and engineers along in stimulating relationships between industry and basic science.

On Education EC recently concluded that Europe must act on training and lifelong learning: less than one person in three aged 25-34 has a university degree compared to 40% in the USA and over 50% in Japan. (EC, 2010b) One of the conclusions of the European Council, regarding innovation is that Europe needs a unified research area (ERA – European Research Area) to attract talent and investment by creating a genuine single market for knowledge, research and innovation. In particular, efforts should be made to improve the mobility and career prospects of researchers, the mobility of graduate students and the attractiveness of Europe for foreign researchers. Moreover, it should be better disseminated the information on publicly financed R&D, especially by establishing links between inventories of EU and national level funded R&D programmes. (EC, 2011g)

Many of the oldest and best established universities are in Europe however the research is often fragmented at local, regional and national levels. As a consequence, there is a slow technology transfer of results, and depending on the type of research, followed by delay in commercialization. There is still missing a unified strategy, without duplicating work, not always resulting from the Intellectual Property Rights protection, which has been now much improved in Europe. (EUMAT, 2006) Additionally, besides the pursuit of scientific excellence research, its policy should be deeply rooted in society, emphasizing sustainable development in fields of major public concern such as health, energy and climate change. (EC, 2007b)

Regarding technology transfer, universities have developed several initiatives to promote the transference of knowledge to industry. Formal mechanisms include: i) sponsored research agreements; ii) inventions disclosures and patents; iii) licences of university intellectual property to firms; iv) the formation of spin-off companies and iv) promotion of students' internship. Technology transfer offices (TTO) are the vehicles by which the university moves technology generated from university research into the public domain. Moreover, many universities, through their TTOs or other programme they create, support and promote local businesses (BREZNITZ et al., 2010) (DOE, 2010)

Other forms of engagement to strengthen link with industry should be workshops, university/ laboratory/industry grants across the basic science – industry interface, and collaborative research which will promote cross-training of the existing and next generations of energy researchers. (DOE, 2010)

In the last year, Universities have intensified activities to impact social development and economic growth. It is expected universities to think outside the box, continuing their social and technological innovation, and also it is expected they make direct contributions to their local and national economies. (BREZNITZ et al., 2010)

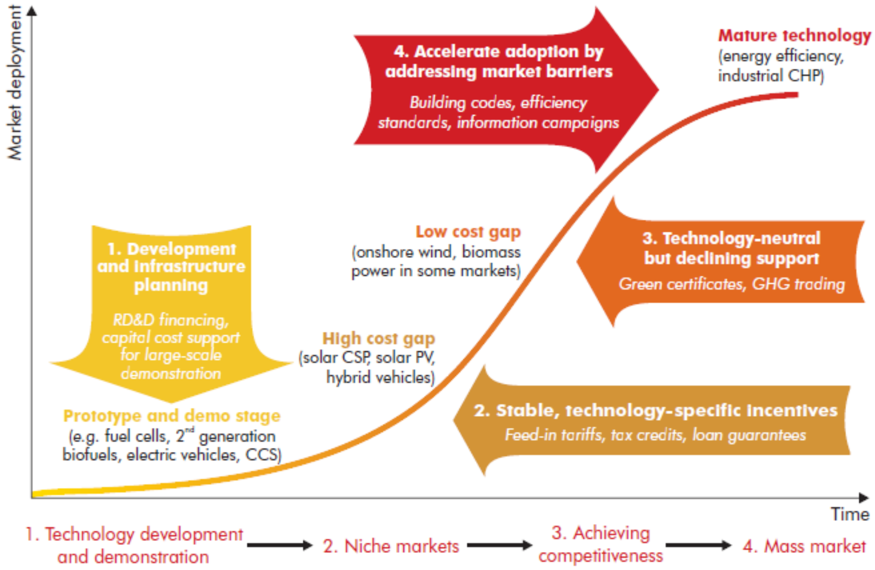
1.2 From Research to Industry

One of the three priorities on Europe 2020 (EC, 2010b) is "*Smart growth – developing an economy based on knowledge and innovation"* which means strengthening knowledge and innovation as drivers of our future growth. This requires improving the quality of our education, strengthening our research performance, promoting innovation and knowledge transfer throughout EU, as well as making full use of information and communication technologies and ensuring that innovative ideas can be turned into new products and services that create growth, quality jobs and help address European and global societal challenges. (EC, 2010b)

R&D spending in Europe is below 2%, compared to 2.6% in the USA and 3.4% in Japan, mainly as a result of lower levels of private investment. It is not only the absolute amounts spent on R&D that count – Europe needs to focus on the impact and composition of research spending and to improve the conditions for private sector R&D in the EU. European smaller share of high-tech firms is one of the main factors of gap between EU and USA. (EC, 2010b) The European Council called for the implementation of a strategic and integrated approach to boosting innovation and taking full advantage of Europe's intellectual capital, to the benefit of citizens, companies - in particular SMEs – and researchers. It will monitor progress in the framework of the follow up to the Europe 2020 Strategy. (EC, 2011g)

Many of the most promising low-carbon technologies currently have higher costs than the fossil-fuel incumbents. It is only through technology learning from research, development, demonstration and deployment (RDD&D) that these costs can be reduced and the technologies become economic. Thus, governments and industry need to pursue energy technology innovation through a number of parallel and interrelated pathways.

Therefore, governments will need to intervene to avoid the enclosing of high-emitting, inefficient technologies. Figure 28 shows how governments must act to implement a range of technology policies that target the cost competitiveness gap while also fairly reflecting the maturity and competitiveness of individual technologies and markets, where the main objectives should be reducing risk, stimulating deployment and bring down costs.



Note: The figure includes generalised technology classifications; in most cases, technologies will fall in more than one category at any given time.

Figure 28 - Policies for supporting low carbon technologies (IEA, 2010b)

The overriding objectives should be to reduce risk, stimulate deployment and bring down costs. Government steps to remove barriers to the entry and growth of new firms may have an important part to play in low carbon energy technology development. (IEA, 2010b)

Almost all renewable energy industries experienced growth in 2009 despite the continuing global economic crisis. A number of industries saw further consolidation as well as a scaling up in manufacturing capacity. China continued to increase its importance as a manufacturer of renewable technologies, particularly wind turbines, solar PV, and solar hot water systems. At the same time, declining costs combined with greater government support through stimulus packages and other policies increased utility interest in renewable energy. (REPN, 2010)

Industry is an important intervenient in the commercializing of clean energy technologies and for re-establishing economic and jobs growth. For industry to succeed in these challenges, it must overcome many barriers and continuously innovate new generations of renewable, sustainable, and low-carbon energy technologies. (DOE, 2010)

Insufficient communication and engagement of scientists and industry constitutes one of the biggest barriers to innovation, due to their differing objectives and operating styles: scientists typically set priorities from the “bottom up“(scientific push), emphasizing understanding phenomena and making every efforts to disseminate results quickly through publication. In contrast, industry often sets priorities from the “top down” (technological pull) based on its most critical needs for specific technologies. Industry emphasizes achieving performance as a higher priority than understanding phenomena. Additionally, intellectual property and proprietary information issues are an always present barrier. (DOE, 2010)

The following examples illustrate possible approaches and principles for engagement of basic scientists with industry, all over Europe. It should be emphasized that many other approaches in interaction with industry are being used but the examples of engagements presented are the most suitable in the scope of this work.

1.2.1 European Technology Platforms

In March 2003, EC called for a strengthening of the European research and innovation area and a new strategic instrument was created, the European Technology Platforms (ETP), to bring together technological know-how, industry, regulators and financial institutions to develop a strategic agenda for leading technologies’. (CORDIS, 2011)

ETPs were set up as industry-led stakeholder forums aiming at defining medium to long-term research and technological objectives and developing roadmaps to achieve them. Their aim was to contribute to increasing synergies between different research actors, ultimately enhancing European competitiveness. FP7 introduced novel approaches to strengthen industry participation and ETPs helped definition of industry relevant priorities.

On the report of the ETP Expert Group it is proposed that in the future all ETPs should be encouraged to work in flexible clusters focused on addressing the key societal challenges facing Europe. (EC, 2010f) They were recently organized by research areas, being Energy one of these areas. Aligned with EU energy strategy, ETPs in the field of energy bring together private and public researches in a set of energy technologies and constitute relevant partners in the debate on energy research priorities at EU level.

In the Energy research area, exists the following ETPs: (CORDIS, 2011)

- Biofuels (European Biofuels Technology Platform);
- SmartGrids (European Technology Platform for the Electricity Networks of the Future);
- TPWind (European Technology Platform for Wind Energy);
- Photovoltaics (European Photovoltaics Technology Platform);
- ZEP (Zero Emission Fossil Fuel Power Plants);
- SNETP (Sustainable Nuclear Technology Platform);
- RHC (Renewable Heating & Cooling).

Other ETPs are transversal and complementary for the Energy thematic, like:

- SusChem (Sustainable Chemistry);
- EuMaT (Advanced Engineering Materials and Technologies).

ETPs contribute to various measures aimed at achieving Europe's future growth, competitiveness and sustainability where the specific objectives are dependent on major research and technological advances in the medium to long term. They are expected to play a key role in ensuring that sufficient funds are directed towards areas with a high degree of industrial relevance.

1.2.2 European Industrial Initiatives (EII)

European Industrial Initiatives (EIIs) were launched in the context of the SET-plan, to allow the public and private sectors to jointly develop technology roadmaps.

Industry-led, the EIIs aim to strengthen industrial participation in energy R&D, boost innovation and accelerate deployment of low-carbon energy technologies. Six priority technologies have already been identified as the focal points of the first EIIs: wind, solar, electricity grids, bioenergy, carbon capture and storage and sustainable nuclear fission. A further initiative on energy efficiency in cities is currently being proposed, with the aim of stimulating the take-up of low carbon technologies developed in the other EIIs or by other programmes. (EC, 2009a)

The SET Plan calls for strategic planning and new governance to align technology development with energy policy goals. Being led by industry, the main areas of activities in the EIIs were defined from the industrials point of view and the main objectives are described in the following table.

Table 2 - Summary of the main objectives for each EII (EC, 2009a)

Initiatives	Main objectives
Wind	• Development of more accurate mapping of wind resources and of capacity potentials in Europe including hostile and complex environments; • 5-10 new testing facilities for new turbine systems; • up to 10 demonstration projects of next-generation turbines including a 10-20 MW prototype; • at least 4 prototypes of new offshore structures tested in different environments; • Demonstration of new manufacturing processes (including logistics strategies and erection techniques in remote and often hostile weather environments); • Demonstration of industrial-scale grid integration (seeing wind farms as 'virtual power plants').
Solar	• R&D programme focused on enhancing the performance and lifetime of PV systems and components, and on developing key technologies for the interface with the power grid; • PV pilot production plants for innovative and cost-effective manufacturing processes, suitable for mass production; • R&D and demonstration programme for CSP technologies focused on reducing generation, operation and maintenance costs; • portfolio of demonstration projects of power production in decentralised applications and in urban communities such as building integrated concepts and innovative, centralised power plants at an industrial scale of high-MW range.
CCS	• A large demonstration programme aiming at the construction and operation of up to 12 industrial-scale CCS projects by 2015; • A research programme building on and complementing the CCS demonstration activities.
Bioenergy	• up to about 30 industrial-size demonstration and/or first-of-their-kind industrial plants across Europe; • setting activities on biomass resources for bioenergy to improve cooperation between stakeholders; • longer-term R&D on emerging and innovative bioenergy value chains.
Electricity Grid	• an integrated R&D and demonstration programme; • a network of up to 20 large-scale demonstration projects covering diverse geographical, social and climatic conditions; • a technical support structure to monitor project progress according to common indicators and to enable successes to be replicated across Europe.
Sustainable nuclear	• the design and construction of demonstration reactors: a sodium cooled fast reactor (SFR) and alternative designs using lead or gas-cooled technology (LFR, GFR); • pilot fuel fabrication workshops for the start of operation of the demonstration plants; • a coordinated R&D programme for reactor safety, performance, lifetime management and waste management; • developing the necessary supporting research infrastructures.

Also in the frame of the SET-Plan, it was established for the period of 2008- 2013 the Joint Technology Initiative (JTI) on fuel cells and hydrogen. The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a unique public private partnership supporting research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies, realising their potential as an instrument in achieving a carbon-lean energy system. (EC, 2009a)

Among the tools envisaged for the implementation of the SET-Plan, European Industrial Initiatives are expected to play a critical role. The key features of a European Industry Initiative as presented in the SET-Plan are the following:

• initiative should not be realistically feasible at national level and should clearly leverage on European scale capability for additional resources and added value;

• it should be industry led, pool public and private financing and share risk via public-private partnership;

• it should be based on the definition and achievement of clear targets with quantified objectives;

• it should boost research and innovation in order to deliver results beyond business as usual.

Also, within the frame of the SET-Plan, with Europe having strong National Research Institutes for Energy as well as excellent research teams working in universities and specialised centres, the Commission proposed the creation of the European Energy Research Alliance (EERA). (EC, 2007c) EERA, established by leading European research institutes, aims to accelerate the development of new generation energy technologies. (EC, 2009a)

1.2.3 KIC InnoEnergy (sustainable energy)

Promoted by the European Institute of Innovation & Technology (EIC), KICs (Knowledge and Innovation Communities) are an operational base initiative. A KIC is a highly integrated, creative and excellence-driven partnership which brings together the fields of education, technology, research, business and entrepreneurship in order to produce new innovations and new innovation models that inspire others to emulate it. (KIT, 2011)

The first three KICs were designated in December 2009 one of which is the KIC InnoEnergy (sustainable energy). InnoEnergy aims at providing new and concrete solutions for: i) the organisation of the innovation chain in Europe in order to speed up the innovation process and to capitalise on research results more effectively and ii) the challenge of transforming EU energy system to become sustainable (technology and innovation-driven).

The InnoEnergy strategy relies on three concepts:

1. Innovation - It facilitates the added value process of turning ideas into solutions and into products. Following this general aim the innovation model uses a simplified innovation process with revolving phases: exploration, selection, implementation and exploitation.
2. Education: Is designed to address the weaknesses of current high-level education programmes in the field of energy in Europe such as the entrepreneurial spirit of professors and students, mobility and industry involvement. The concept covers higher education as well as lifelong learning of professionals.
3. Technology: Complementary to existing initiatives such as the European Strategic Energy Technologies plan, the European Industrial Initiatives and the European Energy Research Alliance. Cross-disciplinary InnoEnergy projects emphasize innovation and education aspects

InnoEnergy operates through six co-location centres, regional hubs forming innovation eco-systems. Figure 29 presents each co-location centre which coordinates InnoEnergy's joint expertise in a certain thematic area and has a track record in education, research and innovation particularly in the field of sustainable energy.

Figure 29 - KIC Innoenergy Co-location plan (KIT, 2011)

1.2.4 International Low-Carbon Energy Technology Platform

Inaugurated at October 15, 2010 and created in response to a request from the G8 and IEA Ministers, the International Low-Carbon Energy Technology Platform seeks to encourage, accelerate and scale-up actions for the development, deployment and dissemination of low-carbon energy technologies. It does this by focusing on practical activities at international, national and regional levels to (IEA, 2011b):

- Bring together stakeholders to catalyse partnerships and activities that enhance the development and implementation of low-carbon energy technology strategies and technology roadmaps at regional and national levels;
- Share experience on best-practice technologies and policies and build expertise and capacity, facilitating technology transition planning that fosters more efficient and effective technology dissemination;
- Review progress on low-carbon technology deployment to help identify key gaps in low-carbon energy policy and international co-operation.

It is not a formal body or institution, but an informal forum that promotes activities and the share of policy-related information among stakeholders interested and willing to help accelerate the spread of low-carbon energy technologies.

Technology Platform activities take forms of:

- Country-led workshops to:
  - identify low-carbon energy technology needs within a specific region or country;
  - assist in developing custom-made low-carbon strategies.
- Roadmap development and implementation:
  - at national or regional level;
  - capitalising on IEA methodology and expertise.
- Linking to other international collaborative efforts, when solicited, to help:
  - identify key gaps;

- avoid overlaps of effort, leveraging expertise and resources;
- contribute to prioritising international action.

- Assembling technology data and policy information to provide:
  - a source of analysis of best-practice policies;
  - an overview of low-carbon technology deployment status;
  - models that can be replicated in different countries or regions.

1.2.5 EU research and innovation funding and initiatives (2007-2013)

Aligned with the priorities of the Europe 2020 strategy and the provisions of the treaties, Horizon 2020 - the Framework Programme for Research and Innovation will focus on addressing societal challenges, encouraging the competitiveness of Europe's industries and the excellence of its scientific and technological base. (EC, 2011a)

There are many funding sources available to support energy-related research activities. Each instrument has a dedicated focus and targets certain actors and activities. Table 3 compiles the main EU funding programmes in the field of renewable energy, energy efficiency and sustainable transport.

Table 3 - Main EU funding programmes in the field of Energy (EC, 2011f)

Area	Renewable Energy	Energy Efficiency	Sustainable transport
Soft measures	Intelligent Energy-Europe European Territorial Cooperation – INTERREG Life long learning (EARDF)	Intelligent Energy-Europe European Territorial Cooperation – INTERREG Life long learning ICT PSP Eco-innovation (URBACT II)	Intelligent Energy-Europe European Territorial Cooperation – INTERREG Life long learning (EARDF) Marco Polo (URBACT II)
Research	FP7 Energy (FP7 Environment) (FP7 Regions of Knowledge) (ERDF) (CF)	FP7 Energy (FP7 Environment) (FP7 Regions of Knowledge) (ERDF) (CF)	FP7 Energy (FP7 Environment) (FP7 Regions of Knowledge) (ERDF) (CF)
Demonstration, Investment and development	FP7 LIFE+ CONCERTO+ (ERDF) (CF) ELENA	FP7 (LIFE+) CONCERTO+ (ERDF) (CF) ELENA	FP7 LIFE+ CIVITAS (ERDF) (CF) ELENA

Note: Items in brackets, e.g. (LIFE+), indicate programmes where energy or sustainable transport are not the primary focus

Materials research is probably the most important element for the development of the necessary technologies needed to provide a clean, reliable supply of efficient energy. EC support under the current Framework Programme (FP7, period 2007-2013) has been targeting research across a wide spectrum of novel materials for energy applications. This is done within Future Emerging

Technologies scheme of the Energy theme in collaboration with the FP7 Nanosciences, nanotechnologies, materials & new production technologies. In order to foster highly creative research groups in the European Research Area, the Energy theme devotes between 10 - 15% of its annual budget to future emerging technology calls for proposals. (EC, 2011d)

Due to multidisciplinary in materials, several European funding initiatives support Materials Research within the structure of the EU 7th Framework Programme (e.g. research on materials for specific applications in Energy can be also funded under Theme 4 - ENERGY, according to the public call for proposals) as well as with other EU funding schemes. (EC, 2011d)

2. Materials for Energy

Materials technology has been considered for decades as one of the most important fields together with biotechnology and information technology, which shall have the greatest influence on the industrial development, society and well-being of the citizens. (EUMAT, 2006)

Materials profit from a wide range of scientific disciplines, such as chemistry, physics, biology and engineering, as well as from all available technologies and multidisciplinary approaches, like nanotechnology and biotechnology. (EC, 2011d)

Today, materials technology including raw material extraction, processing, manufacture and supply is a major employee and may represent 1/5 of the GDP of EU. Advanced materials will require new employee profile due to its very research intensive nature and will offer employment for highly educated professionals. Also, advanced materials technology can create a platform for growth of new enterprises in advanced materials business with high growth rates and good employment possibilities, able to promote transition of European materials technology industry from resource-intensive to knowledge-intensive industry. (EUMAT, 2006)

The “Advanced Materials” market includes the design, manufacturing development and production technologies useful to obtain the product’s final shape as well as the definition of the characteristics of the materials to be used and the parts. (EUMAT, 2006)

The energy sector offers many challenges and opportunities for material science, which can be placed in context by examining the total amount of energy used now and the demand projected for 2030, as well as, the distribution across nations, and the issue of CO_2 emissions. Producing electricity with no CO_2 emissions is a major frontier for materials research. In this sense, technologies for capturing carbon; piping and storing hydrogen; making a new generation of safer, more efficient nuclear reactors; producing electricity from sunlight, wind, and other renewables; and finding better ways of storing electricity pose major challenges and offer huge rewards. Improving the usefulness of these technologies requires an understanding of the markets for energy and the tools that use energy, as well as the level of success that must be achieved for an invention to be interesting commercially. (LAVE, 2008)

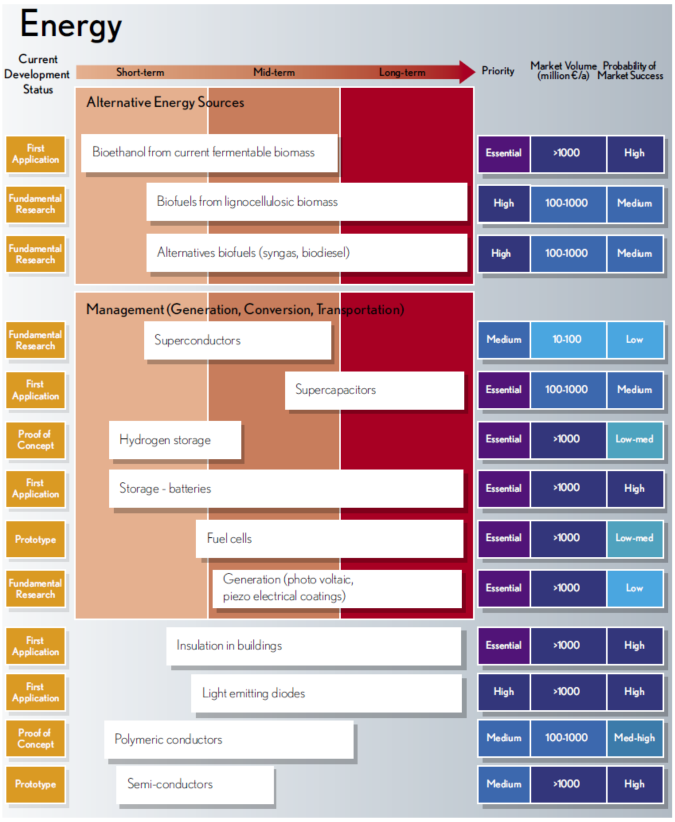
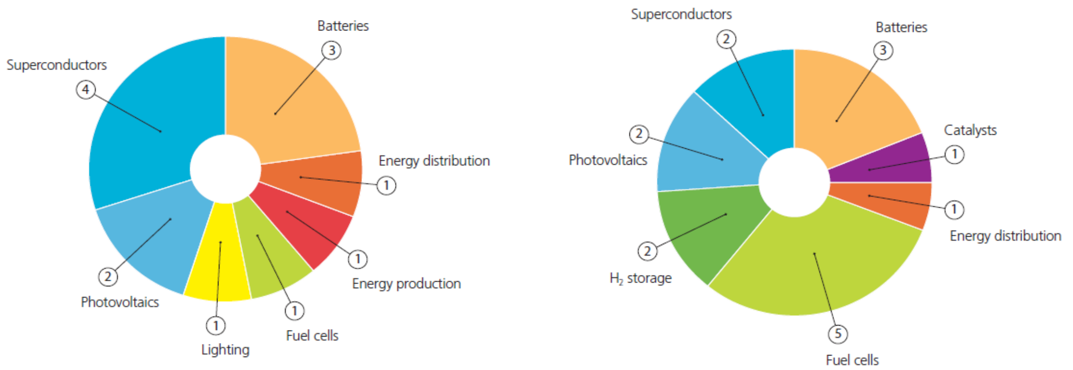


Figure 30 - Roadmap examples on energy technologies (SUSCHEM, 2005)

To overcome the challenges a number of technologies need to be either improved or developed. Some examples are illustrated in the Figure 30 roadmap, which illustrates the current development status along with priority, market volume and probably of market success.

With the advent of nanomaterials, materials research is expected to play an increasing role in sustainable technologies for energy conversion, storage and savings. Although not named as a topic in its own right under the Fifth Framework Programme (FP5 –1998-2002), 14 projects relating to materials for energy applications received contributions within the GROWTH (Competitive and sustainable growth) programme. In FP6, the area was more clearly addressed with a specific topic in the three calls for proposals under Priority 3 (Nanotechnologies and nano-sciences, knowledge-based multifunctional materials and new production processes and devices). (EC, 2008a)



FP5 (€21.3 million) FP6 (€27.6 million)

Figure 31 - Total number of projects in FP5 and FP6 per subarea (materials for energy applications) (EC, 2008a)

3. Innovation and R&D on Materials for Energy

On previous sections of this document it was discussed the energy problem by presenting the general key challenges regarding energy resources, technologies (storage, transmission and transformation) and efficiency. In this section, it will be presented the materials specifications in order to meet these general key challenges. The SET-Plan and its roadmap, which specifies concrete action plans aimed at raising the maturity of the technologies involved in the SET-Plan main targets, are the basis information source to this discussion, as well as review articles of energy related technologies and documents which discuss R&D trends on energy addressing industrial needs. (EC, 2009a)

One of these, the report "*Science for Energy Technology – Strengthening the Link between Basic Research and Industry*" from the USA Department of Energy (DOE) delineates basic science Priority Research Directions (PRD) most urgently needed to address the roadblocks and accelerate the innovation of clean energy technologies. This report summarizes BRN reports ("*Basic Research Needs*") resulting of a series of workshops, carried out in the last 7 years, under the supervision of *Basic Energy Sciences Advisory Committee* (BESAC) and BES. These workshops gathered members from the international scientific community, including researchers and laboratory experts, universities and industry. (DOE, 2010)

Another main source of information was the European Technology Platforms Strategic Research Agendas. All European Technology Platforms (ETPs) have brought together stakeholders (Industry and public researcher centres and national government representatives), reached consensus on a common vision and established (and in some cases already revised) a strategic research agenda (SRA). SRA is created with appropriate involvement of industry and other main stakeholders in order to provide a basis for identification of needs, with the establishment of priorities on the short-term (3-5 years), the medium term (4-10 years) and the long-term (> 10 years) time scale. (EUMAT, 2006)

3.1 Solar Energy

3.1.1 PV Cells

As already stated in section II, the widespread penetration of photovoltaic solar electricity requires significant technological advances regarding performance, cost, and reliability in order to compete effectively against fossil fuel alternatives.

Two routes can be envisaged to reduce the costs of photovoltaic energy production that will be brought about by new science: the first is based on the pragmatic use of new technologies to improve the performance or decrease the cost of current devices and the second might involve new whole-device concepts. In recent years we have seen the emergence of dye-sensitised PV cells by Gratzel (2001) and polymer-based solar cells (including organic/inorganic hybrids) as fundamentally new types of device, although none of these have come close to out performing wafer- based silicon devices in cost or efficiency. (BAGNALL et al., 2008)

Materials R&D challenges for PV technologies include the increase of solar cell efficiency by improving material properties and cell designs. This can be achieved by: i) identifying or developing alternate materials that are abundant, non-toxic and low-cost; ii) developing novel nanoscale surfaces to reduce reflection and increase capture of the full spectrum of sunlight; iii) extending the lifetime of photovoltaic systems by addressing materials aging issues; iv) reducing manufacturing costs and creating efficient, high volume methods to recycle solar system materials at end-of-life; and v) closing the gap between research and commercial cell efficiencies to reduce the cost of power from modules. (MRS, 2010)

The future is the use of nanotechnology in PV cells that will enable the capture and conversion of solar energy more efficiently, inexpensive plastic solar cells or panels that are mounted on curved surfaces and unique forms of PV driven by the imagination of materials scientists: silicon nanowires, nanotubes, flexible plastic organic transparent cells, ultra-thin silicon wafers (MRS, 2010)

To reach these achievements a long-term research programme focussed on advanced PV concepts and systems is needed. (EC, 2009a) The EII on Solar Energy, among others, proposes: better understanding of material behaviour; development of advanced application technologies for active layers, roll-to-roll manufacturing on flexible substrates, high-temperature substrates for ultra-thin polycrystalline silicon cells or high-throughput deposition for other thin-film material systems; advanced concepts (up/down converters, quantum and plasmonic effects to boost efficiency, device concepts for organic/ inorganic hybrids and multi-junction materials, and bulk-type intermediate band materials); technology development for Building-Integrated PV (BIPV); technology development on connection to electricity networks and advanced power storage devices (highly efficient inverters with new semiconductor materials - SiC, GaN). (EC, 2009c) The total public and private investment needed in Europe over the next 10 years is estimated as €16 bn. Up to 15% of EU electricity could be generated by solar power in 2020 as a result of such a programme coupled with market-based incentives. More than 200 000 skilled jobs could be created. (EC, 2009a)

As already been mentioned, the current PV systems commercially available consist of a range of technologies including wafer-based silicon, a variety of thin film technologies. (BAGNALL et al., 2008) Solar cell efficiency tables (GREEN et al., 2011) are published every six months and present consolidated information showing an extensive listing of the highest independently confirmed efficiencies for solar cells and modules - in version 37, first of 2011, fourteen new results are reported. In the next pages R&D needs of the various technology categories including concentrator technologies (CPV) will be analysed.

3.1.1.1 Wafer-based crystalline silicon

Silicon is widely available and current PV production is dominated by single-junction solar cells based on silicon wafers including single crystal(c-Si) and multi-crystalline silicon (mc-Si). (BAGNALL et al., 2008). The learning curve for the progress in silicon wafer-based technology shows that the price of the technology has decreased by 20% for each doubling of cumulative installed capacity. The total PV market has grown by almost 50% per year in the last five years, with crystalline silicon accounting for more than 90% of the total volume. (EPTP, 2007)

Silicon wafers PV costs around US$4/W and, in spite of much progress, this is still about four times too expensive for being truly competitive in commercial production. (BAGNALL et al., 2008)

The manufacturing steps for crystalline silicon modules include: silicon -production, -purification, –crystal growth, wafer slicing, cell fabrication and module assembly. Cost decreasing has been achieved in recent years and need to be followed further and faster in three main aspects: reduction in material consumption, increase in device efficiency and advanced, high-throughput manufacturing. Thus, the research into crystalline silicon photovoltaic technology will primarily have to address the following subjects: (EPTP, 2007)

- reducing specific consumption of silicon and other materials in the final module;
- new and improved silicon feedstock and wafer (or wafer equivalent) manufacturing technologies, that are cost-effective and of high quality;
- increase efficiency of cells and modules and, in the longer-term, using new and integrated concepts;

- new and improved materials for all parts of the manufacturing chain, including encapsulation;
- high-throughput, high-yield, integrated industrial processing;
- finding safe processing techniques with lower environmental impact.

Module assembly is material-intensive and new cheaper, more flexible, highly durable encapsulation materials with improved optical properties are expected to be developed. They may also be better suited for high-throughput manufacturing than the materials currently used. New materials and techniques for connections between cells also need to be developed to improve the automated assembly of very thin wafers. (EPTP, 2007)

3.1.1.2 Existing thin-film technologies

Thin-film solar cells (TFSC's) are deposited directly on large area substrates, such as glass panels or foils. Thin-film PV has an inherent low-cost potential because its manufacture requires only a small amount of active (high cost) materials and is suited to fully integrated processing and high throughputs. (EPTP, 2007)

TFSC's can be generally divided in the following categories (RIBEIRO et al., 2009): amorphous/microcrystalline silicon (a-Si/µc-Si - 11.9% efficiency), CdTe (16.7% efficiency), $CuIn(Ga)Se_2$ (CIGS-19.6% efficiency) and organic based solar cells. (GREEN et al., 2011) a-Si CdTe and CIGS work because they absorb the solar spectrum much more efficiently than c-Si or mc-Si and use only 1–10 µm of active material. (BAGNALL et al., 2008)

At present, the market share of thin-film PV within total PV production is below 10%, but might grow to 20% by 2010 and beyond 30% in the long term. (EPTP, 2007) Thin-film technology has a great potential for cost reduction if materials and manufacturing can be improved by intensive and effective R&D on the fundamental science and production technology.

The main and most important R&D common aspects with highest priorities on existing TFSC are: i) reliable and cost-effective production equipment for all technologies; ii) low cost packaging solutions both for rigid and flexible modules and low cost transparent conductive oxides; iii) reliability of products: advanced module testing and improved module performance assessment; iv) recycling of materials and old modules; v) alternatives for scarce chemical elements such as indium and gallium. (EPTP, 2007)

- **a-Si/µc-Si Solar Cells**

Amorphous silicon (a-Si) was commercialized much earlier and more widely than other TFSC technologies, due to their much stronger worldwide research base. The problem with single junction a-Si has been related to low stability. Crystalline thin-film is gaining interest as a way to reduce the amount of high-grade Si in PV. (RIBEIRO et al., 2009) Multijunction cells based on amorphous Si and amorphous SiGe alloys have been the most economically successful second-generation technology to date due to low cost production and the ability to be integrated into electronics and roofing materials.(GINLEY et al., 2008)

To overcome challenges, the main issues on R&D are on: i) processes and equipment for low-cost large area plasma deposition of micro/nanocrystalline silicon solar cells; ii) specific high-quality low cost transparent conductive oxides (TCOs) suitable for large, high performance modules (>12% efficiency); iii) demonstration of higher efficiency a-Si/µc-Si devices (>15% on laboratory scale), improved understanding of interface and material properties, of light trapping, and of the fundamental limits faced by a-Si/µc-Si based materials and devices. (EPTP, 2007)

- **CdTe**

For CdTe based thin-films PV devices, some environmental concerns were raised about cadmium toxicity and the possibility of contaminating the environment where modules are manufactured, however cadmium tiny amounts can be recycled at the end of module's lifetime. (RIBEIRO et al., 2009)

Key R&D topics are: i) alternative activation/annealing and back contacts for simpler, quicker and greater yield and throughput; ii) new device concepts for thinner CdTe layers; iii) enhanced fundamental knowledge of materials and interfaces for advanced devices with efficiencies (>20% at laboratory scale). (EPTP, 2007)

- **CuIn(Ga)Se_2 (CIGS)**

Copper indium diselenide (CIS), or CIGS when gallium is added, is probably one of the most promising thin film materials, as it holds the record laboratory efficiencies among TFSC and presents excellent stability. However, significant cost advantages have not yet been achieved on a pilot-production level. (RIBEIRO et al., 2009)

For CIGS, it is important to i) improve throughput and yield in the whole production chain and standardisation equipment; ii) develop modules with efficiencies > 15%, developed through a deeper understanding of device physics and the successful demonstration of devices with efficiencies greater than 20% at laboratory scale; iii) develop alternative/modified material combinations, of process alternative like roll-to-roll coating and of combined or non-vacuum deposition methods; iv) produce highly reliable and low cost packaging to reduce material costs. (EPTP, 2007)

3.1.1.3 Organic-Based PV

Organic solar cells have been the subject of R&D for a long time, they offer the prospect of very low cost active layer material, low-cost substrates, low energy input and easy upscaling. (EPTP, 2007) The organic-based PV technology comprises the so-called dye-sensitized solar cells (DSSC's), as well as the polymer solar cells (including organic/inorganic hybrids). Among polymer solar cells, three types can be distinguished: polymer:fullerene, polymer:polymer, and polymer:metal oxide cells. Among dye-sensitized solar cells, liquid and solid state versions have been investigated since the breakthrough report of O'Regan and Gratzel in 1991 (O'REGAN et al., 1991). Although DSSCs and polymer cells are quite different in terms of cell concept and design, the working principle of both rely on a so-called donor/acceptor heterojunction interface. (RIBEIRO et al., 2009)

On DSSCs, the inherent cost reduction potential is based on the use of inexpensive materials such as titanium oxide (TiO_2), which acts as semiconductor. Additionally, very thin layers of the remaining components of the cell are applied, thus contributing to reduce production costs. (RIBEIRO et al., 2009)

Main challenges for both approaches are related to the increase of efficiency, stability improvement and the development of an adapted manufacturing technology. The efficiency of these devices must be raised to 10% with a target of 15% for laboratory cells by 2015, if they are to be deemed to hold potential in the long-term. Only by first reaching such efficiencies on laboratory cells can one hope to develop manufacturing technology for large-area modules with efficiencies over 10%. The increase in the performance requires improved basic understanding of the device physics, the synthesis of novel materials and the development of advanced cell concepts (multi-junction or non-planar approaches). (EPTP, 2007)

3.1.1.4 Advanced inorganic thin films

One example for advanced inorganic thin-film technology is the spheral CIS-approach where glass beads are covered with a thin polycrystalline compound layer and the interconnection process between the spheral cells is fundamentally different from the monolithic module approach typically used. Another important example is the polysilicon thin-film approach where the polycrystalline Si layer is manufactured at temperatures higher than normally used for a-Si:H or microcrystalline Si. (EPTP, 2007)

The upscaling of the deposition equipment to deposit polycrystalline Si active layers at temperatures above 600ºC is still at an early stage, thus further development of suitable ceramic and high-temperature glass substrates is necessary to exploit the full potential of this technology. (EPTP, 2007)

3.1.1.5 Thermophotovoltaics (TPV)

In the long term TPV could be used in concentrating solar thermal power applications (CSP). Before that happens, the technology could be used in combined heat and power systems (CHP). Within Europe there are several lowband gap cell types being investigated for TPV ranging from germanium-based cells to advanced ternary and quaternary alloys incorporating the elements gallium, antimony, indium, arsenic and aluminium. (EPTP, 2007)

Although some R&D is still needed on the individual components of a TPV system (cell, monolithic module integration, emitter, filters), the main challenges are the integration of components in a system, boost reliability and the demonstrate electricity costs less than 0.1€/kWh and a system efficiency of 15%. (EPTP, 2007)

3.1.1.6 Concentrator Technologies (CPV)

The most important benefit of this technology is the possibility to reach system efficiencies beyond 30%, which cannot be achieved by single-junction 1-sun (ie. non concentrating) photovoltaic technology, yet CPV technologies have played a minor role in PV R&D for more than 25 years. However, over the last few years a number of companies have entered the market.

Materials research is needed for all the components in CPV systems for: high-efficiency silicon cells or III-V- compound multilayer cells; combine existing technology of optical systems in reliable, long-term, stable and low-cost ways; module assembly (must be made in a fully automated process, with high-speed and precise placing of the cells); system aspects (considerable part of the cost of a CPV system may be attributed to the tracker and the largest cost in its manufacture is the cost of steel and engineering R&D must find here a potential for cost reductions). (EPTP, 2007)

3.1.1.7 Novel PV technologies (Third generation PV)

The label “novel” applies to development of new ideas that can potentially lead to disruptive technologies. Nevertheless, the likely future conversion efficiencies and/or costs these novel technologies are difficult to estimate. Within this category, a distinction is made between approaches that tailor the properties of the active layer to better match the solar spectrum and approaches that modify the incoming solar spectrum and function at the periphery of the active device, without fundamentally modifying the active layer properties. Advances in nanotechnology and nanomaterials are relevant to both approaches. (EPTP, 2007)

Nanotechnology allows the development of features with reduced dimensionality to be introduced in the active layer: quantum wells, quantum wires and quantum dots. There are three different approaches using these features. The first aims at obtaining a more favourable combination of output current and output voltage of the device, a second approach aims at using the quantum confinement effect to obtain a material with a higher band gap and the third approach aims at the collection of excited carriers before they thermalise to the bottom of the concerned energy band (e.g. hot carrier cells). The research effort for most of these approaches prioritises basic material development, advanced morphological and opto-electrical characterisation, and the development of models that predict the behaviour and performance of the cell when illuminated. (EPTP, 2007)

The theoretical limits of the efficiencies of these devices are as high as 50-60%. Research in novel active layers should be conducted in concert with concentrator system research, since it is highly probable that this technology will perform best under high intensity illumination. (EPTP, 2007)

Also, nanotechnology might again play an important role in tailoring the incoming solar spectrum for maximum conversion to electricity in the active semiconductor layer relies on up- and down-conversion layers and plasmonic effects. (EPTP, 2007)

3.1.2 Concentrated Solar Power (CSP)

The EII on Solar Energy proposes for CSP, among others, actions on new and improved concepts and materials for heat energy storage and heat transfer systems to be developed and tested (transfer fluids, filler materials, change of phase systems, molten salts, ultra capacitors etc.) and integration of low-polluting materials. (EC, 2009c) The overriding need is for industrial up-scaling of demonstrated technologies to reduce costs and improve efficiency, particularly through heat storage.(EC, 2009a)

Therefore, R&D on materials is needed to: i) improve optical materials for reflectors with greater durability and low cost; ii) enhance absorber materials and coatings with higher solar absorbance and low thermal emittance; iii) develop thermal energy storage materials with improved heat capacity; and iv) improve corrosion resistance of materials in contact with molten salts. (MRS, 2010)

The main component where materials face more challenges is thermal storage, in (ESTELA, 2009):

- Evolution of molten salt storage technology with respect to cost, reliability performance, flexibility and safety;
- Develop alternative storage concepts for other molten salts and heat transfer fluids (steam, gas) by material research, heat transfer, process design and operating modes;
- Phase Change Material (PCM)

3.2 Wind Energy

Wind energy has to accelerate the reduction of costs, increasingly move offshore and resolve the associated grid integration issues to fulfil its huge potential. To support its rapid expansion, Europe needs: next generation turbines with new components, new offshore substructures tested in different environments, demonstrate new manufacturing processes and test the viability of new logistics strategies and erection techniques in remote and often hostile weather environments. (EC, 2009a) The key to cost-effectiveness of offshore wind power is high reliability offshore turbines and higher ratings. The massive gears, generators, and blades required for such ratings using conventional technology are presently showstoppers, and offshore maintenance costs add significantly to electricity cost. (DOE, 2010)

To increase efficiency, wind turbine rotor diameters have increased to as long as 110 m. Such sizes demand materials with stable mechanical and environmental properties. The challenges to overcome this include new materials for lighter and stronger blades, including carbon composites which have become well accepted due of their availability (ARUNACHALAM et al., 2008), “smart” blade materials (MRS, 2010), new understanding of reliability limits of structural components in this demanding environment, predictive modelling based on condition-based monitoring, which include sensors included in turbine blades to continuously monitor fatigue damage and signal the need for repair (MRS, 2010), and new lightweight, high-capacity superconductor generators. (DOE, 2010) Fatigue can become a major problem because of alternating stress due to rotation. (ARUNACHALAM et al., 2008)

To meet these challenges EII on Wind Energy proposes actions in order to improve the competitiveness of wind energy technologies, to enable the exploitation of the offshore resources and deep waters potential, and to facilitate grid integration of wind power. These actions, among others, include a R&D programme focused on turbine new materials addressing on and offshore applications. (EC, 2009c) For instance, it promotes research on fatigue tolerant self-healing composite structures for blades, higher current capacity of superconductor wires, and understanding degradation and failure mechanisms based on accelerated materials testing are topics on fundamental research. (DOE, 2010) The total public and private investment needed in Europe over the next 10 years is estimated as €6 bn. The return would be fully competitive wind power generation capable of contributing up to 20% of EU electricity by 2020 and as much as 33% by 2030. More than 250 000 skilled jobs could be created. (EC, 2009a)

In order to produce optimum, high-load structures, fatigue- and impact-tolerant material further studies are required. Catastrophic cost of unscheduled offshore maintenance is one of the main limitations and to avoid it highly accurate predictive models and condition based monitoring are required for the highly loaded composite blades. Many high-strength composites, such as carbon fiber-reinforced plastic used in aerospace applications, are used Fibres containing a one-part or two-part resin system could be a typical self-healing approach. (DOE, 2010)

To reduce design safety factors and costs, a continued characterisation of both existing and new materials is needed along with improved methods of measurement and evaluation. Moreover, new materials could make the cost less dependent on the volatile market prices for steel and cooper. Also, recycling methods for components and materials (e.g. thermoplastics for blades) should be investigated so the quality of materials can be maintained at original levels after separation and recycling. (EWETP, 2008)

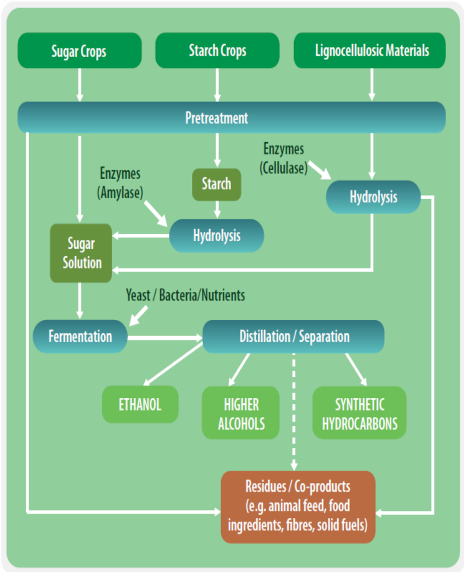
3.3 Biofuels

The use of foodstuffs such as sugars and starches as raw materials is a well-established, commercialized first generation for production of biofuels as well as for primarily ethanol via fermentive processes. Nevertheless, its use puts pressure on the food supply as already discussed in previous sections of this document..

Conventional biofuels will still represent a significant share of renewable fuels in 2020, but in order to reach the 10% target advanced biofuels are needed. (EBTP, 2010) Next-generation biofuels development will focus on non-food feedstocks dominated by lignocellulosic materials which are Earth’s most abundant carbon source and highly renewable providing abundant material to generate biofuels. This kind of materials includes, also, waste from the forestry and paper industries, algae, food byproducts, and municipal solid waste with high cellulose content. (DOE, 2010)

However, lignocellulosics are highly recalcitrant to conversion into biofuels. Figure 32 describes the processes to conversion which fall into two major categories: those using biological processes such as living organisms or enzymes, and those using thermal and traditional catalytic conversion steps. Therefore, programs that resolve these fundamental issues include diversity of biomass and its intermediates in biofuel processing and catalyst discovery, characterization, and performance optimization. (DOE, 2010)

The total public and private investment needed in Europe over the next 10 years is estimated as €9 bn. By 2020, the contribution to the EU energy mix from cost-competitive bio-energy used in accordance with the sustainability criteria of the new RES directive could be at least 14%. More than 200 000 local jobs could be created. (EC, 2009a)



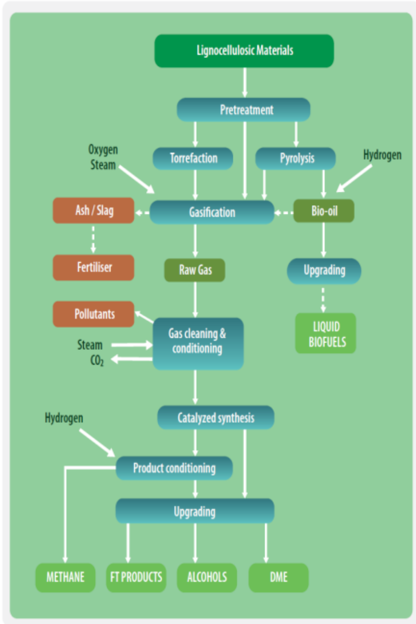


Figure 32 - Biochemical and Thermochemical value chains (EBTP, 2010)

Concerning treatment and trading of biomass, it would be important to develop better knowledge of biomass feedstock properties which includes the development of feedstock quality data (biochemical, physical and chemical) both for dry and wet biomass in relation to diverse end use options and post-harvest operations such as size reduction, densification, blending. (EBTP, 2010)

Cultivation of algae for fuel purposes is still in its R&D phase, and there is no established commercial production of algal biofuel, but it has been estimated that micro-algae could produce several times more oil than the palm oil. (EBTP, 2010) On algae for fuel purposes, materials can play a significant role in capturing CO_2 which is then used as a nutrient to cultivate algae, in chemical processes for water filtration and desalination and in new analytical tools to characterize important biological processes like lipid formation as a function of gene modification. (MRS, 2010)

In order to achieve Europe 2020 objectives, European Industrial Bioenergy Initiative (EIBI) (EC, 2009c) identified eight innovative bioenergy value chains in addition to existing ones:

A) Conversion paths based on thermochemical processes to optimize production from lignocellulosic material - (1) Syngas as intermediary to liquid fuels and chemicals; (2) Bio-methane and other gaseous fuels from biomass via gasification; (3) High efficiency power generation via optimization of syngas; (4) Optimization of production of bioenergy carriers; (5) Co-processing of Biomass and bioenergy carriers with petroleum oil, via other thermochemical processes, e.g. pyrolysis, torrefaction etc.

B) Conversion paths based on biological and chemical processes - (6) Ethanol and higher alcohols from sugars containing biomass; (7) Renewable hydrocarbons from sugars containing biomass via biological and/or chemical process; (8) Production of bioenergy carriers from CO_2 & sunlight through micro-organism based production (algae, bacteria etc.) and further upgrading into transportation fuels and valuable bio-products.

Developing a longer term R&D programme to support the bioenergy industry beyond 2020 and looking towards 2050 is a key parameter for the success of the sector. The setting up of an efficient network of EU Centres of Excellence, with the aim of collecting information on the bioenergy sector, helping the communication between stakeholders and disseminating information, will be the key to achieving the bioenergy objective, being very important to have international collaboration. (EREC, 2010) Bio-energy has to bring to commercial maturity the most promising technologies, in order to permit large-scale, sustainable production of advanced biofuels and highly efficient combined heat and power from biomass. (EC, 2009a)

3.4 Carbon Capture and Storage (CCS)

Fossil fuels play an important role in world base-load energy supply and provide reliable domestic energy security. Nevertheless, if fossil fuels are to remain a component of energy production and reduction of CO_2 emissions is still a main goal, then carbon-neutral energy options must be available and carbon sequestration can become one of the main methods for lightening concerns about GHG and provide sustainable use of fossil fuel resources. (DOE, 2010)

A comprehensive research programme will deliver improved components, integrated systems and processes to make CCS commercially feasible in fossil fuel power plants going into operation after 2020. The total public and private investment needed in Europe over the next 10 years is estimated as €13 bn. The target is to reduce the cost of CCS to 30-50 € per tonne of CO_2 abated by 2020, making it cost-effective within a carbon pricing environment. (EC, 2009a)

Even though most of the technology elements are available, CCS is still not deployed for two key reasons: i) costs and risks still outweigh the commercial benefits and ii) regulatory framework for CO_2 storage is not sufficiently defined. (ZEP, 2006)

Two basic approaches to CCS are available. In one approach, CO_2 is captured directly from the industrial source, concentrated into a nearly pure form, and then pumped deep underground or in the ocean for long-term storage. The second approach captures CO_2 directly from the atmosphere by enhancing natural biological processes that sequester CO_2 in plants, soils, and marine sediments. (BENSON et al., 2008)

In carbon capture systems it is possible to separate CO_2 from other gases involved in combustion and concentrates it in a nearly pure stream suitable for transport. Figure 33 shows the main three approaches to carbon dioxide capture, which are: precombustion – pulls CO_2 from primary fuel before the fuel is burned, postcombustion – pulls CO_2 from flue gases produced by combustion of primary fuel in air, using organic or inorganic solvents (e.g., ammonia, amines) and the use of selective membranes to “filter” CO_2 is currently under development; and oxyfuel – pulls CO_2 from flue gases produced by combustion of primary fuel in pure oxygen. Other industrial processes, including processes for the production of low-carbon or carbon-free fuels, employ one or more of these same basic capture methods. (IPCC, 2005)

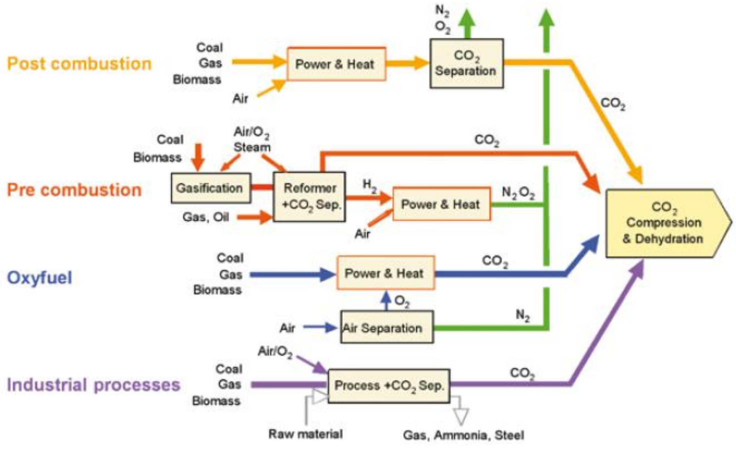


Figure 33 - CO_2 capture systems (IPCC, 2005)

All require a step involving the separation of CO_2, H_2 or O_2 from a bulk gas stream (such as flue gas, synthesis gas, air or raw natural gas). These separation steps can be accomplished by means of physical or chemical solvents, membranes, solid sorbents, or by cryogenic separation. (IPCC, 2005). From the materials point of view the most important are the first three (EC, 2010c)

To meet the challenge on enabling the cost competitive deployment of CCS technologies in coal-fired power plants by 2020-2025 and to further develop the technologies to allow for their subsequent wide-spread use in all carbon intensive industrial sectors, European Industrial Initiative on CCS proposes actions in proving technical and economic feasibility of CCS using existing technology and in developing more efficient and cost competitive CCS technologies. Among others, these actions include collectively development of coherent portfolio that will demonstrate CCS chains comprising different capture (post-combustion, pre-combustion, oxyfuel) and storage options using different fossil fuel types; research on new components and technologies, such as solvents and membranes; research in CO_2 transport which will include improved materials for pipelines. (EC, 2009c)

The implementation of new materials allows the development of a new generation of coal-fired power plants that is emerging with higher efficiencies and thus lower emissions. Whereas the installation of CO_2 sequestration systems in existing units is difficult and economically unattractive, it might be possible to erect such systems as an integrated unit in newly commissioned plants. One of the few technology options, the IGCC process, involves gasifying coal to a combustible gas (syngas) consisting of a mixture of CO, H_2, CO_2, H_2O, and other trace species. IGCC power plants can operate at higher efficiencies (40– 45% higher heating value) than conventional coal plants (35%). Coal gasifiers can also be integrated with high-temperature, ceramic-based, solid-oxide fuel cells. These fuel cells can utilize the syngas directly from the gasifier. (ARUNACHALAM et al., 2008)

On separation with sorbents/solvents, separation is achieved by passing the CO_2-containing gas in intimate contact with a liquid absorbent or solid sorbent that is capable of capturing the CO_2. In the separation with membranes, the membranes are specially manufactured materials that allow the selective permeation of a gas through them. There are many different types of membrane materials (polymeric, metallic, ceramic) that may find application in CO_2 capture systems to preferentially separate H_2 from a fuel gas stream, CO_2 from a range of process streams or O_2 from air with the separated O_2 subsequently aiding the production of a highly concentrated CO_2 stream. A large worldwide R&D effort is in progress aimed at the manufacture of more suitable membrane materials for CO_2 capture in large-scale applications. (EC, 2010c)

The following table gives an overview of both current and emerging technologies for each CO_2 capture technology.

Table 4 - Materials on CO_2 capture technologies (IPCC, 2005) (DOE, 2010)

Separation task	Process streams		Post-combustion capture		Oxy-fuel combustion capture		Pre-combustion capture	
	CO2/CH4		CO2/N2		O2/N2		CO2/H2	
Capture Technologies	**Current**	**Emerging**	**Current**	**Emerging**	**Current**	**Emerging**	**Current**	**Emerging**
Solvents (Absorption)	Physical solvents Chemical Solvents (amines, ionic liquids)	Improved solvents	Physical solvents Chemical Solvents (amines, ionic liquids)	Improved solvents	n.a.	Biomimetic solvents, e.g. hemoglobine derivatives	Physical solvents Chemical Solvents (amines, ionic liquids)	Improved chemical solvents
Membranes	Polymeric	Ceramic Carbon	Polymeric	Ceramic Carbon	Polymeric	Ion transport membranes	Polymeric	Ceramic Palladium
Solid sorbents	Zeolites Activated carbon		Zeolites Activated carbon	Carbonates Carbon based sorbents (MOF's)	Zeolites Activated carbon	Adsorbents Perovskites Oxygen chemical looping	Zeolites Activated carbon Alumina	Carbonates Hydrotalcites Silicates

Oxygen based processes show significant promise for yielding the lowest cost solution for carbon capture and sequestration and, in order to reduce the parasitic load on the power plant, it is required new methods to generate oxygen with lower power requirements. The development of oxygen ion selective ceramic membranes has the potential to significantly reduce the cost of producing oxygen at large scales required for power production, being this also an important issue. (MRS, 2010)

Advanced ultra supercritical (USC) coal-fired power plants use coal-fired boilers with advanced steam cycles involving much higher temperatures and pressures than those presently used in conventional pulverized coal (PC) power plants, which increase the efficiency of steam plants. (VISWANATHAN et al., 2001) The construction of these power plants will be possible by the development of high temperature metals with associated welding and forming procedures. Efficiency gains of at least 8–10% are anticipated, resulting in substantially reduced releases of CO_2 and other fuel-related pollutants and greenhouse gases by nearly 30%. (MRS, 2010)

3.5 Nuclear Energy

Although nuclear power is generally considered one of the most scientific intensive of all forms of energy generation, the basis for designing, building, and operating current plants is largely empirical. Nuclear plants provide some of the lowest cost electricity in the energy generation mix, once capital cost of plants is paid off. More recently, the attention has shifted to its role as a non-CO_2-emitting source of clean energy. (DOE, 2010)

To ensure that nuclear energy remains a long-term contributor to the low carbon economy, building on the safety, reliability and competitiveness of current reactors, the strategic objective of European Industrial Initiative on Sustainable Nuclear Energy is to increase sustainability of nuclear energy through demonstrating the technical, industrial and economic viability of Generation-IV fast neutron reactors (FNRs). The cross-cutting R&D program includes materials science and multiscale modelling of material behaviour (structural materials, fuels, cladding) for design and operational safety and radiation protection, waste management, component ageing and lifetime management. (EC, 2009c) The total public and private investment needed in Europe over the next 10 years is estimated at €7bn. By 2020, the first Generation-IV prototypes should be in operation. The first cogeneration reactors could also appear within the next decade as demonstration projects to test the technology for coupling with industrial processes. (EC, 2009a)

Several areas related to nuclear power could benefit from a stronger fundamental understanding of materials, the changes they undergo in the nuclear reactor, and the degradation mechanisms affecting safe and economic operation. The topics include degradation of many components of the reactor core and primary system, as well as aspects related to the back end of the fuel cycle. (DOE, 2010) Nuclear power has its own unique technical challenges on materials technology related to issues like material & fuel handling, fusion, fission & radiation damage as well as decommissioning & storage. (EUMAT, 2006) Nuclear materials researchers and technologists have gained rich experience in the behaviour of present-generation materials, such as zirconium-based alloys and special steels.

However, sustained R&D on a wide spectrum of materials such as refractory alloys, composites, ceramics, low-activation steels, coatings (RAJ et al., 2008), understanding of long term pressure vessel steel behaviour, corrosion resistant nickel base alloys and uranium oxide fuel pellets. (MRS, 2010).

Thus, nuclear fission has to move towards long-term sustainability with a new generation of reactor type – the Generation-IV reactor. They will be designed to maximise inherent safety, increase efficiency, produce less radioactive waste and minimise proliferation risks. Commercial deployment of these reactors is foreseen for 2040, but to achieve that target. (EC, 2009a) Much of the success and reliability of nuclear power plants is the result of advances in materials:,

Materials R&D should, then, include: i) development of new classes of structural materials capable of operating at temperatures 371°C higher than that of today's light water reactors; ii) development of advanced computational materials performance modelling tools, key enablers to transition new materials into advanced reactor systems; iii) development of proliferation resistant nuclear fuel through advances in ceramics and coatings technology; iv) development of new materials to contain nuclear waste for geologic life times. (MRS, 2010)

3.6 Electricity Grid

Electricity is one of the fundamental enabling clean energy technologies and it's expected a growth in its demand as a consequence of electric power grid versatility in providing energy services, the opportunities for electrification of transportation and the need for transmission of abundant renewable power resources to distant load centres. (DOE, 2010)Technical aspects of the challenges electricity grid faces that will be originated by this rapid growth include both improving existing technology through engineering and inventing new technologies requiring new materials. (AMIN et al., 2008) This includes low conductivity materials and materials with high dielectric breakdown like copper and copper-aluminum alloy conductors; existing and new superconductors; glass, air, vacuum and new insulators. (MRS, 2010)

To ensure that electricity networks are fit for the 21st Century, there is the need to a strongly integrated research and demonstration programme, which enable the development of new technologies to monitor, control and operate networks in normal and emergency conditions. The total public and private investment needed in Europe over the next 10 years is estimated as €2 bn. The goal is that by 2020, 50% of networks in Europe would enable the seamless integration of renewables and operate along 'smart' principles, effectively matching supply and demand and supporting the internal market for the benefit of citizens. (EC, 2009a)

The present generation of superconductor wires is yttrium barium copper oxide (YBCO) films on textured substrates, the so-called coated conductors. According to BES-DOE report, the priority research directions for the electricity grid should include: i) higher performance power electronic materials; ii) superconductor materials for underground transmission and for increased power density and performance in generators, motors, and fault current limiters; iii) electrically insulating materials with improved dielectric and thermal properties; iv) novel composite electrical conductors for high-temperature, low-sag overhead transmission lines. (DOE, 2010)

3.7 Energy Efficiency: Industry, Buildings, Transport and Lighting

3.7.1 Industry

As already been stated, 20% of CO_2 current emissions are due to direct emissions from industry. (IEA, 2010b) Therefore, technologies for effectively and low-cost reducing CO_2, like improvements in existing in CCS technologies and implementation of new technologies on CCS, will play an important role on industry energy efficiency.

Energy efficiency in industry is a main issue, being more significant on raw materials industry. In energy industry, the major challenges are reduced life cycle costs and costs of electricity for all fuel sources. In order to reach the ambitious targets of reduced life costs and reduced environmental impacts of energy sector, significant materials technology challenges are met. In fossil fired plant, special problems are related to gas turbine combined cycle, advanced coal fired and CO_2 sequestration plants, e.g. development of advanced high temperature materials (steels, superalloys and composites). Power plants utilizing renewable fuel, e.g., waste/biomass plants, wind turbines, fuel cells and solar plants will require advanced materials with specific requirements for corrosion resistance (aqueous & high temperature), light weight technologies (composites, plastics) and environmental coatings. (EUMAT, 2006)

Intermetallics constitute an important class of engineering materials which are known for high temperature properties including melting points and high elastic modulus. Typically, they manifest high strength at temperature, creep and environmental resistance (e.g. oxidation, sulfidation) and relatively low densities. They have strong potential for replacing superalloys and stainless steels in moderate and high temperature structural applications. Their exceptional properties lead to increased operating temperatures, efficiency, and reduced maintenance. The best known representatives of intermetallics are shape memory alloys (SMA) (EUMAT, 2006)

One example of this is the production of molten aluminum which creates aggressive environments for processing equipment, thereby requiring refractory materials to contain the aluminum during melting, transfer, treatment, and casting operations. Degradation of these refractories causes issues with reduced product quality and production yields and increases heat losses as the insulative properties of the refractories are compromised. Additionally, large amounts of energy are lost as the refractory coatings are repaired or replaced, during the cooling and subsequent reheating of the equipment, leading to impacts upon energy efficiency. (PETERS et al., 2009)

3.7.2 Buildings

One of the specific objectives for the European Initiative on Smart Cities is targeted to buildings net zero energy requirements or net zero carbon emissions. This can be achieved by refurbishing of existing buildings for lowering possible energy consumption levels maintaining or increasing performances and comfort. This would include innovative insulation material (solid insulation, vacuum insulation, vacuum windows, cool roofs). (EC, 2009c)

These new materials include i) phase change materials capable of storing or releasing large amounts of energy in the walls, floor and roof, thereby saving energy and smoothing the thermal profile; ii) optical metamaterials and photonic crystals potentially enabling optical engineering using structured inorganic nanomaterials to positively influence the solar gain and provide long term durability; iii) electrochromic, suspended particle and liquid crystal glasses responding to occupants and external conditions to actively control both light and solar gain. (MRS, 2010)

On window glazing, materials R&D should focus on new materials by design and synthesis to replace electrochromic tungsten and associated materials systems. These new materials include vanadium dioxide (VO_2), tungsten trioxide (WO_3) and nickel oxide (NiO). Nanotechnology-based solutions should be explored in conjunction with or in place of conventional multilayer thin film processes. (DOE, 2010)

On high-performance opaque envelope materials, new thick film/thin film manufacturing approaches should optimize physical and chemical vapour deposition with ion assist. Entirely new coating processes, such as liquid phase or spray deposition, which can be scaled to commercial processes, are needed. Biomimetic approaches offer a further set of functional designs and new approaches to fabrication of high-performance optical and thermal control structures. (DOE, 2010)

Regarding the space heating and cooling, solutions includes highly efficient heat bombs, solar thermal systems and electricity and heat cogeneration (CHP) systems with fuel cells and hydrogen. (IEA, 2010c) The building industry would benefit from advances in solar technology, particularly in terms of polymer solar domestic hot water systems and combined PV/thermal solar systems (BIPV). (JUDKOFF, 2008)

3.7.3 Transport

Energy efficiency in transportation is another specific objective of the European Initiative on Smart Cities. In this case, the focus is on the large deployment of alternative fuel vehicles (electrical vehicles, hydrogen and fuel cells, low consumption vehicles, natural gas vehicles, biofuels). (EC, 2009c)

Also in transportation, intermetalics, already mentioned above, play an important role. The intensive research on these materials started in mid-1970s in view of expectation that they may become prime candidates for high temperature structural application, especially in jet engines in order to increase service temperature and reduce weight. (EUMAT, 2006)

The future materials for transport could be: i) lightweight materials for automotive, aeronautics, and space applications; ii) multifunctional materials for car interiors, adaptive materials for shock absorbers and new actuator concepts; iii) materials for new generation of motors for automotive: Hybrid, electrical, fuel cells; iv) materials for new engine in aeronautics: higher efficiency through higher temperature; v) new material withstanding UV and atomic oxygen damage for space. (EWG, 2009)

For low consumption vehicles, the combination between the increased fuel efficiency and use of alternate fuels with "lightweighting" (or perhaps downsizing), is achieved by means of advanced High Strength Sheet Steels (AHSS) developed to enable low cost crash-resistant vehicle structures to be manufactured with reduced sheet thickness and vehicle weight. This can also be achieved with light metal developments and application of new aluminium, magnesium, titanium alloys, etc. Carbon fibre composites may also play an increasing role, especially where the weight savings can justify the much greater cost. (MRS, 2010)

Thermoelectric materials were primarily used in niche applications, but with the introduction on broader automotive applications and the effort on waste-heat-recovery technologies, thermoelectric devices are becoming more important. Materials research is at the moment in investigating several systems of materials including typical narrow-bandgap semiconductors, oxides, and cage-structure materials. The emerging field of thermoelectric nanocomposites appears to be one of the most promising recent research directions. (TRITT et al., 2008)

3.7.4 Lighting

As previously mentioned, incandescent light bulb is 95% inefficient at producing light and, nowadays energy-saving starts with the use of compact fluorescent lamps which have a conversion rate of 20%. (HUMPHREYS, 2008)

The first type of SSL source discovered was inorganic light emitting diodes (LED's), which have an inorganic semiconductor junction, and are frequently installed in consumer electronics goods. LEDs are semiconductors in which the light emission comes from a very thin crystalline layer composed of typically two, three, or four elements such as indium gallium nitride (InGaN). (HUMPHREYS, 2008)

Organic light emitting diodes (OLED's) are a more recent discovery, being investigated mainly for displays and diffuse light sources. (WIGGINS et al., 2010) In theory, organic LEDs, OLEDs have a number of attractive properties for solid-state lighting, including ease of processing and low cost, as well as the ability for device properties to be tuned by chemically modifying the molecular structure of the organic thin films. However, despite some impressive research results, in practice, the development of OLEDs for lighting has lagged behind that of LEDs. So far, it has not been possible to achieve simultaneously high brightness at high efficiency with long lifetime. (HUMPHREYS, 2008)

Although existing markets for LEDs are large, the most important target application is home and office lighting, but five main factors prevents the widespread use of GaN-based LEDs, which are: efficiency, heat management, colour rendering, lifetime and cost. (HUMPHREYS, 2008)

Challenges on SSL include improvement of LED system efficiency by a factor of two while simultaneously decreasing the SSL lamp cost by a factor of 10. BES-DOE recommends focusing the basic SSL research toward improving the SSL device efficiency, uncovering the mechanisms limiting device efficiency and reliability, and developing solutions to achieve high device efficiency and reliability under high power density and application-relevant operating conditions. Therefore research key priorities are on i) high-efficiency, visible, solid-state emission at high current density and temperature; ii) white emission through wavelength conversion; iii) OLED materials and structures for reliable, colour-consistent, high- luminance emission. (DOE, 2010)

The next generation of a more efficient, nontoxic source of white light at a reasonable cost for home and office lighting, will almost certainly be inorganic LEDs. Thus, the following key materials problems will need to be addressed: i) increased efficiency of green LEDs, ii) increased efficiency of blue and near-UV LEDs, iii) dislocation reduction, iv) nonpolar and semipolar GaN, v) improved p-GaN, vi) novel wide-bandgap semiconductors and vii) novel phosphors. (HUMPHREYS, 2008)

3.8 Energy Storage

3.8.1 Electrical (Batteries and Supercapacitors)

In order to meet the challenges arising from the use of plug-in electric vehicles, for utility-scale storage, as well as for the intermittency effect of renewable energy sources, the focus should be on batteries and supercapacitors.

As already mentioned, batteries generally represent a high-energy-density and a low-power-density technology. Supercapacitors, on their turn, represent a high-power-density and a low-energy-density energy-storage technology, being able, as shown in Figure 34, to bridge the gap in energy density between batteries and the common capacitor.

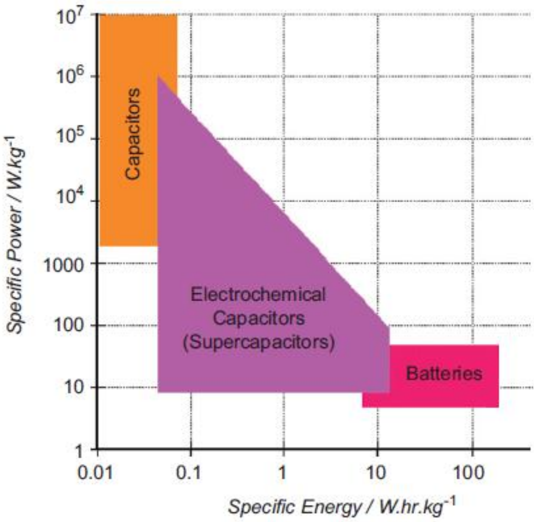


Figure 34 - Energy storage (HALL et al., 2008)

Supercapacitors may thus be used in hybrid energy-storage systems to complement batteries. Neverthless, it is important to notice that supercapacitors do not represent an alternative to batteries and that, in order to meet the challenges of contemporary energy-storage/ power-delivery systems, a synergetic effect must exist between the two technologies. (HALL et al., 2008)

In the case of batteries, nanotechnology could have a impact on its characteristics, namely nanoporous material may enable faster discharge in battery electrodes; carbon nanotubes can enhance their efficiency and conductivity; and ceramic nanoparticles can improve safety by expanding the range of battery operating temperatures (CARPENTER et al., 2008)

Historically, new materials development has often focused on a single material such as anode, cathode, or electrolyte, which does not guarantee improvement in overall battery performance. A battery is a system, and the integrated functionality of all components must be addressed. A better energy storage system would maximize the active material, but reduce the overhead, which in turn would reduce cost. Hence, the near-term industry approach is to move to thicker electrodes and larger-sized cells that reduce packaging, but still have all of the other inert materials, such as separator and foil. (DOE, 2010)

The lithium-ion (Li-ion) and sodium sulphur (NaS) batteries represent the leading technologies in high-power-density battery which means they offers greatest potential for future application in a wide variety of energy storage systems. (HALL et al., 2008) On the European Roadmap for Electrification of Road Transport the involved companies and organisations from the automotive and energy sectors agreed on actions to be taken, which include among others, R&D activities on lithium batteries. (ERTRAC et al., 2010)

For lithium-ion batteries to achieve higher energy density, lower cost, and longer lifetime while maintaining safety it is required new cathodes, non-flammable electrolytes and anodes. The major challenges on sodium batteries are safety and corrosion prevention arising from the high operating temperatures (above 300°C). Finding low-temperature electrolytes with high-sodium ionic conductivity is a major challenge. Sodium anodes can operate with a variety of cathodes, including sulphur and transition metal halides such as nickel/nickel chloride. (DOE, 2010)

For lithium-ion battery electrolytes a number of candidates are less expansive, are more stable, have higher capacity, and exhibit less volume expansion on discharging than the lithium cobalt spinel ($LiCoO_2$) now in common use. The challenge is to select materials classes with desirable properties and optimize them by adjusting composition, which could be i) lithium nickel oxide ($LiNiO_2$); ii) layered alloys of $Li(Ni_xCo_{1-x})O_2$; iii) lithium manganese spinel ($LiMn_2O_4$). (DOE, 2010)

The area with greatest potential for the materials research is the cathode. Phosphates such as lithium iron phosphate (LiFePO4) are promising cathode materials. Several materials have been used, starting with titanium disulfide TiS_2, followed by lithium cobalt oxide $LiCoO_2$ and variants with nickel and manganese [$Li(NiMnCo)O_2$], lithium manganese spinel ($LiMn_2O_4$), and most recently $LiFePO_4$. Other phosphates such as lithium manganese phosphate ($LiMnPO_4$) and lithium cobalt phosphate ($LiCoPO_4$) are promising, and mixed compositions with Fe, Co, and Mn content provide a rich phase space to be explored. (DOE, 2010) (WHITTINGHAM, 2008)

Regarding anode for lithium-ion batteries, most recently purified natural graphites have replaced the expensive synthetic carbons. In spite of the effectiveness of graphite, other anodes with higher energy density or which do not require a solid electrolyte interface layer are possible. Promising candidates include: silicon; carbon nanotubes; $LiTi_{15}O_5$; $LiTi_2O_4$; cupric oxide (CuO); titanium dioxide (TiO_2); tin dioxide (SnO_2) and grapheme. Nanostructuring plays a key role in many of these anode materials, to facilitate lithiation and mitigate large volume changes. (DOE, 2010) (WHITTINGHAM, 2008)

Electrolyte in battery or electrochemical capacitor systems drives and restricts many of the operating characteristics as well as the range of compatible materials that can be used for cathodes and anodes. New electrolytes include boron salts - Lithium bis(oxalate)borate ($LiB(C_2O_4)_2$) (LiBOB) is interesting for its potential low cost, ready availability, and good ionic conductivity. With suitable modification, lithium borohydride ($LiBH_4$) offers high ionic conductivity at room temperature. Polymer electrolytes are gaining popularity for their potentially high energy densities, close to the limit for Li-ion batteries. Ionic liquids, with high ion mobility at low temperature, low vapour pressure, and non-flammability offer interesting possibilities. (DOE, 2010) (WHITTINGHAM, 2008)

Moving away from lithium, systems based on sodium might be considered, although low melting point of sodium leads to safety concerns for consumer applications. Lower operating temperatures on sodium batteries require tuning the properties of the standard electrolyte beta-alumina (Al_2O_3) with additives to get adequate ionic conductivity. New polymer-based electrolytes allow operation as low as 25° to 90°C. At low temperature, sodium and sulfur remain promising candidates for anode and cathode materials, with transition metal halides such as nickel chloride and ferrous chloride receiving strong attention as alternative cathodes. (DOE, 2010) (WHITTINGHAM, 2008)

As previously discussed supercapacitors represent a high- power-density energy-storage technology, however they are susceptible to self discharge. High capacitances are achieved by reducing plate separation to a few angstroms and also by increasing the plate- specific surface areas via the use of high-surface-area carbon electrodes. (HALL et al., 2008)

The three main areas offering challenges associated with the development of carbon-based supercapacitors are development of electrodes, electrolytes and package. Regarding to the electrode development the key challenges could be achieved by the development of nanostructured carbons and controlled-porosity polymers. On electrolyte development the key challenges could be overcome by working on ionic liquid electrolytes which is in the early stages but it is possible that such electrolytes with low viscosities at room temperature may be developed. (HALL et al., 2008)

3.8.2 Hydrogen

Water electrolysis technology, which uses electrical energy to produce hydrogen, is currently a mature technology. The main limitation at the present time, that is common to all hydrogen applications, is hydrogen's low energy volume density and the difficulties in storing large quantities in a manageable volume.

There are significant research programmes underway in this area and in improving the efficiency of the electrolysis and fuel cell energy conversion cycles. Overall hydrogen is a promising technology for the mid to longer term but a number of the technologies are likely to be exploited prior to the significant developments in hydrogen technology and storage that will be required for it to become a cost effective option for energy storage on a large scale. (EC, 2008b)

Hydrogen can be burned either to provide heat, or to drive turbines, or in internal combustion engines for motive and electrical power. Many of these technologies need improvements in materials and processes to improve efficiency and durability. (EC, 2011d)

Storing hydrogen in materials can occur via absorption, in which hydrogen is absorbed directly into the storage media; adsorption, in which hydrogen is stored on the surface of storage media; or chemical reaction. Materials used for hydrogen storage can employ one or more of these mechanisms and may be grouped into four general categories (DOE, 2007):

- Metal hydrides storage materials offer great promise and further research is required to overcome several critical challenges including low hydrogen capacity, slow uptake and release kinetics, and high cost. Thermal management during refuelling is also a challenge, as the significant amount of heat released must be safely rejected or captured for use. (DOE, 2007) Reversible metal hydrides for improvement of energy storage capacity of conventional hydrogen storage systems by a factor of two (energy storage capacity is up to ten times higher than that of lithium ion batteries);

- Carbon-based materials or high surface area sorbents are still in the early stages of investigation. The focus of research is metal-carbon hybrid systems. Scientists are working to better understand the mechanisms and storage capabilities of these materials and improve the reproducibility of their measured performance, in order to estimate the potential to store and release adequate amounts of hydrogen under practical operating conditions. Metal organic frameworks (MOFs) are new, cage-like, highly porous materials composed of metal atoms as well as organic linkers. Recent studies have shown that certain MOFs can store hydrogen by adsorption at low temperatures. A key focus area for future research is to tailor materials so hydrogen can be stored within them at room temperature; (DOE, 2007)

- Chemical hydrogen storage, hydrolysis reactions, hydrogenation/dehydrogenation reactions, and several new chemical approaches are under investigation; (DOE, 2007)

- New materials and processes, initial studies have indicated that a significant amount of hydrogen can be incorporated into conducting polymer structures. These and other new concepts are yet to be explored for their viability to vehicular hydrogen storage applications. (DOE, 2007) Also, further research is needed to develop low-cost materials resistant to hydrogen-assisted cracking and embrittlement. (MRS, 2010)

In transportation, hydrogen storage presents a major materials research challenge, namely, to find a storage medium that combines a hydrogen density greater than that of the liquid with fast kinetics allowing rapid charging and discharging. The challenge is to find a storage material that satisfies three competing requirements: high hydrogen density, reversibility of the release/charge cycle at moderate temperatures in the range of 70–100°C to be compatible with the present generation of fuel cells, and fast release/charge kinetics with minimum energy barriers to hydrogen release and charge. (CRABTREE et al., 2008)

Additionally, new materials for proton conducting membranes that operate above the boiling point of water are seriously needed. Catalysts for the oxygen reduction reaction that produces water at the cathode present a special challenge—platinum, the best performing catalyst, is too expensive and limited in supply to meet widespread global transportation needs. (MRS, 2010)

3.9 Fuel Cells

Material development for enhanced lifetime is a major challenge in fuel cell basic R&D due to the close link between electricity flow and corrosion processes, morphological changes, building of resistive layers and exhaustion of catalytically active components. (EC, 2011d)

The Joint Technology Initiative (JTI) on fuel cells and hydrogen was established for 2008-2013 with a budget of 470 M€ of Community funding to be at least matched by industry. Meeting the market entry targets set by industry will require substantial additional effort. The additional public and private funding needed is currently estimated as €5 bn for the period 2013-2020. (EC, 2009a)

Commercialization of fuel cells in stationary electricity generation and transportation has been limited by performance, durability, and/or cost of the cathodes, anodes, and electrolytes used in their design, in spite of the fact that they offer high conversion efficiency of chemical fuel to electricity and heat (up to 50% for electricity and over 80% if the waste heat is used for combined heat and power). (DOE, 2010)

Four types of fuel cells, have reached a maturity allowing initial market penetration. Proton Exchange Membrane Fuel Cells (PEMFCs, 80°C) and Phosphoric Acid Fuel Cells (PAFCs, 200°C) are constrained by cathode stability and cost; both of these systems currently require platinum-based catalysts. Molten Carbonate Fuel Cells (MCFCs, 650°C) and Solid Oxide Fuel Cells (SOFCs, 600–1000°C) are attractive for stationary power use, but are subject to materials degradation and failure due to high-temperature cycling of the cathode, electrolyte, and interconnects between cells in the stack. (DOE, 2010) The following table summarizes the properties on these four types of fuel cells.

Table 5 - Key features of four fuel cell types with greatest application potential (DOE, 2010)

	PEMFC	SOFC	PAFC	MCFC
Electrolyte	Hydrated proton Exchange membrane	Perovskites (Ceramics)	Immobilized Phosphoric Acid in SiC	Immobilized Liq. Molten Carbonate in $LiAlO_2$
Electrodes	Carbon	Perovskite and perovskite/metal cermet	Carbon	Nickel and Nickel Oxide
Catalyst	Platinum	Perovskite and perovskite/metal cermet	Platinum	Nickel and Nickel Oxide
Interconnect	Carbon or Metal	Nickel, Ceramic, or Steel	Graphite	Stainless Steel or Nickel
Temperature	40-80ºC	600-1000ºC	200ºC	650ºC
Largest Impact Application	~100 kWa for Transportation	1–1000kW for Stationary Combined Heat and Power	~200–400 kW for Distributed Stationary	250–2000kW for Stationary Combined Heat and Power
Maturity	Pre-Commercial Prototypes	Commercialized at Low Volume	Commercialized at Low Volume	Commercialized at Low Volume

3.9.1 Polymer Electrolyte Membrane Fuel Cells (PEMFCs)

The specific areas of research for PEMFCs, include: i) lower-cost material alternatives: development of alternative membranes; reduction of the complexity of an integrated system; minimization of the temperature constraints; increase of the power density; scaling up production; ii) fuel cell system development: heat management, water management, power management, etc. (the system design depends very much on application); iii) system efficiency: systems with reformer should reach 40% efficiency while the hydrogen-fuelled systems should have efficiency around 50%. (BTI, 2011)

To achieve automotive loading targets, research directions on PEMFC's could be on the replacement of platinum catalysts with platinum alloys, platinum-shell/affordable-core materials, or preferentially faced nanostructures such as platinum-nickel alloy (Pt_3Ni (111)). Good progress has also been made with Pt-free catalysts. Materials synthesis, discovery, and characterization are key activities for bringing proton exchange membrane fuel cells to competitive viability. The two most serious materials challenges are i) promoting the oxygen reduction reaction at the cathode and ii) the proton exchange membrane. (DOE, 2010)

3.9.2 Solid Oxide Fuel Cells (SOFCs)

SOFCs High operating temperature, poses multiple challenges to their performance and cost. High temperatures lead to high thermal stress due to thermal expansion, ultimately producing cracking and failure. Long warm-up times mitigate cracking due to thermal stress, but significantly lower commercial viability and raise operating cost. Sealing the multilayer components of a fuel cell is difficult at high temperature and surface areas also decline at high temperature. The high operating temperature also affects the interconnect materials and bipolar plate connecting the cells in a stack, which must survive reducing and oxidizing atmospheres while maintaining high electrical conductivity and negligible ionic conductivity. Metals and alloys do not fulfill these conditions; thus, interconnect materials are typically ceramics based on the perovskite system lanthanum chromite (LaCrO3).

Lowering operating temperature creates significant materials and chemistry challenges. The ionic conductivity of the oxide electrolyte drops strongly with temperature, limiting reaction rate and power density. Lower temperatures inhibit catalytic activity of the hydrocarbon-to-hydrogen reforming process, requiring new anodes that catalyze the reforming reaction at intermediate temperatures. At the cathode, lower temperature lowers oxygen reduction reaction kinetics. (DOE, 2010)

Therefore, the main challenges for SOFC, includes: i) decrease manufacturing and operation costs; ii) lower operating temperature: down to 600-800°C; iii) improving lifetime. (DOE, 2010) (BTI, 2011)

Research directions on SOFC's could be on the use of electrolytes with higher ionic conductivity for lower operating temperatures, in the range of 600° to 800°C. One promising solution is to reduce electrolyte layer thickness, which shifts the rate-limiting step from bulk diffusion to surface exchange. Thin electrolytes, however, promote pinholes and cracks, causing cross-mixing of electrolyte gases and lowering cell performance. Higher ionic conductivities can be achieved with new electrolytes, with structures in the fluorite, oxygen-deficient perovskite, pyrochlore, apatite, or scheelite families. (DOE, 2010)

(DOE, 2010)

3.9.3 Phosphoric Acid Fuel Cells (PAFCs)

Stack life is the critical issue and the e cathode is a key life-limiting component, and solutions are needed to increase or retain cathode chemical activity to meet the durability requirement.

On PAFCs, it is important to replace the phosphoric acid electrolyte, while retaining low-vapor-pressure and thermal stability. Therefore, proton conducting materials operating in the 170° to 190°C range that do not adsorb on Pt are needed. Experiments should be carried away to isolate and understand the mechanisms of Pt dissolution and coarsening as a function of temperature and potential. (DOE, 2010)

3.9.4 Molten Carbonate Fuel Cells (MCFCs)

One of the main drawbacks is the severe oxidizing conditions present at the cathode which limit the number of metals that can be used as electrocatalysts.

Regarding to MCFCs, its evolvement is dependent on the search for cathode materials with slower dissolution in the molten electrolyte takes three directions: i) coating the cathode with an anti-corrosive protective layer, ii) doping nickel oxide to slow down dissolution, and iii) trying new materials such as lithium cobalt spinel ($LiCoO_2$) for its low reactivity with molten carbonates. The dissolution rate depends on carbonate solution pH and, thus, on other cations in the electrolyte mix, creating a rich multiparameter phase space to search for promising trends. The uncoated conventional NiO cathode can be doped with iron (Fe), magnesium (Mg), and other cations to adjust pH and slow the corrosive reaction. New cathode materials such as lithiated transition metal oxides are promising candidates. (DOE, 2010)

IV – Characterization of CICECO

1.1 General Characterization

Centre for Research in Ceramics and Composite Materials (CICECO) was created in March 2002 at the University of Aveiro, Portugal, with the mission of developing the scientific and technological knowledge necessary for the innovative production and transformation of ceramics and composite materials. (CICECO, 2011)

CICECO is the largest Portuguese institute in the field of materials science and engineering, comprising 50 academic staff, 35 full-time researchers and, in December 2010, 54 post-doctoral associates, 82 PhD students, and ca. 115 other students. CICECO is one of the most productive Portuguese research institutes in all scientific areas and is probably the best equipped institute in the country to perform research in materials science. (CICECO, 2011)

Research is organised in 3 lines and 8 interdisciplinary groups from Departments of Chemistry, Ceramics and Glass Engineering and Physics, chosen taking into account surrounding industrial environment (ceramics, chemical and forest-based companies), skills, expertise and motivation to develop new and stimulating scientific and technological fields. (CICECO, 2011)

The research lines and groups are: (CICECO, 2010)

LINE 1: Advanced Micro- and Nanostructured Materials for Communications technology

- GROUP 1: Inorganic Functional Nanomaterials and Organic-Inorganic Hybrids ;
- GROUP 2: Electroceramics;
- GROUP 3: Magnetostructural and Multiferroic Modulation of Correlated

LINE 2: Advanced Materials for Industrial Applications

- GROUP 4: Reactive Ceramic Components for Process Control;
- GROUP 5: Ceramic Composites and Functional Coatings for Structural Applications;
- GROUP 6: Wastes Recycling and Green Products.

LINE 3: Biorefineries and Biomaterials

- GROUP 7: Macromolecular Materials and Biorefineries;
- GROUP 8: Biomedical and Biomimetic Materials.

Another important structure in CICECO is its knowledge transfer interface, CDTM - Centre for Materials Design and Technology, which aims at contributing to the development of R&D activities through knowledge valorisation.

1.2 CICECO Commitment to Industry

CICECO is aware of the need to transfer the results of research to companies and the bridge is performed through CDTM. Currently, there are 65 different companies which benefit from this connection by means of more then 120 protocols and contracts. (SOUSA PAIS, 2011)

CDTM mission is to transfer the knowledge created within CICECO to society, fostering its valorisation, having four main goals: (SOUSA PAIS, 2011)

1. Promotion of CICECO´s intellectual property valorisation and entrepreneurship;
2. Promotion and support to CICECO - industry interaction;
3. Funding programmes identification & support to proposals submission;

4. Promotion of CICECO image to society.

CDTM is involved in the promotion of Entrepreneurship within CICECO, through the promotion of an Entrepreneurship culture among researchers and the support of all activities that may lead to entrepreneurship projects. As a result, CICECO already presents several cases of spin-offs, some of them success cases: FOODMETRIC SA – solutions for food industry based on fast Instrumental analysis methods and chemometrics, TETRACARBON - solutions based on advanced ceramics and materials coated with diamonds and NANOSMARTEK – Nanotechnology solutions applied to the protection against corrosion. (SOUSA PAIS, 2011)

An interesting example within CDTM activities for promotion and supporting CICECO on industry interaction is the technology platform IDPoR – Research and Development in Polymers from Renewable Resources. This R&D Platform aims at the development of scientific and technological knowledge driven by the needs and competitive challenges of a group of six national major companies, throughout the promotion of fundamental R&D which interests all associates, offering training courses, performing research contracts, applying for funding programmes to promote R&D, identifying new products, emerging technologies and scientific know-how and promote technology transfer between CICECO and the companies associated. (IDPOR, 2011)

In 2010, CICECO integrated a consortium of R&D and Innovation institutions in the frame of the European Program INTERREG IVB – Atlantic Area to develop a project called ENERMATaa. This project aims at promoting R&D and Technology Transfer networking among partners, in the field of Materials for Energy, with the purpose of creating a sustainable transnational network between public research institutions and also with industry in the Atlantic Area. CICECO is one of the eighteen entities involved and one of the seven key partners being leader of one of the main activities of the project: "Sharing and Cross-Referenced Running of Technological Platforms". (ENERMAT, 2010) This shows CICECO interest in the Energy thematic and, moreover, its interest to improve technical and scientific competences around this theme.

1.3 CICECO Competencies on Energy

CICECO is a very large lab and its researchers possess vast competences in several relevant fields being Materials the common link. Although several successful examples of technology transfer activities, a significant part of its research is more fundamental. Therefore, the identification of major technological developments which can be licensee opportunities requires a structured approach. The Energy field comprises several technical challenges which can be overcome through new materials development.

Aware of the importance of this thematic, CICECO strategically decided to identify and organize all its competencies in the Energy field. Doing so, CICECO identified four key energy areas which catalogue activities in progress and activities to be pursued, which are:

- Photovoltaic Cells & Lighting;
- H_2 Production and Storage, Fuel Cells and Batteries;
- Clean carbon based energy sources;
- Energy Harvesting (Thermoelectrics, Magnetocalorics, Piezoelectric Materials and Others).

CICECO is currently focussed in the identification, organization and structuring of its competencies in the Energy field. These competencies are sum-up in Table 6 and this information shows that, besides the activities in progress, CICECO also identified activities it considers to be important to pursue, in order to define future strategies towards energy technologies.

Table 6 - Main CICECO competencies on Energy thematic

Area	Activities in progress	Activities to be pursued
PV Cells	• ALD and/or CVD for various nano-structured semiconductor coatings, such as Ti or Zn oxide nano –rods suitable for dye sensitized solar cells; • Surface modification of TiO_2 NPs with metal sulphide nanophases; • Enhancement of light absorption in wide band gap semiconductor alloys; • Preparation and surface modification of ZnO nanostructures (spheres, nanowires and nanofibers) and carbon nanotubes for incorporations in P3HT based nanocomposites;	• Hybrid solar cells; • Improve PV cells light gathering efficiency; • Incorporation of trivalent lanthanide ions into hybrid solar cells to enhance the absorption both in the UV (down-conversion) and in the NIR (up-conversion); • Incorporation of inorganic NPs in TiO_2 to improve photon harvesting in the visible; • PV effect bared on nanoferroelectrics; • Optimization of wide bandgap-based solar cells; • Improvement of efficiency in hybrid solar cells, including encapsulation of anisotropic particles in block copolymers via using macroRAFT;
Lighting	• Light emission of organic-inorganic hybrids, silicates, nanocrystals and MOF's; • Applications of organic-inorganic hybrids in SSL; • Plasmonic and non-plasmonic enhancement of light emission in Semiconductor heterostructures; • Light emission of polyoxometalate based materials; • Ligand design for the improvement of light harvesting by crystalline MOFs;	• Metal-free organic-inorganic hybrid phosphor for smart LED-based lighting and LED-addressed displays; • Conception and design of LED structures based on wide band gap semiconductors using noble metals to promote light emission; • High efficient and tunable emission from materials based on lanthanide coordination compounds; • Computational prediction of promising organic ligands for highly photoluminescent MOFs.
H_2 Production and Storage	• Hydrogen storage (hydrides, etc.); • Carbon nanotubes; zeolites, MOFs, mesoporous materials ; • Electrolysis; • 3D support structures and catalyst design – the spillover approach; • Nanosize metal catalyst dispersion in 3D support structures; • Computer simulation; • Electrode materials for steam electrolysis;	• Hydrogen production; • Water electrolysis: electrodes and electrocatalysts; photoelectrochemically active electrodes; • High temperature steam electrolysis; • Synthetic fuel production; • Biogas Upgrading; • Intermediate temperature electrolysis; • Electrochemical H2-Storage;
Fuel Cells	• Materials for SOFC; • Improve performance and longevity of SOFC; • Conductors: Ceramic protonic, Hybrid and composite; • Electrocatalysts; • Computer simulation of ionic transport in solids;	• Polymeric fuel cells; • Alternative solid electrolytes; • Electrodes for fuel cells; • Computer modelling of electrode processes;
Batteries	• Scanning Force Microscopy Analysis of Charge/ion diffusion processes;	• Supercapacitors development; • Li-batteries and Li-microbatteries; • Alternative battery concepts and materials;
Clean carbon based energy sources	• Production and characterization of fuels and biofuels (Fossil fuels and Biogas, Bioalcohols, Biodiesel, Bio-oils…); • Spent Sulfite Liquor Saccharides conversion to 2^{nd} generation bioethanol; • Purification of biogas and natural gas (ionic liquids, MOFs, zeolites…); • Saccharides conversion into novel fuels; • Mixed conducting membranes for syngas production; • Computational Design of Materials for Adsorption and for Adsorptive Separation Processes; • CO_2 capture (cements); • Modelling of membrane reactors for energy-related processes with CO_2 capture.	• Second generation bioethanol for industrial implementation; • Bio-oils; • Biomass and coal gasification; • Syngas production and purification; • Electrochemical upgrading of biogas; • Computational Design of Materials for Adsorption and for Adsorptive Separation Processes - new approach based on theoretical design of nanoporous materials to suit a particular goal; • CO_2 conversion; • Development of functional MOFs for CO_2 capture and storage.
Thermoelectric	• Oxide thermoelectrics for waste heat recovery; • Modeling of thermoelectric properties of semiconductor materials. • Study of the influence of size and shape on the heat conduction; • Study of thermoelectric effects in mixed ionic-electronic conductors;	• Development of oxides with high figures of merit for thermoelectric applications; • Development of strategies to optimize design of efficient thermoelectric materials; • Establishment of "Golden Rules" for material selection and design; • Thermo-electrochemical converters;
Magnetocaloric	• Magnetocaloric thermal cycles and device design;	• New topic electrocalorics: oxides / polymers / multiferroic composites / hybrid systems;
Electrocaloric	• Electrocaloric materials with high efficiency	
Piezoelectric Materials	• Development of highly efficient lead-free materials for energy harvesting; • Bioorganic materials with high piezoelectric effect; • Lead free piezoelectric compositions;	• Piezoelectric prototypes for wasted energy harvesting on motorway. Implantable microgenerators for microdivices; • Lead free piezo harvesters;
PCM's	• Development of mortars with PCM; • Computational methods for heat transfer in PCM materials; • PCM-Carbon composites with enhanced thermal and electrical conductivities;	• Use of PCM to store energy obtained from solar cells; • Highly efficient photovoltaic devices based on ferroelectrics.
Others	• Shape memory alloys;	

V – Discussion

As a result of the analysis presented on Part II and in order to be able to analyse each thematic on energy and which are the best options for the future, Table 7 intends to summarise examples on benefits and disadvantages of each resource based, mainly, on economy, environment and sustainability. This discussion will be carried out following the topics availability, climate changes, safety and technological development.

Table 7 - Summary of some benefits and drawbacks of each resource and technology, resulting from the analysis of the Energy problem

		Main Benefits	Main Problems
Solar Energy		• largest availability; • does not generate unpleasant residues; • doesn't pollute environment; • GHG emissions are not significant;	• **low efficiency;** • **high initial cost;** • **conversion on low portions of the solar spectrum;** • occupation and competition on large areas of land; • **use of toxic materials in the manufacture of photovoltaic cells;** • visual impact on the rural environment and urban development; • potential bounded by geographical constrains.
Wind Energy		• does not generate unpleasant residues; • doesn't pollute environment; • GHG emissions are not significant; • wind turbines are built in short periods of time and provide greater adaptability in responding to electrical demand;	• **fatigue due to rotation;** • **corrosion on off-shore structures due to environmental adversity;** • noise and visual impact on landscapes; • diminishing of property value; • potential impacts to birds; • potential bounded by geographical constrains.
Hydropower		• does not generate unpleasant residues; • doesn't pollute environment; • GHG emissions are not significant; • highly developed technology.	• Impacts to fish habitat and loss of terrestrial habitat; • Dislocation of populations;
Ocean Energy		• does not generate unpleasant residues; • doesn't pollute environment; • GHG emissions are not significant;	• **Least mature of the renewable energy technologies;** • **Reliability on facing weather conditions;**
Geothermal Energy		• No significant air pollution; • GHG emissions are not significant;	• **accessibility to deep fluids;** • **extreme hot corrosion conditions of fluids**; • potential impacts to water resources; • seismic effect;
Bioenergy		• production of fuels from renewable sources; • lignocellulosic materials diminishes the pressure on food supply, requires less fuel, fertilizers and other inputs; • lignocellulosic is the earth most abundant carbon source, highly renewable and provides ample material for biofuels; • net GHG emissions can be reduced; • can be sustainable (it depends on agricultural practices and availability of water).	• Cost of producing biofuels today is often higher than current cost of imported oil (strong incentives needed); • pressure on food supply; • **aggressiveness of chemicals and catalysts for lignosellulosics;** • competition with other uses for land and water resources; • groundwater impacts from agricultural chemicals; • GHG emissions from biomass production and processing.
Nuclear Energy		• Non-CO2-emiting source of clean energy; • GHG emissions are not significant; • integration with renewables;	• Cost on nuclear power stations; • **safety and potential contamination from nuclear accidents;** • potential contamination of groundwater from waste disposal;
Fossil Energy	**Oil**	• High energy density of primary energy supply;	• **large GHG emissions;** • finite resource availability; • price change; • oil spills and explosions.
	Natural Gas	• High energy density of primary energy supply; • decrease on price; • availability on shale gas; • air pollution: small amounts of SO_x, and NO_x; • emits less CO_2 than oil or coal.	• **moderate to high GHG emissions;** • **extraction of shale gas;** • gas leaks and explosions.
	Coal	• High energy density of primary energy supply; • low price; • finite resource but widely available; • production of substitutes to oil;	• **large GHG emissions;** • mining impacts; • generation of unpleasant residues; • air pollution if controls not used (e.g., SO_x, NO_x, Hg).
	Fossil energy with CCS	• reduction in GHG emissions;	• **cost increment;** • unsafely storage; • potential groundwater impacts from migration of CO_2.

Note: In bold are highlighted some of the main problems which can be overcome with R&D on materials science

Given the finite supply and the scarcity of fossil fuels, availability has become a major criterion when decisions must be made in order to select future energy sources. Therefore, when the criteria is the availability of resources, renewables, coal and nuclear, show the highest potential of being massively used in the future.

On the other hand, climate changes and GHG emissions are, also, relevant criteria to consider and, once more, fossil fuels are not the most convenient choice, since this energy source is largely responsible for CO_2 emissions. Thus, in this case, the best choices are renewables and nuclear.

Regarding safety, nuclear is definitely not a good choice along with fossil fuels and, once again, renewables are ahead.

Technological development is most evident in the case of technologies linked to fossil fuels, nuclear and hydropower, with other renewables having the need to increase their technological maturity in order to become a better choice.

Renewables are the best choice of all options except when it comes to technological maturity. In this case, renewables must become mature technologies in order to increase efficiency at a lower cost. Also, if the availability of coal and nuclear sources is to be taking into account, then carbon capture and storage must become more cost effective and nuclear must become more safe and environmental friendly.

In all this cases, R&D on materials science is one of the best means to achieve technological breakthroughs that are determinant to overcome the main drawbacks of each energy source. Some of the main problems which can be overcome with R&D on materials science are highlighted in bold in Table 7, mainly those related to efficiency, cost and durability.

With the existence of critical mass of specialized researchers and with the development of initiatives to promote the transference of knowledge to industry, the universities are well positioned to address technological innovation.

All over Europe several initiatives of engagement of research centres with industry in the energy field exist, namely, the European Technology Platforms (ETP), the European Industrial Initiatives (EII) and the Knowledge and Innovation Communities (KIC).

In the case of ETPs, several are directly linked to the energy field and some are transversal to other areas. Their main objective is to define medium to long-term research and technological objectives and developing roadmaps to achieve them being one of the key roles to ensure that sufficient funds are directed towards areas with a high degree of industrial relevance. EII were launched in the context of the SET-plan technology roadmaps, therefore, totally towards energy field and allow the public and private sectors to jointly develop technology roadmaps. These roadmaps are essentially focused on research, development and demonstration programme and they include specific R&D programmes in several areas in the energy field, namely, on materials science. InnoEnergy (sustainable energy), one of the three KIC initiatives, aims at providing new and concrete solutions to all intervenients, therefore, its strategy relies on three concepts: innovation, education and technology. Not only it works the link between research and industry but, also, it is involved in high-level education programmes in the field of energy.

At OCDE level there is the International Low-Carbon Energy Technology Platform which is also directly and exclusively linked to the energy field. Like ETPs, it is a forum that promotes activities and the share of policy-related information among stakeholders interested and willing to help accelerate the spread of low-carbon energy technologies.

All of these structures provide important strategies in order to overcome the main energy problems, either by the definition of policies or by the establishment of technological roadmaps.

In order to devise major trendlines for research a bibliographic analysis on materials R&D was carried out based mainly on the documents Europe 2020 (EC, 2010b) and SET Plan (EC, 2009a) including its roadmap (EC, 2009c). Figure 35 summarises the strategy behind the analysis carried out in this dissertation, in order to select the areas to explore and present the main challenges for materials science.

In this case, the objectives for 2020 set by the European Council in 2007 (EC, 2007a) and supported by the flagship initiative "Resource efficient Europe" of the Europe 2020 Strategy (EC, 2010b) are on the base of the European energy strategy and, in order to address the seven major challenges highlighted in Figure 35 the following energy areas were selected: Solar Energy, Wind Energy, Bioenergy, Nuclear Energy, Carbon Capture and Storage (CCS), Energy Efficiency: Lighting, Buildings, Industry and Transport, Electricity Grid, Energy Storage: Batteries, Supercapacitors and Hydrogen, and Fuel Cells. Therefore, other energy areas not within these seven major challenges, were not discussed.

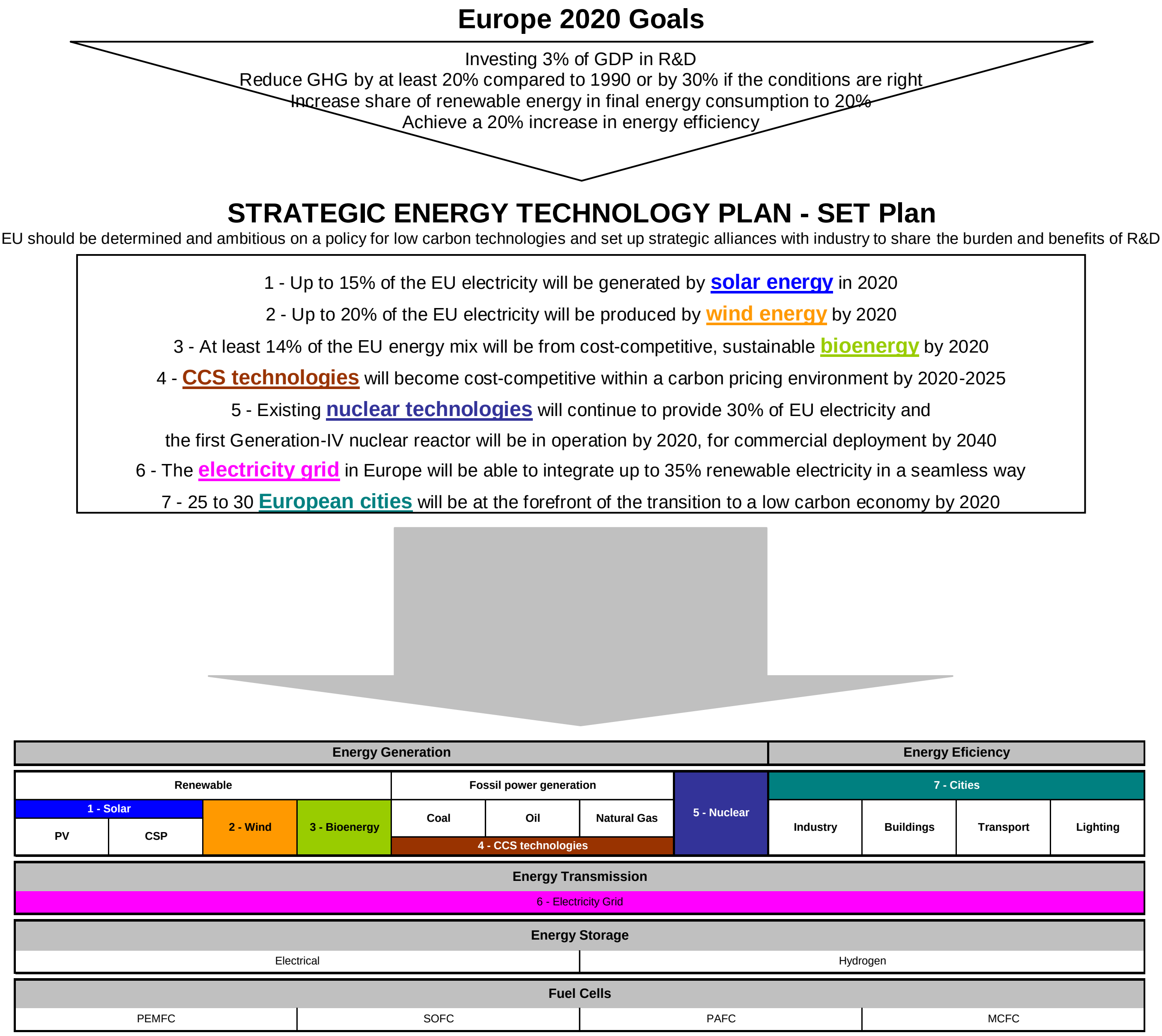


Figure 35 - Strategy to present the main challenges for Materials Science

The next step was to mach the results obtained by the bibliography analysis regarding to the main challenges for materials R&D and CICECO research activities and existing competences.

The results are organized and presented by the same order as they are presented in Figure 35, and Table 8 summarizes these results.

Table 8 – Summary of main challenges on materials R&D to address Energy main problems

Area		Main general challenges	Opportunities for R&D on Materials Science
Solar Energy	PV	• Materials toxicity and cost; • Reflection and capture of the full spectrum of sunlight: novel nanoscale surfaces; • Manufacturing costs and efficiency; • Lifetime (aging issues): new protective materials for longer-term stability; • Recycle solar system materials at end-of-life; • Thermal Photovoltaics (TPV); • Concentrator solar cells (CPV) with very high efficiencies;	• Waffer-based crystalline silicon: new and improved materials for all parts of the manufacturing chain, including encapsulation; • Thin films technologies: - a-Si/µc-Si Solar Cells: high-quality low cost transparent conductive oxides (TCOs), better understanding of material properties, on light trapping and on the fundamental limits; - CdTe: better fundamental knowledge of materials; - CuIn(Ga)Se_2 (CIGS): alternative/modified material combinations, of process alternative like roll-to-roll coating and of combined or non-vacuum deposition methods; • Organic-Based PV: - dye-sensitized solar cells: inexpensive materials like TiO_2 – semiconductor, improved and stable sensitizers, solid electrolytes, encapsulation to ensure lifetime; - polymer solar cells: improved and stable polymers, stabilization of nanomorfology; • Advanced inorganic thin films deposition technology on spheral CIS and improving poly-Si electronic quality, deposition upscaling; • Cell types for TPV: germanium-based cells to advanced ternary and quaternary alloys incorporating the elements: gallium, antimony, indium, arsenic, aluminium. • CPV cells: High-efficiency silicon or III-V- compound multilayer cells; • Novel PV Technologies – Nanotechnology (basic material development).
	CSP	• Durability and cost: improve optical materials for reflectors; • Solar absorbance and thermal emittance: enhance absorber materials and coatings; • Thermal energy storage materials with improved heat capacity; • Corrosion resistance of materials in contact with molten salts;	Storage: •Evolution of molten salt storage technology (cost, reliability performance, flexibility and safety); •Develop alternative storage concepts for other molten salts and heat transfer fluids (steam, gas); •Phase Change Material (PCM);
Wind Energy		• Lighter and stronger blades (high strength materials that resist corrosion and fatigue); • Sensors included in turbine blades to continuously monitor fatigue damage and signal the need for repair; • Solutions for the gearing efficiency;	• High-strength composites such as carbon fibre-reinforced plastics; • Fibres with a one-part or two-part resin (self-healing approach); • Recycling methods for materials;
Bioenergy		• Biofuels development focused on non-food feedstocks; • Aggressive chemical processes and catalysts for breaking down cellulose and materials with long lifetimes to contain and manipulate these corrosive chemistries; • Catalytic materials for conversion and special chemical routes for the production of hydrocarbon chains from cellular membranes in algae;	Thermochemical processes (lignocellulosic material): • Syngas as intermediary to liquid fuels and chemicals; • Bio-methane and other gaseous fuels from biomass via gasification; • Co-processing of Biomass and bioenergy carriers with petroleum oil, via other thermochemical processes, e.g. pyrolysis, torrefaction etc. Biological and chemical processes for conversion paths: • Ethanol and higher alcohols from sugars containing biomass; • Renewable hydrocarbons from sugars containing biomass via biological and/or chemical process; • Production of bioenergy carriers from CO_2 & sunlight through micro-organism based production (algae, bacteria etc.).
Nuclear Energy		• Fuel handling, fusion, fission and radiation damage as well as decommissioning and storage; • New classes of structural materials capable of operating at temperatures 700°F higher than that of today's light water reactors; • Advanced computational materials performance modelling tools; • New materials to contain nuclear waste for geologic life times; • Proliferation resistant nuclear fuel through advances in ceramics and coatings technology;	• Sustained R&D mainly on refractory alloys, composites, ceramics, low activation steels, and coatings and the related processing technologies; • Understanding of long term pressure vessel steel behaviour, corrosion resistant nickel base alloys, dimensionally stable zirconium fuel cladding and uranium oxide fuel pellets; • Structural materials: Steels, Alloy steels, Superalloys, Ceramics, Composites, Coatings; • Functional materials: Filters, Active carbons; • Multifunctional materials: SHM materials for remote robots, Self-repair materials, SMART materials;
Carbon Capture and Storage		• Advanced materials and coating techniques to allow operation of steam cycles at higher temperatures and pressures; • Oxygen ion selective ceramic membranes; • High temperature metals with associated welding and forming procedures;	• Solvents (Absorp.) – Physical/chemical solvents (amines, ionic liquids); • Membranes - Polymeric; • Solid Sorbents - Zeolites, activated carbon, alumina; • Emerging Technologies: - Solvents (Absorption) - Biomimetic solvents, e.g. hemoglobine derivatives, chemical solvents; - Membranes - Ceramic, Carbon, ion transport, Palladium; - Solid Sorbents - Carbonates, Carbon based (MOF's), Adsorbents, Perovskites, Oxygen chemical looping, Hydrotalcites, Silicates.

Note: In blue is highlighted the matching between CICECO competencies and results from bibliographic analysis

Table 8 – Summary of main challenges on materials R&D to address Energy main problems (cont.)

Area	Main general challenges	Opportunities for R&D on Materials Science
Energy Efficiency – **Lighting**	• Improvement of LED system efficiency while simultaneously decreasing the SSL lamp cost : - high-efficiency, visible, solid-state emission at high current density and temperature; - white emission through wavelength conversion; - OLED materials and structures for reliable, colour-consistent, high- luminance emission • Inorganic LEDs - next generation of lighting more efficient, nontoxic source of white light at a reasonable cost.	• LEDs: - increase efficiency of green LEDs; - increase efficiency of blue and near-UV LEDs; - dislocation reduction; - nonpolar and semipolar GaN; - improved p-GaN; - novel wide-bandgap semiconductors; - novel phosphors. •OLEDs: - development of a fundamental understanding of the molecular interactions among OLED hosts, guests, interfaces, impurities, contacts, and environmental agents such as oxygen and water; - systematically determine the mechanisms that limit OLED device reliability, and its dependence on the energetics of the materials and relationship to emission wavelength.
Energy Efficiency – **Buildings**	• Materials capable of storing or releasing large amounts of energy in the walls, floor and roof; • Optical metamaterials and photonic crystals potentially enabling optical engineering using structured inorganic nanomaterials to positively influence the solar gain and provide long term durability; • Electrochromic, suspended particle and liquid crystal glasses responding to occupants and external conditions to actively control both light and solar gain; • BIPV – polymer solar domestic hot water systems and combined PV/thermal solar systems	• Phase Change Materials; • Window glazing - new materials to replace electrochromic tungsten: Vanadium dioxide (VO_2); Tungsten trioxide (WO_3); Nickel oxide (NiO); Nanotechnology-based solutions in conjunction with or in place of conventional multilayer thin film processes; • On opaque envelope materials: - New thick film/thin film manufacturing approaches; - New coating processes, such as liquid phase or spray deposition; - Biomimetic approaches - functional designs and new approaches on fabrication of high-performance optical and thermal control structures.
Energy Efficiency – **Industry**	• Cost effectively reducing carbon dioxide (CO_2) and other criteria pollutants; • Corrosion-resistant alloys for high-temperature power conversion, decreasing maintenance and increasing efficiency; • Advanced power handling electronics; • Power plants utilizing renewable fuel, will require advanced materials with specific requirements for corrosion resistance (aqueous & high temperature), light weight technologies (composites, plastics) and environmental coatings;	•development of advanced high temperature materials (steels, superalloys and composites); •Intermetallics (SMA)
Energy Efficiency – **Transport**	• Alternative fuels with low carbon generation; • New energy storage systems; • New generation of motors for automotive: hybrid, electrical, fuel cells; • Lighter materials which satisfy rigorous safety, durability, manufacturing and cost criteria; • waste-heat-recovery technologies based on thermoelectric devices.	•Advanced High Strength Sheet Steels (AHSS) developed to enable low cost crash-resistant vehicle structures to be manufactured with reduced sheet thickness and vehicle weight; • Light metal developments and application of new aluminium, magnesium, titanium alloys, etc.; • Carbon fibre composites may also play an increasing role; • Thermoelectrics: narrow-bandgap semiconductors, oxides, cage-structure materials, nanocomposites.
Electricity Grid	• Higher performance power electronic materials; • Superconductor materials for underground transmission and for increased power density and performance in generators, motors, and fault current limiters; • Electrically insulating materials with improved dielectric and thermal properties; • Novel composite electrical conductors for high-temperature, low-sag overhead transmission lines;	• Low conductivity materials and with high dielectric breakdown including copper and copper-aluminum alloy conductors; • Existing and new superconductors; • Glass, air, vacuum and new insulators; • yttrium barium copper oxide (YBCO) films - coated conductors; • Structural materials: Ceramics, Polymers composites; • Functional materials: Piezoelectric materials, Superconductors;

Note: In blue is highlighted the matching between CICECO competencies and results from bibliographic analysis

Table 8 – Summary of main challenges on materials R&D to address Energy main problems (cont.)

Area		Main general challenges	Opportunities for R&D on Materials Science
Electrical Storage	Batteries	• Power density and cost; • Safety and corrosion due to high operating temperatures; • lithium-ion batteries new cathodes, non-flammable electrolytes and anodes; • sodium batteries: finding low-temperature electrolytes with high-sodium ionic conductivity. Sodium anodes can operate with a variety of cathodes, including sulphur and transition metal halides such as nickel/nickel chloride; materials for overall battery performance as an integrated system of all components.	•Li-ion battery: - electrolytes: $(Li(Ni,Co,Al)O_2$ derivative; Layered alloys of $Li(Ni_xCo_{1-x})O_2$; Lithium manganese spinel $(LiMn_2O_4)$; - cathodes: Lithium phosphates: $LiFePO_4$, $LiMnPO_4$, $LiCoPO_4$; - anode: Silicon; Carbon nanotubes; $LiTi_{15}O_5$; $LiTi_2O_4$; Cupric oxide (CuO); Titanium dioxide (TiO_2); Tin dioxide (SnO_2); Grapheme • New electrolytes: boron salts - $LiB(C_2O_4)_2$ (LiBOB) and $LiBH_4$, polymer electrolytes, ionic liquids; • On sodium batteries: - lower operating temperatures require tuning the properties of the standard electrolyte beta-alumina (Al_2O_3) with additives to get adequate ionic conductivity. Nanotechnology - nanoporous material, carbon nanotubes, ceramic nanoparticles;
	Supercapacitores	•Energy density and cost; • reducing plate separation and also by increasing the plate- specific surface areas via the use of high-surface-area carbon electrodes.	• Electrode - development of nanostructured carbons and controlled-porosity polymers; • New electrolytes: boron salts - $LiB(C_2O_4)_2$ (LiBOB) and $LiBH_4$, polymer electrolytes, ionic liquids;
Hydrogen Storage		• cost of hydrogen (production and delivery – must be competitive with conventional fuels); • inexpensive, long-lived materials for pipelines; • lightweight materials for storage tanks on cars; • storage material to satisfy high hydrogen volumetric density, reversibility of the release/charge cycle at moderate temperatures and fast release/charge kinetics; • low-cost materials resistant to hydrogen-assisted cracking and embrittlement;	• Reversible metal hydrides; • Carbon-based Materials or High Surface Area Sorbents - better understand the mechanisms and storage capabilities - Metal-carbon hybrid systems (MOF's,...); • Chemical Hydrogen Storage - hydrolysis reactions, hydrogenation/dehydrogenation reactions, and several new chemical approaches; • New materials and processes - Polymer structures; •Structural materials: Steels, Alloy Steels, Composites; • Functional materials: Carbon nanostructures, Activated carbon membranes;
Fuel Cells	PEMFC	•Lower-cost material alternatives: - alternative membranes and catalysts; - reduction of the complexity of an integrated system; - increase power density; • System development and efficiency: - heat , water and power management; - cathode stability; - systems with reformer – 40%, H_2-fuelled system - 50%. • Most important: - Promoting the oxygen reduction reaction at the cathode; - Proton exchange membrane.	• Replace platinum catalysts with: - Platinum alloys; - platinum-shell/affordable-core materials; - faced nanostructures such as platinum-nickel alloy $(Pt_3Ni\ (111))$; • Pt-free catalysts;
	SOFC	•Costs and lifetime; • Materials degradation and failure due to high temperature cycling - Lower operating temperature: down to 600-800°C; New anode and cathode materials and new electrolytes for lower temperatures;	• new electrolytes with higher ionic conductivities for lower operating temperatures, with structures in: Fluorite, oxygen-deficient perovskite, pyrochlore, apatite, scheelite families; • reduce electrolyte layer thickness;
	PAFC	• lifetime; • cathode stability; replace phosphoric acid electrolyte, while retaining low-vapour pressure and thermal stability;	• Proton conducting materials operating in the 170° to 190°C range that do not adsorb on Pt; • Isolate and understand mechanisms of Pt dissolution and coarsening as a function of temperature and potential.
	MCFC	•electrocatalysts to be used on the severe oxidizing conditions present at the cathode; materials degradation and failure due to high temperature cycling;	•Search for cathode materials with slower dissolution in the molten electrolyte: - coating cathode with an anti-corrosive protective layer; - doping nickel oxide to slow down dissolution; - trying new materials such as lithium cobalt spinel (LiCoO2); •New cathode materials: lithiated transition metal oxides.

Note: In blue is highlighted the matching between CICECO competencies and results from bibliographic analysis

Comparing the information presented in Tables 6 and 8, it is possible to find significant matches in most areas (highlighted in blue). So it is possible to conclude that research activity is being developed within CICECO in most of the energy areas, and it is significantly aligned with the strategic areas identified as the main Materials challenging areas in the Energy field.

Following the proposed matching, there are specific scientific and technical competencies well identified within CICECO in most of the energy areas like Bioenergy, Carbon Capture and Storage, Lighting, Proton Exchange Membrane Fuel Cells and Solid Oxide Fuel Cells. Moreover, there are some areas where it is possible to identify relevant competencies but, due to its transversal applicability, they do not appear in a distinct area. One example of this is Piezoelectric materials which have numerous applications, namely they may play a very relevant role on energy harvesting.

In areas, like photovoltaics, electrical storage (batteries and supercapacitores) or hydrogen storage, research activities were identified as important to pursue in a near future and there is a clear intention to give them more attention, proven by the several activities to be pursued and the analysis performed on Table 8 may be useful in the definition of research lines. In the specific case of Photovoltaics CICECO has identified some competencies but recognises that much more should be done, having already identified more specific activities to be pursued in the near future.

In areas like CSP - Concentrated Solar Power (solar energy), wind energy, nuclear energy, electricity grid, it was not identified any research activities within CICECO, although there are specific technical and scientific competences that may be useful for the development of innovative solutions in those areas. For instance, the CICECO “Surface Engineering and Corrosion Protection” research group that studies new materials with self-healing properties and protective coatings which can be important for wind and nuclear energy.

Also in areas of energy end use like buildings, industry, transport CICECO has R&D and competencies which could eventually be applied to one or more of these areas, but further analysis and research needs matching should be done in order to identify future complementarities.

VI – Conclusions

Population growth and economic development is leading to a rising in the global demand for energy with consumers in developing and emerging countries using products which consume increased amounts of energy. The nuclear disaster in Japan has raised the concerns and fears around the lack of security of this source of energy in most countries around Europe questioning on the maintenance of their power plants leading to the increasing of demand for other sources of energy. Also, the risks of failure on oil supply were never so high being expected that the crude oil price remains high over the next few years.

As science evolves and more discoveries are done every day, it is difficult to actually define which energy technologies will be the best suited and which will be the less. The best way to deal with this problem, and choose the best approaches, might be to better understand the energy system and geographical advantages.

There is not a single solution for the energy problem and this is a big challenge. It is important to understand that no single technology can meet the world's energy needs. Therefore a combination of many technologies is required. This problem can only be overcome by combining different solutions which include improvements in energy efficiency and systematic deployment of the various technologies but any strategy for the future must take into account not only the potential of different energy sources, but also the penalties that each originates.

There are aspects of the environment and security to be taken into account. Of course we also need to consider the costs of each energy source, but we must not forget that these costs also depend on the costs of the pollution prevention and reduction of risks of accidents.

Coal and nuclear sources are still largely available and renewable resources are by definition infinite, therefore when it comes to make a decision taking availability into consideration, renewables are the best option, along with coal and nuclear. But there is the drawback of intermittence and general lack of technological maturity in renewables, CO_2 emissions in coal, safety and environmental issues in nuclear. When it comes to choose regarding climate changes, the choices rely on renewables and nuclear energy but, once again, there are the problems of intermittence in renewables, security and environment problems in nuclear energy.

Renewables are the natural choice when it comes to decide based on availability, safety and environmental friendly but, excluding hydropower, in order to reach technological maturity, renewables must overcome big challenges on technological development.

Among renewables, solar energy is the most promising source of energy. With the large availability of all primary energy resources, solar is the renewable energy source which needs more efforts on technological breakthroughs, since it constitutes the most inefficient of all renewable technologies and it is, also, the one which is less cost effective, leading to a small contribution in the world total primary energy supply of less than 1‰.

Also, to continue choosing coal as a sustainable source of energy, technical breakthroughs must be carried out towards less expensive carbon capture and storage technologies and safer CO_2 storage. In the same way, nuclear energy needs technologies which improve safety and environmental drawbacks.

Energy efficiency is a central issue in the EU's Europe 2020 Strategy, being one of the most cost effective ways to enhance security of energy supply, and to reduce GHG and other pollutants emissions. In transport, buildings and industry, opportunities for technological breakthroughs should be turned into business opportunities. This is why the EU has set a target for 2020 of saving

20% increase in energy efficiency, and why this objective was identified in the Energy 2020 as a key step towards achieving our long-term energy and climate goals.

Lighting uses one-fifth of electricity generation output and it is also extremely inefficient. Incandescent light bulbs convert about 5% of the electricity they use into visible light. Most of the household utilities are more efficient and, therefore, energy savings from lighting have more potential than most other utilities.

Buildings are responsible for about 10% of global CO_2 emissions and the percentage increases approximately 30%, if the direct emissions from electricity use in this sector are included. More than a half of the existing buildings are still standing in 2050 and this leads to a conclusion that configuration and acquisition of new technologies to the current buildings will be important in order to achieve better energy savings and less potential CO_2 emissions.

Regarding the energy use in industry it is important, in the near future, for new industrial plants to be built with the best technologies available to improve energy efficiency and, consequently, reduce energy consumption. Another important feature in the industrial power plants is the need to reduce CO_2 emissions and it is, therefore, imperative to improve carbon capture and storage technologies in order to make them cost effective and improve safety on CO_2 storage.

Transportation is responsible for most energy consumed both in Portugal and in Europe Union and this sector is currently responsible for 22% of CO_2 emissions worldwide. In order to reduce the CO_2 emissions until 2050, it will be necessary to decrease the rhythm of growth in the use of fossil fuels in transportation and this can be achieved through higher energy efficiency and the use of technologies with low carbon generation. This is possible through the use of lightweight and hybrid vehicles and this calls for technological improvements on electrical and hydrogen storage and, also, on fuel cells.

As a result, all these kind of challenges increase the need for R&D towards market deployment and materials science is one of the most important areas which can play a major role in further development of emerging solutions.

The EU directives are defined taking into account political, economical and environmental issues, and industry needs, as a result of their consultation and after analysing outputs from joint structures between stakeholders (research institutions and companies). As a result, the areas presented to analyse R&D on materials science are all the areas EU identified as necessary in order to meet Energy challenges and industry needs.

Strategic partnerships with industry and interdisciplinary R&D on materials may be among the best strategies to overcome the energy challenges. Universities play a role in the establishment of these partnerships with CICECO being is in a great position to address these challenges.

Universities have developed several initiatives to promote the transference of knowledge to industry and technology transfer offices (TTO) are the vehicles by which the university moves technology generated from university research into the public domain. Universities have intensified activities to impact social development and economic growth and it is expected that they continue their social and technological innovation.

All over Europe there are several approaches which exist for engagement of basic scientists with industry in the energy field, namely, European Technology Platforms, European Industrial Initiatives and Knowledge and Innovation Communities.

To support further developments of research activities within the energy field, CICECO should also continue to promote international collaborative research projects to boost competences and have access to specific technical facilities.

The analysis performed in this dissertation, on the main areas of R&D in the energy field, was based in European strategic documents which are also in the base of the specific research subjects in the energy theme of framework programme. This programme open several calls a year which are important opportunities to developed collaborative research with other relevant European research institutions and industry. Therefore, with CICECO competencies being in alignment with the strategies outlined in result of European strategies, it is possible to say that CICECO is in a good position to access these funds in order to support its research activities.

Moreover, the establishments of links with European initiatives like the technological platforms are also important initiatives to promote research and furthermore contacts with relevant companies that operate in the energy field.

CICECO already has well defined strategies to transfer its knowledge to companies. CICECO is currently focussed in the organization and structuring its competencies in the Energy field and has now a more accurate perspective of its competencies in this field.

For a future action CICECO has now tools to define an integrated strategy of collaborative research with the industrial sector to fully develop all its potential in this field.

It could be interesting for CICECO to carry out further analysis in order to evaluate which technologies are closest to commercial applicability and those that may show opportunities for technology transfer. It could be important to approach companies in order to better understand their main R&D interests and try to validate the main challenges and activities to pursue in a near future.

In summary, it is possible to say that CICECO is well positioned for addressing major research needs regarding materials for energy, either by its activities already in progress or by the activities that CICECO intends to pursue. Nevertheless, further analysis has to be made in order to evaluate effective and/or possible applications regarding the competencies identified as well as which technologies are closest to commercial applicability and those that may be opportunities for technology transfer.

VII - Evolution perspectives and future work

In a following step and to specifically evaluate the effectiveness of the CICECO positioning in the energy field, it could be interesting to evaluate effective and/or possible applications regarding the competencies identified, as well as, to analyse its positioning towards market deployment. This could be done by inquiring companies on their main R&D interests in order to, also, validate the main challenges identified.

It could also be interesting to identify companies that are in alignment with the strategic areas within CICECO creating symbiosis in each one of these areas in order to foster collaborative research and joint projects.

This work presents a methodology which allowed the development of a matrix that cannot only be used by CICECO but may as well be applied to other research centres or other types of institutions, in order to establish alignment of activities with European strategies on the Energy field and to devise strategies for future actions.

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