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A European Strategic Energy Technology Plan (SET-Plan)

TECHNOLOGY MAP

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A Technology Map
for the European Strategic Energy Technology Plan

1. INTRODUCTION

The Technology Map is a brief and comprehensive description of the current status and prospects of key energy technologies aiming to provide information for the identification of potential European initiatives that could be considered as part of a European Strategic Energy Technology Plan (SET-Plan). This is achieved by assessing the potential of a set of technologies and the barriers and needs for their further development and deployment, highlighting the role of energy technology innovation in support of achieving the EU energy policy goals. The information included in the Technology Map is planned to be revisited and updated regularly.

The focus of this document, which constitutes the first version of the Technology Map for a European Strategic Energy Technology Plan, is primarily on energy supply technologies. The potential of demand-side measures has already been identified in the 'Energy Efficiency Action Plan' – COM (2006) 545. It is the intention of the authors to address demand-side technologies in detail in the next update.

The Technology Map addresses the following technologies:

- Power and Heat
  - Wind power generation
  - Solar photovoltaic power generation
  - Concentrated solar power generation
  - Solar heating and cooling
  - Hydropower generation
  - Geothermal
  - Ocean wave power generation
  - Cogeneration of heat and power
  - Zero emission fossil fuel power generation
  - Nuclear fission power generation
  - Nuclear fusion
- Energy Infrastructures

    - Electricity networks (Smart Grids)
- Transport
    - Biofuels
    - Hydrogen and fuel cells

Other technologies that are critical for the transition to and operation of a more sustainable energy system, such as electrical and hybrid vehicles, energy storage, etc. will be addressed in the next update of the technology Map.

The Technology Map describes for each technology:

- The current status and the anticipated technical developments,
- The current and future share in the European energy demand,
- The quantified impacts of technology penetration on:
    - Greenhouse gas emissions, measured through quantities of CO_2 avoided,
    - Security of supply, through quantities of fossil fuel saved,
    - Competitiveness, through changes in the overall cost of energy production due to the penetration of the technology,
- Barriers to penetration in the European energy market,
- Needs to realise its potential,
- Synergies with other technologies and sectors.

The information used for this Technology Map is drawn from the JRC analyses and technology reviews as well as from the Expert Workshops and Hearings organised for each technology in the course of spring 2007, in the context of the preparation of the SET-Plan Communication.

A synopsis of the outcome of the assessment of these technologies can be found at the end of this document.

2. METHODOLOGY

The quantification of the effects of the penetration of the different technologies considered in the Technology Map on the EU energy policy goals is made following a common assessment framework. The methodology comprises the following steps:

1. the establishment of penetration levels for each technology according to the baseline scenario, which is considered as a business-as-usual,
2. the assumption of two distinct penetration scenarios for each technology that represent alternative views of market potential,

3. the evaluation of the effects of the additional to the baseline penetration of each technology individually through four indicators, namely, CO_2 avoided, carbon mitigation cost, fossil fuels saved, and changes in the overall production cost of the energy carrier that the technology produces (electricity, heat, or transport fuel).

It is stressed that the assessment is not made at the energy system level. Consequently, the impacts of the various technologies cannot be added up since it is not feasible that all technologies achieve the envisaged maximum potentials simultaneously. In addition to physical and technical constraints of the energy system, social and consumer acceptance is an important barrier for the deployment of a number of technologies. Furthermore, the reported values do not represent the total contribution of a technology but the differential contribution compared to the baseline. The time horizon considered for the assessment is 2030.

A key assumption of the assessment framework is that all technologies considered replace their fossil fuel based conventional counterpart technologies that produce the same energy carrier. For example, wind and ocean energy substitutes electricity from fossil fuel power plants; solar heating systems replace boilers fuelled by oil or gas; and hydrogen and biofuels replace conventional gasoline and diesel.

2.1. The baseline

The 2007 update of the "European Energy and Transport Trends to 2030" is used as the baseline for the assessment. The following information was extracted, and in a limited number of cases estimated, from the baseline: gross electricity, heat and transport fuel consumption; fuel mix for the generation of heat and electricity; CO_2 emissions of the power and transport sectors; and energy costs (cost of primary energy sources, production cost of electricity and heat, and transport fuel cost at the pump[1]).

2.2. Input

The primary technology-specific information feeding to the analysis includes market shares over time, production costs, and CO_2 emissions generated by the technology per energy output considering its life cycle. This information has been obtained from:

- The reports of the SET-Plan hearings and workshops,
- Impact assessments, namely of the sustainable fossil fuels Communication and the RES roadmap of the Energy Package,
- JRC in-house data,
- The results of relevant EC co-funded projects through the Framework Programmes.

It should be stressed that due to uncertainties in technology-specific information (e.g. capital and operating current and future costs, regional costs and operating conditions, future market penetration) the results for each technology should be treated as indicative and relative estimates.

1 Especially for the evaluation of the hydrogen and fuel cell technologies, the annual cost of passenger cars per distance driven (fuel and vehicle expenditure) is considered.

2.3. Output

The four indicators are calculated as follows:

1. Annual CO_2 emissions avoided: This indicator is calculated by multiplying the additional energy generated by the technology annually, with respect to the baseline, with the difference between the specific CO_2 emissions of the baseline technologies that are replaced and the specific life cycle emissions of the technology under review.

2. CO_2 mitigation cost: This is derived by dividing the incremental generation costs caused by the penetration of the technology in the baseline scenario with the annual CO_2 savings (see indicator 1). The incremental generation costs are calculated by multiplying the amount of additional energy generated annually by the technology with the difference between the cost of the energy carrier produced by the technology and the baseline cost for the same carrier.

3. Fossil fuel savings: The value of this indicator is equal to the quotient of the additional energy produced by the technology by the efficiency of the conventional fossil fuel technologies it replaces taking into consideration the fuel mix.

4. Additional cost of energy: This indicator reflects the change in the overall cost of production of the energy carrier in the baseline caused by the penetration of the technology considered. It is however understood that this indicator only partially reflects the cost competitiveness of each individual technology as it depends on market shares. It is calculated according to the following formula:

$$\frac{x \times COE_T + (1 - x) \times COE_{BL}}{COE_{BL}} - 1$$

where:

x is the additional share of the specific technology in the baseline gross consumption of the relevant energy carrier;

COE is the production cost of the energy carrier; T as a subscript refers to the technology considered and BL refers to the baseline cost.

Cumulative values of the indicators 1 and 3 and average values for indicator 2 for the 2010–2030 period are also calculated and reported.

3. WIND POWER GENERATION

3.1. Technological state of the art and anticipated developments

Modern wind power technology is largely based on know-how gathered from European RD&D and deployment activities related to inland (onshore) wind energy. Onshore, wind energy is a mature technology. Ongoing R&D efforts are primarily focussed on maximizing the value of wind energy and taking the technology offshore. Capital investment costs for wind generation plants are of the order of €1000 to €1200 per kW for onshore technology (inclusive of grid connection costs), and €1200 to €2200 per kW for offshore (exclusive of grid connection costs). Typically, average capacity factors for wind power installations are 1,800-2,200 full-load hours onshore and 3,500-4,000 full-load hours offshore.

The main technological development in recent years is a trend towards ever larger wind turbines (WTs). Since the first commercial WTs of the 1980s, WT size has evolved from 0.022 MW to multi-MW machines of about 6 MW today. Currently the average turbine size in the EU is around 1.3 MW onshore and 2.1 MW offshore. By 2030, average turbine sizes of 2 MW and 10 MW are expected for on- and off- shore respectively, with gigawatt (GW)- size wind farms likely for offshore. The recent push in scaling-up of turbine size is driven primarily by the move to take the technology offshore, as higher wind speeds and wind energy generation can be reached here. Moreover, the move is important as fewer suitable onshore sites are available due to land constraints. The further upscaling of wind turbines leads to new challenges in the field of load control and wind turbine construction materials. Moving offshore has also meant increased technological focus on foundations and materials adapted to the marine environment. In the near term, continued wind deployment will need to be accompanied by developments in storage technologies and increased grid flexibility, to be able to accommodate increasing levels of wind energy penetration in the electricity network.

3.2. Industry status and potential

Onshore technology currently constitutes the majority of installed wind capacity; however, deployment off-shore is steadily growing and is expected to constitute 50% of EU installed capacity in the long term. Today, installed wind capacity in the EU is about 50 GW, contributing 3% to European gross electricity consumption. On average installed wind capacity has grown at a rate of 25% per year over the last few years. Wind is expected to be one of the main contributors of electricity production from renewable sources (RES-E). The installed capacities of wind for the EU-27, assumed in the baseline, are: 120 GW in 2020 and 148 GW in 2030. The estimated maximum potential for wind in the EU-27 is up to 180 GW by 2020 and 300 GW by 2030. This represents about 11 % and 18 % of projected EU gross electricity consumption by 2020 and 2030 respectively. After 2030, the contribution of wind energy to EU electricity consumption is expected to stabilise, with market structure shifting from additional capacity to replacement capacity.

With respect to the global wind energy scene, the EU is one of the front-runners in innovation and is a lead player on the market. Two-thirds of the global installed wind capacity is located in the EU, and seven of the top ten wind turbine manufacturers are located in Europe, accounting for 80% of the global market. Wind energy is also experiencing a surge in emerging economies, such as India and China, and is finding use in developing countries in non-energy sectors, such as water desalination.

3.3. Impacts

3.3.1. Carbon Dioxide Emissions

If the maximum potential is realised, wind energy could potentially avoid an additional 100 Mt/year CO_2 in 2020 and 250 Mt/year CO_2 in 2030. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be an additional 2400 Mt CO_2.

3.3.2. Security of Supply

Increased generation from wind will partially avoid the need for new fossil fuel-based plants for meeting electricity demand needs. At the same time, increased wind energy in the electricity system can mean increased use of reserve power (and possibly even additional reserve capacity), as a result of the unpredictability of wind energy generation. As reserve power is largely fossil-fuel based, this would result in a decrease in the net avoided fossil fuel use. This is however, not expected to be an issue at wind energy penetration levels below 20%. Achieving the maximum potential for wind energy could lead to avoiding an additional 35 Mtoe of fossil fuel use in 2020 and 75 Mtoe in 2030, with a maximum cumulative fossil fuel avoidance an additional 700 Mtoe for the period 2010 to 2030, if additional use of fossil-fuel reserve power as a result of wind energy is negligible.

3.3.3. Competitiveness

In the near term, the increase of namely onshore wind in the electricity mix could result in small increase in overall electricity cost. In the medium to long term, the penetration of wind energy to its maximum potential could bring about a slight decrease of the overall production cost of electricity by 0.3 % in 2020 and a more significant decrease of 2 % in 2030, with respect to the baseline. These figures however depend to a large extent on the expected production cost of wind electricity offshore, as this will have a progressively increasing share in total wind generation in the period up to 2030.

The continued innovation and growth of the EU wind energy sector will enable the EU to continue playing a major role in the increasingly competitive global wind energy industry, and thus to continue to reap benefits from export of technology and know-how. It will also mean a net increase in new jobs for Europe.

3.4. Barriers

The two main barriers to large-scale wind deployment are grid integration and present limitations that prevent further upscaling. Current electricity transmission and distribution systems have been designed and developed to manage more traditional generation technologies, and are not appropriate for large-scale wind penetration, whether centralised or distributed. Increasing shares of wind energy will require a new grid philosophy and flexible, robust transmission and distribution grid infrastructures. As regards upscaling, new materials, control strategies and concepts need to be developed in order to cope with and/or reduce mechanical loads on wind turbine components and to increase reliability. In addition, the limitation of existing EU research facilities (both public and industry-housed), for testing wind technology at an appropriate (large) scale, and under relevant climatic conditions, poses a potential barrier to the up-scaling of wind technology and the drive towards offshore deployment. Energy storage mechanisms to compensate for the fluctuating, unpredictable nature of wind generation will be critical enablers for large-scale wind deployment, and thus need to be developed accordingly. At the regulatory level, lack of harmonisation has resulted in disparate levels of support across the EU, with no or marginally effective support in many Member States. Social acceptance of wind energy remains a major barrier. Furthermore, there is a shortage of qualified work force for the sector, which is expected to worsen with the anticipated market growth.

3.5. Needs

In order for the sector to continue innovation and maintain its lead position, continued RD&D support is needed to realise the up-scaling of current technology and the drive towards offshore deployment. In particular, it is important to ensure the channelling of R&D support to the thousands of small and medium enterprises (SMEs) making up the component supply chain, to enable them to keep the required innovation pace and expand their manufacturing capacities. The strong position of the European wind energy research base needs to be further reinforced and cooperation amongst turbine manufacturing research institutes and OEM-companies should be stimulated. In particular, attention should be focussed on issues related to upscaling. Appropriate, EU-harmonised regulatory frameworks are also needed to address the issues of grid integration, accompanied by the upgrading of physical grid infrastructures, including integration of large-scale storage systems. The onus of grid investment must reflect the cross-cutting nature of the issue for the power sector as a whole. Further strengthening of the internal market is needed, with a continued supportive framework for wind, in the form of targets, supply obligations or feed-in tariffs. Measures are also needed to increase acceptance and support for wind energy. Maintaining EU expertise requires adapted training programmes and researcher schemes to provide the quantity and quality of work force needed for the EU wind industry. Suitable platforms for collaboration on key technological issues, such as resource estimation and mapping, are also required.

3.6. Synergies with other sectors

Although there are synergies with other forms of renewable energy supply, they each have their have their own distinctive technological and market attributes, and thus their own challenges and perspectives for growth. Exchange of technological know-how with other sectors, such as aeronautics, smart grids, oil and gas off shore technologies, storage, hydrogen, could facilitate shared technological progress and economies of scale for wind and these other sectors. In the specific case of offshore wind deployment, transfer of know-how with the oil and gas industry is expected.

4. SOLAR PHOTOVOLTAIC POWER GENERATION

4.1. Technological state of the art and anticipated developments

Photovoltaic (PV) systems are currently based predominantly on crystalline silicon technology and are mature for a wide range of applications. Today the average turn-key price of a small to medium size (3 to 20 kW_p) PV system is €5/W_p and for large systems in the multi MW_p range about 3 - 4 €/W_p. The efficiency of commercial flat-plate modules and of commercial concentrator modules is up to 15% and 25%, respectively. The typical system energy pay-back time depends on the location of the installation. In southern Europe this is approximately 1 to 2 years and increases at higher latitudes. Finally, the average generation cost of electricity today is about 30€c/kWh, ranging between 20 and 45 €c/kWh depending on the location of the system.

Crystalline silicon-based systems are expected to remain the dominant PV technology in the short term. In the medium term, thin films will be introduced as integral parts of new and retrofitted buildings. Finally, in the long term, new and emerging technologies will come to the market, such as high concentration devices that are better suited for large grid-connected multi-MW systems, and, compact concentrating PV systems for integration in buildings. It is expected that crystalline silicon, thin films and other technologies will have equal shares in the installed PV capacity in 2030. The cost of a typical turn-key system is expected to be halved to €2.5/W_p in 2015, and reach €1/W_p in 2030 and €0.5/W_p in the longer term. Simultaneously, module efficiencies will also increase. Flat-panel module efficiencies will reach 20% in 2015 and up to 40% in the long term, while concentrator module efficiencies will reach 30% and 60% in 2015 and in the long term respectively. It is expected that if these technology developments are realised, the cost of electricity from PV systems will be comparable to the retail price of electricity in 2015, and to the wholesale price of electricity in 2030.

4.2. Market and industry status and potential

The total installed capacity of PV systems in the EU in 2006 was 3.4 GW_p, representing approximately 0.5% of the total EU electrical capacity. The electricity generated by PV systems that year was approximately 2.5 TWh, or 0.1% of the demand. The annual installations of PV systems in 2006 in the EU reached 1250 MW_p, with approximately 1150 MW_p installed in Germany, due to an attractive long term financial support in the form of feed-in tariffs. The European photovoltaic industry currently has an important role in PV technology development capturing about 30% of the world market of photovoltaic modules.

The PV sector expands annually in Europe with high growth rates, of the order of 40% on average since 2000. The installed capacities of PV systems for the EU-27, assumed in the baseline, are: 12 GW in 2020 and 22 GW in 2030. The estimated maximum potential for PV systems in the EU-27 is up to 125 GW by 2020 and 665 GW by 2030. This represents about 3% and 14% of projected EU gross electricity consumption by 2020 and 2030 respectively.

4.3. Impacts

4.3.1. Carbon Dioxide Emissions

If the maximum potential is realised, PV systems could potentially avoid up to 60 Mt/year CO_2 in 2020 and 320 Mt/year CO_2 in 2030. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be up to 2.2 Gt CO_2.

4.3.2. Security of Supply

Achieving the maximum potential for PV systems could lead to avoiding up to 20 Mtoe of fossil fuel use in 2020 and 100 Mtoe in 2030, mostly natural gas and oil used for the generation of peak load electricity, with a maximum cumulative fossil fuel avoidance of 690 Mtoe, for the period 2010 to 2030. Furthermore, as PVs can be used as decentralised power generation devices, their deployment on a large scale will help ease congestion in the power grid and will lead to reduced costs for the restructuring of the electricity transmission network.

4.3.3. Competitiveness

The penetration of PV systems to their maximum potential could bring about an increase of the overall production cost of electricity up to 7% in 2020 and 17% in 2030, with respect to the baseline. In addition, PV systems have a direct impact on local wealth development as a significant number of jobs are created locally, associated with sales, installation and maintenance of the systems. On average, 50 specialised jobs are created for each new MW of production capacity.

4.4. Barriers

The main barrier to large-scale deployment of PV systems is the high production cost of electricity, due to the significant capital investment costs. It is noted however that investment costs are continuously decreasing, Other barriers include the lack of skilled professionals, the usage of precious raw materials e.g. silver, the need to develop methods for recycling, the introduction of new materials, regulatory and administrative barriers, such as access to grid and long waiting times for connection, and finally, lack of public awareness including from construction experts that inhibit the integration of thin films in buildings.

It is noted that the issue of silicon availability has been resolved as new production units are currently under construction. The shortage of silicon in the past has been a consequence of the lack of development of new silicon purification facilities as well as due to high rates of market growth.

4.5. Needs

Research is vital for increasing the performance of PV systems and accelerating the deployment of the technology. Furthermore, the development of a healthy and growing market is essential for the development of PV technologies as this will stimulate competition within the industry, which in turn will trigger further innovation. Research push tools need however to be combined with market pull mechanisms for the expansion of production capacity. The consequent development of economies of scale will lead to cost reductions. To this end, the maintenance of feed-in tariffs for the next decade could be crucial for the sector as this would allow the industry to grow by providing a stable investment environment. Furthermore, a framework that will allow the European PV industry to export to developing countries will help the expansion of the sector, which will further benefit the deployment of PV systems in Europe.

4.6. Synergies with other sectors

The PV industry is not in competition with other RES-based electricity generation industries. The ultimate goal of the community that supports PV systems is to make the technology competitive with all sources of electricity in the medium term and then allow all technologies to compete for their fair share in electricity generation. Moreover, the PV sector has the same concerns about electricity generation and transmission as the other RES-electricity technologies, such as access to grid, financial support and approval procedures. Further synergies should be pursued with the building and construction sector for raising awareness and facilitating the integration of thin films in new and retrofitted buildings. Finally, shared technology developments could be envisaged with solar heating and cooling and the concentrated solar power sectors with regards to materials and energy storage devices.

5. CONCENTRATED SOLAR POWER GENERATION

5.1. Technological state of the art and anticipated developments

After 10 to 12 years of low developments, the concentrated solar thermal power sector (CSP) is now reviving due notably to a favourable supporting framework in Spain and increasing investments in the US. Concentrated Solar Power Plant (CSP) consists, schematically, of a solar concentrator system made of a receiver and collector to produce heat and a power block (in most cases a Rankine cycle). Three main CSP technologies are under development:

Trough, Tower/Central and Dish. Today CSP technologies are in the stage of a first commercial deployment for power production in Europe. Due to past developments in the US (~350 MW_e in operation since 1980), the most mature large scale technology is the parabolic trough/ heat transfer medium system. In Europe, a parabolic trough power plant of 50 MW_e power capacity with 7.5 hours of storage (Andasol 1) is under construction in Granada in Spain, expected to be in operation in 2008. Two more plants of 50 MW_e each are scheduled to be built on this site. Central receiving systems (solar tower) are the second main family of CSP technology. An 11 MW_e saturated steam central receiver project, named PS 10, is operating since March 2007 in Andalusia. This is the first commercial scale project operating in Europe. Solar Tres is another project under development in Spain based on a molten salt central receiver system. Construction is expected to start end of 2007. Parabolic Dish engines or turbines (e.g. using a Stirling or a small gas turbine) are promising modular systems of relatively small size (between 5 to 50 kW_e), in the development phase, and are primarily designed for decentralised power supply. The solar only average load factor without thermal storage of a CSP plant is about 1800 to 2500 full-load hours per year. The level of dispatching from CSP technologies can be augmented and secured with thermal storage or with hybridized or combined cycle schemes with natural gas, an important attribute for connection with the conventional grid. For instance, in the Solar Tres project, 15 hours molten salt storage is included leading to a capacity factor of 64% without fossil fuel power back-up. Several Integrated Solar Combined Cycle projects using solar and natural gas are under development, for instance, in Algeria, Egypt, India, Italy and Morocco.

Capital investment for solar-only reference systems of 50 MW_e are currently of the order of 3 300 to 4 500 €/kW_e. The upper limit accounts for systems with thermal storage to achieve capacity factor of between 5000 to 6000 hours. Depending on the Direct Normal Insolation (DNI), the cost of electricity production is currently in the order of 20 c€/kWh (South Europe – DNI: 2000 kWh/m^2/a). For DNI in the range of 2300 or 2700 as encountered in the Sahara region or in the US, the current cost could be decreased by 20% to 30%. The important resource base in neighbouring Mediterranean countries of Europe makes it possible to envisage importing CSP energy. For a given DNI, cost reduction of the order of 25% to 35% is achievable due to technological innovations and process scaling up to 50 MW_e. Facility scaling up to 400 MW_e will result in cost reduction of the order of 14%.

5.2. Market and industry status and potential

The economic potential of CSP electricity in EU-15 is estimated to be around 1500 TWh/year, mainly in Mediterranean countries (DNI > 2000 kWh/m^2/year). It is assumed that no installed capacity of CSP energy is forecasted in the baseline scenario. The estimated maximum potential for CSP in the EU-27 is up to 1.8 GW by 2020 and 4.6 GW by 2030. Assuming that a grid infrastructure has been built with Northern Africa Countries, the maximum CSP electricity imports would be up to 55 TWh and 216 TWh between 2020 and 2030 respectively. The maximum penetration of CSP electricity for 2020 and 2030 would generate about 1.6% and 5.5% of the projected EU gross electricity consumption. In these scenarios, no fossil fuel back-up is assumed, with average load factors at about 6 000 full load hours in 2020 and 2030, due to the use of thermal storage.

The European industry currently has a market leadership in CSP technologies worldwide. At this stage of development, there is a supply chain industry already able to offer turn-key equipments for power plants in the range of 10 to 50 MW_e. However, an industrial ramp-up in all aspects (engineering, procurement and construction, components, manufacturing, maintenance) will be necessary to go from current market shares to significant ones.

5.3. Impacts

5.3.1. Carbon Dioxide Emissions

If the maximum potential is realised, CSP energy could potentially avoid up to 35 Mt/year CO_2 in 2020 and 130 Mt/year CO_2 in 2030, with respect to the baseline. The corresponding maximum cumulative avoided CO_2 emission for the period 2010 to 2030 would be up to 1035 $MtCO_2$.

5.3.2. Security of Supply

Achieving the maximum potential for CSP could lead to avoiding up to 10 Mtoe of fossil fuel use in 2020 and 40 Mtoe in 2030, with a maximum cumulative fossil fuel avoidance of 315 Mtoe, for the period 2010 to 2030. These figures do not account for the possible needs for fossil-fuel based power back-up to firm CSP capacities.

5.3.3. Competitiveness

The penetration of CSP to its maximum potential will bring about an increase of the overall cost of electricity production up to 0.3% in 2020 and in 2030, with respect to the baseline.

5.4. Barriers

The cost-competitiveness of CSP plants is a key barrier. There is a strong need for developing long term policy frameworks to foster and secure CSP technology developments and investments worldwide. On the technology front, component improvements and scaling-up of first generation technologies are necessary for cost reduction. The demonstration of new technologies at system level and relevant scale is also crucial for CSP cost-competitiveness on the long term. However, these R&D and innovation activities are not covered by industrial and private funds. As a result, there is a current shortage of equity capacity. This situation is also relevant for today's technology. The necessary work on critical elements for first generation technologies such as adjustment of steam turbine to CSP specification is not performed today. Reaching a critical mass among players is an essential ingredient. Yet, a structuring of the CSP industry as well as an expertise broadening is on-going, but, it is still in its infancy. Finally, the development of specific enabling technologies, for example, grid infrastructure for importing CSP energy from neighbouring countries, is an important focus for the sector developments.

5.5. Needs

The implementation of long term frameworks with support schemes is critical to accelerate the deployment of CSP technologies. Extending the Spanish model to other EU MS and fostering its promotion worldwide is important to build a global market. Joint developments with North Africa would allow the EU to benefit from higher solar resource levels. It is important to open the European market for the import of solar electricity from North Africa. A critical element of this action is the establishment of a pan-Mediterranean grid infrastructure. On the technology front, increased R&D efforts and strategic alignment of national and EU programmes are necessary to realise all the potential embedded in technology innovation. Demonstrating next generation CSP technologies is critical to address medium to long term competitiveness, but also to attract investors. Due to the private financing dilemma, innovative funding schemes will have to be developed.

5.6. Synergies with other sectors

Hydrogen production is a potential industrial field for synergies with CSP technologies. Although these concepts are at an R&D phase, current developments on the heliostat or other heat transfer components will certainly benefit this field. In the short term, shared developments can be envisaged with concentrated photovoltaics as their concentrators respond to the same kind of usage. Other areas of developments besides electricity production are district cooling and water desalinisation.

6. SOLAR HEATING AND COOLING

6.1. Technological state of the art and anticipated developments

Solar-thermal systems currently installed in Europe (active and passive) are predominantly based on glazed flat plate and evacuated tube collectors. The vast majority of the European capacity (90%) comprises single family house units used for the supply of domestic hot water. The remaining capacity consists of an equal share of domestic hot water – multi-family house units, and, single family house combi-systems that deliver both hot water and space heating. In addition, there are a few large scale systems installed in Denmark, Sweden, Germany and Austria which deliver heat to district heating networks. Some of them are coupled with seasonal heat storage. Finally, there are a limited number of installations in industrial sites for the provision of low temperature process heat. The average turn-key cost of a solar-thermal system today is about €1100/kW_{th} for pumped systems installed in central and northern Europe, and €600/kW_{th} for thermo-siphon systems, which are used typically in southern Europe. In general, the former type of equipment can meet 50-70% of the hot water needs for a house, generating 500-650 kWh of useful heat for each kW_{th} installed. The latter type of system can provide 70-90% of the hot water requirements of a building generating 700-1000 kWh for each kW_{th} installed.

The solar-thermal technology that can provide all heating and cooling needs of a building with good insulation has already been demonstrated. Further technological developments are anticipated in the near term, which will improve the competitiveness of the technology and facilitate the expansion of the solar-thermal market. These technology improvements include the development of new systems that will incorporate superior collectors based on advanced polymeric materials, vacuum insulation and sophisticated heat storage media, combined with intelligent heat management controls. These systems will be integrated in new and retrofitted buildings with new insulation, such as in facades, to provide hot water, and space heating and space cooling. In addition, the technology of concentrated collectors will be further developed for use in systems that will provide low and medium temperature process heat to the industrial sector. If the solar-thermal capacity in Europe continues to expand, it is expected that system costs for small scale forced circulation units installed in central Europe will be decreased to €400/KW_{th} in 2030.

6.2. Market and industry status and potential

The total installed capacity of solar-thermal systems in Europe in 2006 was 13 GW_{th}, which produced approximately 0.7 Mtoe of useful heat. Only a small fraction of the installed capacity, about 30 MW_{th} have been installed in the European industrial sector, providing 1.5 ktoe of low temperature heat. Annual installations in the EU reached 2.1 GW_{th} in 2006, compared to 1.5 GW_{th} in 2005 and 1.1 GW_{th} in 2004. The average growth rate of installed capacity during the period 2000-2005 was 13%, which is below the world average for the same period (15%). Three countries capture 72% of the market in the EU, as a result of long-term financial incentive schemes: Germany (with 49% of the installed capacity), Austria (12%) and Greece (11%); followed by France, Spain and Italy, albeit with much smaller markets.

The potential for the penetration of solar heating and cooling technology in Europe, especially in the building sector, is large. Provided that energy efficiency and energy savings measures, including good insulation, can significantly decrease domestic heat demand, the technology could meet most the needs of new and well retrofitted houses in terms of space heating and hot water. The installed capacities of solar-thermal systems for the EU-27, assumed in the baseline, are: 52 GW in 2020 and 135 GW in 2030. The estimated maximum potential for solar-thermal systems in the EU-27 is up to 320 GW by 2020 and 700 GW by 2030. This represents about 3% and 7 % of projected EU heat demand by 2020 and 2030 respectively.

6.3. Impacts

6.3.1. Carbon Dioxide Emissions

If the maximum potential is realised, solar heating and cooling systems could potentially avoid up to 30 Mt/year CO_2 in 2020 and 65 Mt/year CO_2 in 2030. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be up to 600 Mt CO_2.

6.3.2. Security of Supply

The penetration of solar heating and cooling systems will decrease the consumption of fossil fuels, oil and natural gas, and electricity used for space heating and cooling and for hot water. Furthermore, solar-cooling technology can also help alleviate problems associated with peak loads in the electricity system, as it will offer air-conditioning that will not be based on electricity. Achieving the maximum potential for solar heating and cooling systems could lead to avoiding up to 25 Mtoe of fossil fuel use in 2020 and 50 Mtoe in 2030, with a maximum cumulative fossil fuel avoidance of 500 Mtoe, for the period 2010 to 2030.

6.3.3. Competitiveness

The penetration of solar heating and cooling systems to their maximum potential could bring about an increase of the overall production cost of heat up to 2% in 2020 and 1% in 2030, with respect to the baseline. Furthermore, the European economy will benefit from the development of new business and services, mostly SMEs, and from the exports of solar heating and cooling systems around the world, mainly in the developing countries.

6.4. Barriers

The major barrier to the uptake of the solar heating and cooling technology is the high capital cost of the systems and the lack of financial incentives for building owners. Furthermore, the cost-competitive deployment of solar heating and cooling is hindered by technical bottlenecks. Heat storage is considered the most important technical bottleneck for the further expansion of the solar-thermal market. Other major bottlenecks include the unavailability of commercialised cooling machines for solar cooling applications and the lack of advanced polymers for integration of collectors in buildings. There is also a shortage of skilled professionals, qualified installers and technologists/scientists, which currently has an impact on system reliability.

6.5. Needs

There is a need for research and development on high density storage media, such as thermo-chemical and phase change materials, able to store enough heat to meet the requirements of a building for long periods of time. These developments will also benefit other sectors and technologies where energy storage plays a crucial role. Furthermore, advanced materials need also to be developed for other parts of a solar thermal system: new polymeric materials and glasses with improved optical properties for collectors, improved heat transfer materials for temperatures up to 250°C, as well as insulation, both for the solar thermal system as well as for buildings. In addition, new approaches need to be developed for the integration of solar heating and cooling systems in buildings, as well as the necessary building codes. Finally, there is a need for financial incentives to enable large investment in the sector as well as for the removal of legislative and administrative barriers which currently limit or prevent the deployment of solar-thermal technology.

6.6. Synergies with other sectors

Solar heating and cooling systems will be complementing other RES technologies and energy efficiency measures in the future. Possible synergies include: with heat pump technology for the provision of low temperature heat and for cooling; with cogeneration systems (CHP) and biomass for the provision of hot water and process heat; and with photovoltaic systems and CHP for power generation. Synergies with other technologies and sectors include: with the construction community for the integration of solar systems in buildings, and for raising awareness of constructors about the benefits of solar-thermal systems; and with the chemistry research community for the development of new materials for storage, improved heat transfer, insulation, advanced collectors and glasses (the latter also in collaboration with the glass industry).

7. HYDROPOWER GENERATION

7.1. Technological state of the art and anticipated developments

Hydropower is a mature renewable power generation technology. At present, it amounts to 70% of the electricity generated from renewable energy sources in Europe or 10% of the total electricity production in the EU-27. The large and medium scale hydropower market (>10 MW_e) – referred to hereafter as large scale- is a well established market in Europe. More than 50% of favourable sites have already been exploited across the EU-27. Yet, this market is still the case of and for industrial activity. Three main drivers are pushing developments in this field: the erection of new large hydropower plants, with a huge market potential in India and China, but also to a lesser extent in Europe, the rehabilitation and refurbishment of existing hydropower facilities, and the need for additional renewable power capacities. The refurbishment market segment is of interest for Europe with overall, an aging hydropower park, but also to ensure that no energy capacity losses are incurred with the implementation of higher environmental standards. Efficiencies improvements that can be expected from upgrading operations are of the order of 5%. Equally interesting for Europe is the need for new renewable power capacities as embedded in the European targets for renewable energy by 2010 and 2020 and the correlated needs for back-up/firming capacities to ensure grid stability due to increasing penetration of stochastic power. Hydro technologies can make a significant contribution to this topic as a storage technology. A renewed and growing interest for pumped storage schemes has been accounted for in the last 5 years in Europe. These systems develop cycle efficiencies of the order of 80%. For all these markets, hydropower technical and economic performances are very dependent on the site specifications and utility operating strategies. Average load factors of large scale hydropower plants range from 2 200 to 6 200 full-load hours per year in Europe, with an average at about 3 000 to 3 500 hrs. Capital investment costs for building large hydropower facilities (> 250 MW) are of the order of 800 to 3 700 €/kW$_e$. Capital cost for hydro-pumped storage is of the same order of magnitude.

About 11 GW$_e$ of small scale hydropower (<10 MW$_e$) are operating in the EU-25. The largest remaining potential in Europe lies in low head plants (< 15m) and in the refurbishment of existing facilities. About 65% of Small Hydro plants located in Western Europe and 50% in Eastern Europe are more than 40 years old. Similarly to large hydropower plants, capital investment costs are project characteristics dependent. Average capital costs for small hydropower plants are of the order of 1 200 to 3 500 €/kW. Of particular interest, very low head hydro turbines (head < 5m) is a promising distributed generation technology that can be implemented for instance, in untapped water resources at present (e.g., waterways), with about 1 to 1.5GW potential in Europe. These systems are now in the demonstration stage. Typical power rating is of the order of a few hundreds of kWs to 1MWe. Finally, an additional important driver for the development of the whole sector in Europe are the multi-purpose concepts. Hydropower can be implemented in combination with other hydro activities such as flood regulations, wetland management with no additional water resources and environmental impacts. It is noted that climate change can have an important influence on water resources regionally, with negative impacts foreseen mostly for southern European countries.

7.2. Market and industry status and potential

Today's hydro-power installed capacity in EU-27 is about 106 GW$_e$ (without hydro pumped storage). Approximately 90% of this potential is covered by large hydropower plants. The total electricity production in 2005 was about 310 TWh/year in the EU-27. The technical economic potential of Hydropower electricity in Europe (EU-27) is estimated to lie between 450 to 500 TWh/year. The installed capacity of large scale (and small scale) hydropower for the EU-27, assumed in the baseline, are: 100 GW (14.5 GW) in 2020 and 100 GW (15.5 GW) in 2030. Assuming that significant R&D and investment support for installing new capacities and refurbishment operations are made (85% of today's installed capacity refurbished by 2030), the estimated maximum potential for large (small scale) hydropower plants in the EU-27 is up to: 108 GW (18 GW) by 2020, 112 GW (19 GW) by 2030. These capacities would generate about 8.7 (1.6) %, and 8.3 (1.6) % of projected EU gross electricity consumption by 2020 and 2030 respectively. At present about 30 to 35 GW of pumped hydro storage capacity is installed across the EU-27. The retrofitting of existing facilities into a storage scheme provides an important potential base for pumped hydro storage development.

Three large European companies are acting in the large to medium scale hydropower market worldwide. These companies are currently facing a strong international competition (e.g. USA, China and India). The market for small hydropower is more accessible to small companies, with several European manufactures with a recognised industrial position worldwide.

7.3. Impacts

7.3.1. Carbon Dioxide Emissions

If the maximum potential is realised, large scale (and small scale) hydropower could potentially avoid up to 15 (7.5) Mt/year CO_2 in 2020 and 20 (6.5) Mt/year CO_2 in 2030, with respect to the baseline. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be up to 270 (110) $MtCO_2$.

7.3.2. Security of Supply

Achieving the maximum potential for large scale (and small scale) hydropower could lead to avoiding up to 5 (2.5) and 6 (2) Mtoe of fossil fuel use in 2020 and in 2030, with a maximum cumulative fossil fuel avoidance of 80 (35) Mtoe, for the period 2010 to 2030.

7.3.3. Competitiveness

The penetration of large scale (and small scale) hydropower to its maximum potential will bring about an increase of the overall cost of electricity production up to 0.2 (0.02)% in 2030, with respect to the baseline. It is noted that the figures do not account for the crucial grid balancing role of hydropower.

7.4. Barriers

Significant advances have been made in hydro machineries in the past decades, with important prospects for further improvements. By contrast, the slow uptake of these new advances and inadequate research investments can be accounted for. This is partially due to a general misperception that hydro is a mature family of technologies with no significant prospects for additional developments in the future; and because institutional barriers still exist that hampers its development (e.g. long lead time to obtain or renew concession rights, grid connections etc). Meeting stringent environmental standards for water management can sometimes limit the plant capacity, but is also a driver for innovation and improved performances. A coherent policy framework and simplified administration procedures are necessary. New R&D,D efforts need to be made in this field to harness the untapped hydro potential, upgrade the existing hydropower base (higher energy outputs with higher environmental performance) and to maintain the competitiveness of the EU industry. The EU hydropower industry needs to be supported to perform the required work in areas such as modelling for refurbishment operations, turbines/pumps, power electronics and civil work developments to reduce their costs further, to ensure a high resource management with high environmental performance and system efficiencies under variable loads. This is especially important for very low head developments with a small enterprises industry base (< 25 employees) having limited R&D and financial capacities.

7.5. Needs

There is a need for increased and focused Research and Development geared to harness the untapped hydro potential in Europe (low head/very low head) but also to improve the resource exploitation of the existing generation base (refurbishment activities, multi-purpose schemes) and to offer technological solutions to a changing market environment with a growing share of stochastic power (hydro pumped storage), while ensuring a high degree of sustainability (compliance with Water Framework directive). Demonstrating the technology should be an integral part of these efforts to validate technology developments at the system level, to exhibit the latest developments to attract investors and to get closer to the end-users. This development effort should go hand in hand with the set-up of innovative financing schemes to provide financial capacities to the EU industry to carry out these developments. Market support and simplification of administrative procedures for concession rights and permit authorisations are complementary aspects to ensure the deployment of the outcomes from R&D programmes.

7.6. Synergies with other sectors

Hydropower, especially large and medium scale hydropower at a system level, but also small scale hydropower at a distributed generation level (e.g. wind/hydro storage) can play a crucial role in the integration of other renewable energy sources by providing reserve, storage and balancing capacities for the European electricity grid. In addition, hydropower can be implemented in combination with other hydro activities (irrigation dams, water management, pisci-culture etc.) in multi-purpose concepts.

8. GEOTHERMAL ENERGY

8.1. Technological state of the art and anticipated developments

The geothermal energy sector comprises electric power production and heat production sectors. A further distinction is made for the heat sector according to whether the geothermal energy is used directly (low and medium temperature applications) or indirectly (very low temperature applications or heat pumps). Capital investment costs related to geothermal electric installations are of the order of 1500 €/kW. In the heat sector, investment costs for direct heat district heating systems range from 300 to 1000 €/kW, and for geothermal heat pumps, approximately €2000 per ton of capacity, with average capacities of 5-20 kW_{th}. Average system availability for geothermal energy applications is around 95%. In the power sector, geothermal energy is used primarily as baseload supply, and thus has a high load factor of approximately 8000 full-load hours. In the heating sector the load factor is much more variable.

Various levels of technological maturity exist, depending on the specific energy product (electricity or heat) and, in the case of heat, the conversion process, where geothermal energy may be used directly (e.g. district heating) or indirectly (e.g. heat pumps). In electricity sector, current focus is on R&D in enhanced geothermal systems (EGS); the main avenue, currently, for expanding geothermal electricity generation in the EU. In addition, possibilities for exploiting low temperature resources via binary plant technology are an area of focus. In the heat sector, for direct-use applications, such as district heating (DH), efforts are directed at identification of new markets, for example in Eastern Europe; while, for indirect-use applications (heat pumps), attention is on deployment. In terms of development of the geothermal sector as a whole, identification and exploitation of alternative and cascading uses of geothermal energy will be important for improving the economics of the technology. There is scope for transfer of knowledge between sub-sectors, and thus economies.

8.2. Industry status and potential

Currently just over 1 GW geothermal electric power (of which 0.95 GW operational) is installed in the European Union, producing roughly 7,000 GWh of electricity per year. With regards to the heat sector (direct and indirect use), EU installed capacity is almost 9 GW_{th}, accounting for an annual heat production of 85 PJ. The geothermal market is currently concentrated in a number of countries across Europe, with Italy, France, Portugal (EU27), Iceland and Turkey leading the electricity sector, and Sweden, Italy, Greece, France, Germany, Hungary (EU27), Turkey, Iceland and Switzerland leading the heating sector. In the long term, further growth of the sector will require bringing the technology to other areas of the EU.

In the power sector, the installed capacities of geothermal energy for the EU-27, assumed in the baseline, are: 1 GW in 2020, and 1.3 GW in 2030. The estimated maximum potential for geothermal power in the EU-27 is up to 6 GW by 2020 and 8 GW by 2030. This represents about 1 % and 1.3 % of projected EU gross electricity consumption by 2020 and 2030 respectively. In the heating sector, the estimated maximum potential for geothermal is up to 40 GW by 2020 and 70 GW by 2030 (direct and indirect use combined). In the near term, to 2010, growth in the geothermal sector is expected to come primarily from continued exploitation of "hot spot" areas. In the medium to long term, the goal is to expand geothermal deployment beyond these areas, into new countries. Moreover, new concepts, such as EGS, offer significant potential for expanding geothermal energy resources.

8.3. Impacts

8.3.1. Carbon Dioxide Emissions

If the maximum potential is realised, geothermal power and heat combined, could potentially avoid up to 40 Mt/year CO_2 in 2020 and 50 Mt/year CO_2 in 2030. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be up to 700 Mt CO_2.

8.3.2. Security of Supply

Increased electricity and heat generation from geothermal resources will partially avoid the need for new fossil fuel-based plants. Achieving the maximum potential for geothermal power and heat could lead to avoiding up to 12 Mtoe of fossil fuel use in 2020 and 16 Mtoe in 2030, with a maximum cumulative fossil fuel avoidance of 200 Mtoe, for the period 2010 to 2030.

8.3.3. Competitiveness

The penetration of geothermal power to its maximum potential could bring about a decrease of the overall production cost of electricity by 0.3 % in both 2020 and 2030, with respect to the baseline. On the other hand, the penetration of geothermal heat to its maximum potential could bring about an increase of the overall production cost of heat of the same order of 0.3 % in both 2020 and 2030, with respect to the baseline.

8.4. Barriers

The main barrier to enhanced geothermal deployment is a lack of appropriate legislation and financial incentives; in particular, RES-E support schemes across the different Member States (MS) are inconsistent and in some cases inadequate. A lack of clarity in legal framework and administrative procedures for geothermal exploitation means long lead times for obtaining the necessary permits and licences and uncertainties for investors, such as in the right to own and use geothermal energy. Lack of acceptance, due to negative impacts of geothermal exploitation (e.g. visual and odour-related impacts) could hinder large-scale deployment.

Fragmentation of existing knowledge hinders progress in the sector and knowledge gaps (technological and environmental) increase the financial risk. Enabling technologies, such as binary cycle and improved exploration and drilling techniques, can improve the economics of geothermal energy and need to be developed accordingly. Finally, there is a shortage of qualified work force for the sector.

8.5. Needs

There is a need for coherency in the various financial support mechanisms already in existence in different Member States, and a need to create additional financial (incentives) and regulatory (standards) support instruments. With regards to administrative barriers, legal frameworks and regulations, concerning the ownership and exploitation of geothermal energy, must be clarified, and permit procedures harmonised. Increasing the acceptance of geothermal energy will require education and awareness campaigns at all levels, as well as R&D for minimizing the environmental impacts of geothermal exploitation. There is also a need for RD&D support to enable technological advancement and deployment of emerging concepts (e.g. EGS, hybrid systems), as well as for the exploitation of cascading uses. In the specific case of EGS, the focus is to establish a number of “lighthouse” plants across the EU. International research collaboration and centralisation of existing knowledge and data in geothermal and related sectors, in and outside of the EU, will be critical for exploiting synergies between the sectors. Assuring sufficient qualified work force for the sector requires vocational training and certification programmes.

8.6. Synergies with other sectors

There are clear synergies with the oil and gas, regarding geological knowledge and expertise. In the carbon dioxide storage sectors, there is a need for similar types of information as for emerging geothermal energy technologies (e.g. EGS), which could provide synergies. At the same time, the potential use of a single site for geothermal energy or carbon dioxide storage could result in competition between the two sectors. Synergies with the biomass sector may be possible from the cascading use of geothermal heat in biomass processes.

9. OCEAN WAVE POWER GENERATION

9.1. Technological state of the art and anticipated developments

There are several forms of ocean energy, for instance, marine current, wave and tidal energy. In this document, only the energy withdrawn from surface waves by mechanical devices will be analysed. It is noted that technology developments in other fields of ocean energy have taking place worldwide since the 60's, as illustrated by the 240 MW tidal power plant of La Rance in France. Capturing the energy from waves is a complex issue, which is very location specific. A large number of devices and designs are currently being studied and/or developed. Up to 50 types of wave energy converters have been accounted for in a recent study, less than 20% are at a full scale prototype stage. The main principles proposed for wave energy extraction are *terminator*, a structure placed perpendicular to the main direction of the wave, *oscillating water column* which generates electricity from the wave heave pressure effect in a shaft, *point-absorber*; a floating structure that absorbs energy from all directions by virtue of its movement at or near the surface of the water, *an attenuator*, similar to a terminator but oriented parallel to the direction of the waves, and *overtopping devices*, a floating reservoir, partially submerged, in which a head of water is created and further used to run hydro turbines. Wave energy is also distinguished according to the location of the power plant, whether shoreline, near to shore (~< 20 m depth) or off shore (~>40 m depth). Rated power capacities of a single system are of the order of 70 kW to a few MWs. Several units (e.g. to several MWs) can be assembled to create a wave energy farm. Average load factors for wave power installations are within 3 500 to 4 000 full load hours per year (shore-line technology capacity factor can be around 2 000 full-load hours). The cost of current prototypes are of the order of 6 450 to 13 500 €/kW. This leads to a cost performance average estimate in the range of 30 to 35 c€/kWh. Initial capital investment costs of first production units are estimated to be of the order of 2 500 to 7 000 €/kW. It is noted that the cost of wave power is very site and technology specific. The energy captured by ocean wave energy is mostly derived from a transfer of wind energy to the surface of the ocean. Due to the difference of properties in the energy carrier media (water), wave energy is less intermittent and more predictable than other renewable technologies such as wind, although ocean measurement and forecasting techniques over long distances need to be developed and implemented to improve the predictability.

Large scale wave power demonstration facilities are currently being erected or planned in the very near term. European companies are active in shoreline, near-shore and off-shore based devices. Among the different converters capable of exploiting off-shore wave power, the Pelamis Wave Energy Converter – an attenuator technology- developed by Ocean Power Delivery is at an advanced stage of development. A 750 kW size unit is already in operation in Scotland. This technology is the object of a commercial contract for a farm in Portugal. At present, three machines, with a total capacity of 2.25 MW, are in an implementation phase. Overall, nine wave energy systems based on different technologies developed by European stakeholders are being tested under real sea conditions. In the meantime, specific development zones including testing facilities and grid infrastructure are being established in Ireland, the UK, Portugal, Finland and Italy.

9.2. Market and industry status and potential

The economic and technical electricity production potential for ocean wave power estimated for Europe is about 150 to 240 TWh/year. In the EU-27, the Atlantic arc from Scotland to Portugal is the most favourable area in terms of resources. The installed capacity of wave energy, assumed in the baseline, is 0.9 GW in 2020 and 1.7 GW in 2030. The estimated maximum potential for wave energy in the EU-27 is up to 10 GW by 2020 and 16 GW by 2030. These capacities would generate 0.8% and 1.1% of the projected EU-27 electricity consumption by 2020 and 2030 respectively.

A new industry is currently being created. This sector provides opportunities for spin-offs for off-shore activities (e.g. oil industry, ship building).

9.3. Impacts

9.3.1. Carbon Dioxide Emissions

If the maximum potential is realised, wave energy could potentially avoid up to 15 Mt/year CO_2 and 25 Mt/year CO_2, with respect to the baseline. The corresponding maximum cumulative avoided CO_2 emission for the period 2010 to 2030 would be up to 275 Mt CO_2.

9.3.2. Security of Supply

Wave energy technologies can replace fossil fuel-based power plants in the peak to medium scale baseload ~ 3000 hrs to 4 000 hrs. Achieving the maximum potential for wave energy could lead to avoiding up to 5 Mtoe of fossil fuel use in 2020 and 10 Mtoe in 2030, with a maximum cumulative fossil fuel avoidance of 80 Mtoe, for the period 2010 to 2030. These figures do not account for the possible needs for fossil-fuel based power back-up to firm wave power capacities.

9.3.3. Competitiveness

The penetration of wave energy technologies to its maximum potential will bring about an increase of the overall cost of electricity production up to 0.5 % in 2020 and 0.7 % in 2030, with respect to the baseline.

9.4. Barriers

The main barrier to wave energy expansion is its current lack of cost-competitiveness due to its infancy state of development and its specific operating marine environment. Appropriate grid infrastructure and connections will be important for its further development. For an installation located at 100 km from the shore, the grid component can represent up to one third of the cost. Grid connections to on-shore grids can also be problematic, as in some cases the grid is too weak to absorb the electricity production from wave energy power stations. In addition, licensing and authorisation costs and procedures are very high and complex. It can take up to 1 to 2 years to obtain the permit, with a cost of up to one million euros. Permit procedures are long due to a lack of dedicated or experienced administrative structures. Maintenance and plant construction are also very high, especially in the start-up phase. There is currently little experience on maintenance for off-shore facilities. For the time being, off-shore infrastructures from oil industry (ships, platform equipments) are used to carry out these operations which turn out to be costly. Equally, there is a need for specific engineering capacities. Technology learning is currently slow and expensive. Most of the engineering know-how is from the off-shore industry. The lack of tailored engineering expertise can result in over sizing of equipment and, consequently, increased capital investment cost. Fully fledged development and operating costs are beyond the capacities of Small and Medium Enterprises (SME's). Large industries are already involved, but there is a need for long term strategic development and deployment planning to secure industrial investments. Finally, with the advent of the deployment of ocean energy technologies, coastal management is a critical issue to regulate potential conflicts for the use of coastal space with other maritime activities.

9.5. Needs

At this stage of development, ocean wave energy technologies entail significant financial risk and infrastructure investment. Public intervention is essential to share the risks between private and public stakeholders. It is essential to install the first generation capacity to acquire experience on performance and maintenance, and attract investors. To do so, the design and implementation of support measures based on feed-in tariffs, capital investment incentives are crucial. Establishing standards, dedicated reference testing centres, and developing specific engineering capacities are also important to accelerate the technology learning curve. In the same line, the wave ocean energy community needs to acquire a sufficient critical size. Information exchange and coordination efforts among the stakeholders must be fostered. It is equally important that the expert wave energy community trains a new generation of scientists and attracts people from different horizons such as off-shore wind energy to foster know-how transfer. With large expansion of ocean wave energy, the requirements for grids will become acute. In many cases, there is no grid available in the nearby on-shore areas for connections. On the Atlantic arch, significant investments will have to be made.

9.6. Synergies with other sectors

There are significant synergies with the off-shore oil industry, off-shore wind technology, and hydropower. Technology learning in the field of ocean energy is expensive. The costs and efforts can be reduced by fostering cross-sectoral knowledge and know-how transfer. As an example, joint activities with the hydropower sector could reduce and alleviate the time and cost of turbine developments.

10. COGENERATION OF HEAT AND POWER

10.1. Technological state of the art and anticipated developments

Various technologies are used for power generation in existing cogeneration systems (Combined Heat and Power - CHP) and co-produced heat is used in different forms and on different temperature levels. Therefore, energy conversion efficiency considerably varies among different systems. The average overall efficiency in EU CHP industry is around 70%, while average electrical efficiency is less than 25%. However, overall efficiency of newly installed CHP systems varies from 60 to 90% while electrical efficiency is about 30÷55%. In general, electrical efficiencies of CHP plants are lower than that from centralised power plants using the same fuels, and this relative ranking will remain. Further increases of electrical efficiency are expected, particularly for gas turbines, but also internal combustion engines and steam turbines. At the present time natural gas is the preferred fuel which can be used in all types of equipment, but CCGT and gas turbine are expected to be predominant future technology for large scale, natural gas operated units. Coal and biomass are mainly, although not necessary, restricted to steam turbine CHP units.

More recently, attention has also given to the development of small-scale CHP systems because of the large potential market in the residential and commercial sectors. Small CHP units of 100 kW_e and above, represent a steadily growing market with features rather similar to large units. Micro-CHP units, particularly below 20 kW_e, are still in the R&D and demonstration phase (Stirling engines, organic Rankine cycle, micro-turbine), while only internal combustion engines of that size are already on the EU market. Electrical efficiency of such units is still low and improvements are expected (e.g. up to 30% for micro-turbines). Particular interest for CHP is development of stationary fuel cells, as their electrical efficiency is high compared to other options (i.e. 34÷50% electrical and up to 90% overall efficiency) and they have some operational advantages (noise, size, etc.). Significant progress is expected with MCFC and SOFC for industry and public applications, and PEMFC for households (micro-CHP).

To achieve high conversion efficiency, CHPs are principally driven by heat demand. Therefore, load factor varies significant by different applications, and in average is approximately 3200 h for public CHP units (heating) and about 4000÷5000 h for industrial applications.

Specific investment for typical state-of-the-art CHP is in the range of 650÷950€/kW$_e$ for large size units and about 900÷1500€/kW$_e$ for medium size. For biomass systems specific investment is about 1900÷3000€/kW$_e$. Investments for small scale and micro-CHP are in the range 1500÷2500€/kW$_e$ and for fuel cell based CHP from 8000 up to 20000€/kW$_e$. Since the later is the price for early field test, a significant price decrease is expected for the deployment phase.

10.2. Market and industry status and potential

The installed capacities of CHP for the EU-27, assumed in the baseline, are: 160 GW$_e$ in 2020 and 169 GW$_e$ in 2030. The estimated maximum potential for CHP in the EU-27 is up to 185 GW$_e$ by 2020 and 235 GW$_e$ by 2030. This represents about 18% and 21% of projected EU gross electricity consumption by 2020 and 2030 respectively.

Presently, installed CHP capacity in the EU-27 is about 95 GW$_e$, which generates about 11% of electricity demand. As a fuel, natural gas at about 40% dominates the CHP market, followed by coal at 27%. Renewables, mainly biomass, but also combustible waste, are becoming increasingly important having reached 10%. CHP systems have significant penetration in the EU industry, producing approximately 16% of industry final heat demand. The baseline assumes further growth in this segment, to about 23% by 2030. Important CHP applications are district heating and cooling (DHC) systems, where 68% of DH supply is CHP based. Here the baseline does not foresee future increase. Significant potential over baseline growth for industry heat demand is not assumed, but additional potential to the baseline is expected in DHC segment through conversion of heat-only boiler system to those of the CHP type (up to 80% contribution by 2030).

An important growth is assumed in biomass based CHP, mainly in DH but also in industry. The estimated maximum potential for the installed capacity of biomass CHP in the EU-27 is up to 42 GW$_e$ by 2020 and 52 GW$_e$ by 2030. These CHP capacities would generate about 4.7% and 5.3% of projected EU gross electricity consumption by 2020 and 2030 respectively. Moreover, assumption is that biomass CHPs present approximately 2/3 of the total installed capacities of biomass based power plants.

Growth is also assumed in distributed power generation, but mainly after 2020. While fuel cell based CHP are not assumed in the baseline, the estimated maximum potential for such CHPs in the EU-27 is up to 9 GW$_e$ by 2020 and 15 GW$_e$ by 2030 (assuming mainly natural gas fuelled units). This represents about 1% and 2% of projected EU gross electricity consumption by 2020 and 2030 respectively.

Finally, the estimated maximum potential for the fossil fuel capacities in the EU-27 is up to 140 GW$_e$ by 2020 and 175 GW$_e$ by 2030, which is rather similar to the baseline assumptions. This represents about 13% and 16% of projected EU gross electricity consumption by 2020 and 2030 respectively (considering only generation in cogeneration process).

In addition, EU has a strong industrial base in manufacturing CHP plants, so given that these companies export CHPs world wide and global growth of CHP market is forecasted, EU manufacturers should remain a key player on the CHP market in future.

10.3. Impacts

10.3.1. Carbon Dioxide Emissions

If the maximum potential is realised, future energy savings by CHP could potentially avoid an additional 85 Mt/year CO_2 in 2020 and 95 Mt/year CO_2 in 2030. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be an additional 1400 $MtCO_2$.

10.3.2. Security of Supply

Achieving the maximum potential for CHP could lead to avoiding an additional 30 Mtoe of fossil fuel use in 2020 and 35 Mtoe in 2030, with a maximum cumulative fossil fuel avoidance of an additional 500 Mtoe, for the period 2010 to 2030.

10.3.3. Competitiveness

The penetration of CHP to its maximum potential could bring about an increase of the overall production cost of electricity up to 1% in 2020 and 3% in 2030, with respect to the baseline.

10.4. Barriers

Significant CHP raise has been delayed, so far, by the lack of coherent policies in some Member States, low degree of regulations harmonisation and relatively high start-up costs, but also by barriers to grid access and system integration. Technological barriers, as a result of out-dated and inefficient old-type equipment, remain in a many CHP systems, although significant technological advances have been made in the past decade. Besides, as heat demand driven systems, CHPs can efficiently run only during a part of the year or even day, which reduces their potential competitiveness. Market uncertainties about fuel prices also inhibit investment, particularly in recent years. These factors impinge on financial status of CHP, and here the liberalisation of the market has exposed both new and old systems to very competitive conditions where short term profitability is the governing factor. Regulatory issues regarding grid access and connection are secondary compared to previous points, but are nevertheless inhibiting the growth of medium sized CHP systems. However grid connection and integration could be a bigger problem with introduction of micro-CHP on a large scale. Besides, high cost of small and micro-CHP (including fuel cells), limited operating and design experience in households and tertiary sector applications are additional barriers for this market segment.

10.5. Needs

Critical support is expected from development of favourable policy/regulatory framework to enable new investments in CHP. Focus is needed on better biomass technology efficiency and co-firing of biomass and coal. Important requirements for DHC are development of new pipeline structures with low cost and less disrupting methods of laying networks, and the need for techniques to minimise heat losses and permit accurate heat consumption measurements. Targeted R&D, to support commercialisation of the technology, is vital for micro-CHP technologies and particularly fuel cells. Demonstration projects should be used in conjunction with financial mechanisms to stimulate mass production of micro-CHP and fuel cells, and to build up service infrastructure that these devices will need. Also, the important progress should be done in electricity distribution grid integration and management. Besides requests for advanced CHP system operation are thorough review on the portfolio of thermal (and possibly electricity) storage technologies and improved cooling systems. Finally, the key to growth is the development and use of more efficient equipment and stable long term fuel and electricity prices. Efficiencies of 20% are needed for 1kW unit and in excess of 30% for bigger systems (over 35% for large, centralised systems).

10.6. Synergies with other sectors

Renewables and CHP both require a decentralised heat and electricity supply approach, and compliment each other in meeting demands. Besides, with the increase in stochastic power generation from renewables, supply of peak loads on the power market will become even more significant than today, so CHPs could adapt their operations to supply this market segment. However, this will require greater use of energy storages, i.e. heat. Moreover, DHC networks can be used to absorb excess of electricity from wind and solar power generation. With respect to distributed generation, CHP can play a major role in strengthening the electricity distribution grid by assisting grid stabilisation and reducing the need for further investment.

11. ZERO EMISSION FOSSIL FUEL POWER GENERATION

11.1. Technological state of the art and anticipated developments

The main fossil fuel based electricity generation technology in the EU is *pulverized coal*. A typical state-of-the-art supercritical pulverised coal plant has 45% efficiency, while few, more advanced coal power plants demonstrate efficiencies up to 48%. The specific capital investment of the technology is currently of the order of €1300/kW. It should be noted that contractor prices have recently increased by about 25% over the past few years as a result of the increase of material costs, mainly steel. The second most important technology is *gas turbines in combined cycle* burning natural gas. State-of-the-art plants have energy efficiencies ranging between 57% and 60%. Their specific capital investment is of the order of €600/kW.

It is expected that, in 2020, pulverised coal plants will have efficiencies around 50%, and natural gas combined cycle plants about 65%. Other technologies, such as integrated gasification in combined cycle (IGCC) and circulating fluidized bed combustion could be commercialised during the same period, with efficiencies reaching 45%-55%.

Zero emission fossil fuel power plants (or ZEP plants) make the assumption that they will capture at least 85% of the CO_2 formed during the power generation process. The CO_2 that will be captured is planned to be transported to suitable underground locations where it will be stored permanently and safely. Currently, all elements of the technology of ZEP plants have been developed and utilised by other industrial sectors however on much smaller scales than those needed for electricity generation: capture technology (pre- and post- combustion and oxyfuel) is at an advanced stage of research; large scale transport of CO_2 using pipelines has been commercialised in N. America; and a number of industrial CO_2 storage facilities are operational around the world, storing about 3 Mt of CO_2 annually. In addition, 79 CO_2-EOR projects worldwide currently inject about 40 Mt of CO_2 annually into oil reservoirs. Overall, the ZEP plant technology is ready to embark on its demonstration phase.

From the technology point of view, ZEP plants can be commercialised as of 2020, with first-of-a-kind plants coming into operation by 2015. The first generation of commercialised pulverised coal, combined cycle gas turbine and IGCC plants with CO_2 capture are expected to have efficiencies of 33%, 48% and 35% respectively, with corresponding specific capital investments of the order of €1800/kW, €1300/kW and €1700/kW. The cost of CO_2 capture can be about €25-30/t in 2020. By 2030, it is also anticipated that technological developments will have reduced the efficiency gap between ZEP plants and similar plants without capture to about 8 percentage points or less. Similar developments will have ensured that the capital cost of ZEP plants will be decreased by 10% to 25% compared to the first generation units. These developments should bring the cost of CO_2 capture to about €20/t.

11.2. Market and industry status and potential

Currently, fossil fuel power plants are the backbone of the European electricity generation system, providing for 56% of the total electricity demand, followed by nuclear energy (31%) and renewables (13%). In the EU, coal plants have a share of 29% in electricity generation and natural gas combined cycle plants 19%. All energy forecasts show that fossil fuels will remain the main fuel for electricity generation in the medium and long term, retaining a share in power generation of the order of at least 40-50% in 2030. The actual share of advanced coal and natural gas technologies in the future fossil fuel power plant fleet will depend on the prevailing fossil fuel prices and the evolution of the carbon market. ZEP plants could compete with conventional power plants for a share in power generation capacity as soon as they are commercialised, or their deployment could be regulated. The actual level of penetration will depend on the time of commercialisation and deployment, the regulatory framework, the environmental constraints and the extent of the CO_2 transport network. The baseline assumes that ZEP plants are not commercially deployed in the EU-27 before 2030. The estimated maximum potential for ZEP plants in the EU-27 is up to 190 GW by 2030. This represents about 32% of projected EU gross electricity consumption by that year.

11.3. Impacts

11.3.1. Carbon Dioxide Emissions

Currently, the electricity sector is responsible for approximately 40% of the CO_2 emissions in the EU. The anticipated increase in efficiency of fossil fuel power plants without capture is expected to decrease CO_2 emissions by 8% in the long term. The commercial deployment of ZEP plants is expected to have a further major impact in the reduction of greenhouse gas emissions, on a multi-million tonne scale per annum. If the maximum potential is realised, ZEP plants could potentially avoid up to 700 Mt/year CO_2 in 2030, depending on the time of deployment of the technology. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be up to 4.7 Gt CO_2.

11.3.2. Security of Supply

It is likely that the deployment of ZEP plants will be associated with an increase in the consumption of coal for economic reasons and as a result of coal's improved environmental footprint. However, the lower efficiency of ZEP plants (in comparison with non-ZEP ones) will lead to higher specific fuel consumption. Achieving the maximum potential for ZEP plants could lead to an increase in fossil fuel use by up to 85 Mtoe in 2030, with a maximum cumulative additional fossil fuel consumption of 590 Mtoe, for the period 2010 to 2030. However, given that coal resources are more widely spread around the world than other conventional fuels, coal supplies do not rely on rigid delivery paths, and coal is traded in a global and liquid market, the increased consumption may not negatively affect the security of supply. On the other hand and to the extent that an increased demand for coal could lead to some increase in the world coal price, the EU could benefit from domestic resources which at present price levels face unfavourable economics.

11.3.3. Competitiveness

The deployment of ZEP plants will have an impact on the generation cost of electricity. However, it is not yet clear how much effect this will have on the competitiveness of the European economy. The penetration of ZEP plants to its maximum potential could bring about an increase of the overall production cost of electricity up to 5.5% in 2030, with respect to the baseline. On the other hand, the development of ZEP plant technology in the EU will make Europe a world leader in the energy technology markets, increasing the potential for exports and hence benefit the competitiveness of the European industry and will create business opportunities.

11.4. Barriers

The high cost of first-of-a-kind plants, needed for demonstrating key technological components and building confidence on CO_2 emission reduction potentials has been cited as one of the main barriers to progressing further with the technology. Other key issues that need to be addressed include the lack of an enabling framework that tackles among others the permitting of storage sites and uncertainties in carbon prices and the emissions trading scheme, the lack of business plans for evaluating carbon value chains, and public acceptance. The further development and up-scaling of capture technologies necessitates a significant additional R&D effort. Focal points of additional work in capture and storage are the improvement of power plant efficiency, which will also benefit conventional power plants; the reduction of capital costs so that the capture cost can fall below €20-30 per tonne of CO_2 avoided; the development of innovative and more cost-effective capture processes; the development of new materials, including membranes; the better integration of plant components with a concurrent increase in plant availability; the assessment of the European CO_2 storage capacity; the safety of storage; monitoring of storage sites for leakage; and the long term assurance of the permanence of storage.

11.5. Needs

The development of a regulatory market framework and of appropriate policies that will give positive signals to the power sector to invest in ZEP plant technology is a requirement for the further development and deployment of the technology. Of equal importance is the research for the up-scaling and further development of technology. Finally, the financing and regulation of the infrastructure for CO_2 transport and storage will need to be addressed on both the European level and the Member State level.

11.6. Synergies with other sectors

Hydrogen has been identified as one of the possible additional products that could give an added value to ZEP plants operating in a poly-generation scheme based on gasification technology, producing also other synthetic fuels, including natural gas. The excess hydrogen available in the market combined with the current hydrogen prices and the power industry forecasts for the development of a hydrogen market in the near and medium term do not however give the right signal to the companies in the power sector to get involved in hydrogen production. Additionally, enhanced interactions with the materials research community can facilitate the development of new materials needed for efficiency improvements and cost reductions.

12. NUCLEAR FISSION POWER GENERATION

12.1. Technological state of the art and anticipated developments

Nuclear fission energy is a competitive and mature low-carbon technology, operating to high levels of safety within the EU. Most of the current designs are Light Water Reactors (LWR), capable of providing base-load electricity often with availability factors of over 90%. With the aging of Europe's power generation capacity in general there is an urgent need for investment to meet the expected energy demand and to replace infrastructures. It is estimated that an investment of around 900 billion Euros will be needed in the next 25 years for power generation alone in order to provide the 400GW_e of additional and replacement capacity that will be required in that time frame. It is reasonable to assume that out of these 400GW_e, about 100GW_e will be nuclear Generation III (Gen-III) LWR plants, representing an investment of 150G€ over 20 years (for an average Overnight Construction Cost – OVN – of 1500€/kW_e). However, the further expected global expansion of the LWR fleet has repercussions regarding availability of uranium resources. Current estimated exploitable reserves are in the range of 15Mt. The present global rate of consumption of about 67000t/y will rise to an anticipated 90000t/y in 2025 for an installed world nuclear capacity of between 449 and 553GW_e. Assuming the installed nuclear capacity increases linearly up to 1300GW_e in 2050, the current known uranium resources would be completely earmarked for the LWR fleet by this date. This underlines the need to develop the technology for a new generation (Gen-IV) of fast reactors better able to exploit the resources (typically multiplying the energy production by more than 50 for the same quantity of uranium) and thus achieve much greater sustainability of nuclear energy.

12.2. Market and industry status and potential

The installed capacities of nuclear fission power for the EU-27, assumed in the baseline, are: 115 GW_e in 2020 and 100 GW_e in 2030. The estimated maximum potential for CHP in the EU-27 is up to 150 GW_e by 2020 and 200 GW_e by 2030. This represents about 28% and 37% of projected EU gross electricity consumption by 2020 and 2030 respectively.

Today nuclear fission energy generates 31% of the EU-27 electricity production. Presently, there are 158 nuclear reactors in operation, representing an installed capacity of approximately 135GW_e. Most of those are LWRs that have been in operation for about 20 years on average. Current plans in most EU member countries are to extend their lifetime on a case by case basis beyond 40 years, and eventually beyond 50 years. Gen-III reactors, such as EPR (European Pressurised-water Reactor), are evolutionary LWRs taking advantage of the experience of operating designs with a strong optimisation of their safety and economic performance. They are currently being deployed, for example, in Finland and in France (in both cases, the EPR is the chosen Gen-III reactor) where commercial operation is planned to start around 2010 and 2013 respectively. With regard to the various Generation IV reactors currently under investigation, sodium-cooled fast reactors may be ready for industrial deployment by 2040. The first steps in this direction being taken in Europe are the pre-selection by 2009 and final selection by 2012 of the innovative design features and technologies of the nuclear systems themselves, the fuel and the fuel cycle; these will then be demonstrated in a prototype reactor of 250-600 MW_e to be operational around 2020. The gas-or lead-cooled fast reactor should also be investigated, as an alternative to sodium, though industrial deployment is likely to take longer. The plan is to select the alternative fast reactor technology by 2010-12, on the conclusion of current pre-conceptual design research, followed by the building of a 50-100 MW_{th} experimental reactor by 2020 within a Joint Undertaking between EU countries. High temperature reactors dedicated to cogeneration of process heat for the production of synthetic fuels or industrial energy products could be available to meet market needs by 2025, which would trigger requirements to construct "first of a kind" demonstrators in the shorter term, on a similar timescale to the prototype and experimental fast reactors. Supercritical water reactors and molten salt reactors, as well as accelerator driven sub-critical systems dedicated to transmutation of nuclear waste, are currently being assessed in terms of feasibility and performance, though possible industrial applications have yet to be clearly identified.

12.3. Impacts

12.3.1. Carbon Dioxide Emissions

Nuclear energy does not produce CO_2 at the point of electricity production, and is a very low-carbon emitter on a full life cycle analysis (equivalent to or lower than renewable sources). If the current EU production of nuclear electricity were replaced by a representative mix of the other generating technologies, an additional 800 Mt of CO_2 per year would be emitted by the electricity generating sector. Therefore, nuclear power is by far the main source of greenhouse gas emission free electricity generation available today. Nevertheless, if the maximum potential is realised, nuclear fission could potentially avoid an additional 160 Mt/year CO_2 in 2020 and 400 Mt/year CO_2 in 2030. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be an additional 3800 $MtCO_2$.

12.3.2. Security of Supply

Achieving the maximum potential for nuclear fission could lead to avoiding an additional 50 Mtoe of fossil fuel use in 2020 and 120 Mtoe in 2030, with a maximum cumulative fossil fuel avoidance of an additional 1100 Mtoe, for the period 2010 to 2030.

The use of nuclear energy increases the security of supply by limiting the dependence on foreign imports of gas and other fossil fuels for electricity production. In addition, uranium reserves are predominantly found in politically stable nations such as Canada and Australia, and the EU has control over the rest of the fuel production cycle (enrichment, fuel fabrication). The high energy density of the fuel also means it is easy to stockpile reserves. Another possible use of nuclear energy in the future, through the development of (very) high temperature reactors (VTHR) for the cogeneration of electricity and process heat, is for the massive production of H_2 (also through electrolysis), biofuels and other synthetic fuels for transport applications, which would also reduce dependence on oil imports.

12.3.3. Competitiveness

The economic competitiveness of nuclear power for electricity production can be considered as rather high. The penetration of nuclear fission to its maximum potential could bring about a decrease of the overall production cost of electricity by 0.5% in 2020 and a more significant 2% in 2030, with respect to the baseline. Europe has invested a lot in developing its own nuclear power generation and fuel cycle technologies, making it the main producer of nuclear electricity in the world. Competitiveness would be even more enhanced in the event of an increase in carbon taxes – and, more generally, other externalities. The Sustainable Nuclear Energy Technology Platform (SNE-TP), launched in September 2007, will foster an EU common approach to the safe and competitive operation of existing nuclear power plants and the progress towards the establishment of a more sustainable nuclear sector through R&D of key innovative technologies, including the production of diversified energy products. On the global scene, a consolidation of the main world nuclear players into a few large consortia has occurred. As far as utilities are concerned, cross-boarder mergers and alliances are at play in Europe.

12.4. Barriers

The fundamental barrier to exploitation of the predicted renaissance in nuclear power lies with the lack of a clear European strategy on the use of nuclear power, and this deficiency in more widespread political support in the EU may undermine the strength of EU industry for the development of new technology. Even if international cooperation currently exists at the level of research, international competitors of EU Industry have a strong support for R&D, which puts them in a potential better position to gain leadership in the near future. The shortcomings with regard to harmonised regulations, codes and standards may weaken the competitiveness of Europe's nuclear sector and hinder the further deployment of Gen-III technology in the near term. Public acceptance remains an important issue, but even though opinion is not very favourable in a number of MS, there are signs that the mood is changing. Nonetheless, concerted efforts are still required, based on objective and open dialogue amongst all stakeholders. The management of nuclear waste is a key element of this dialogue; national programmes, with EU support for R&D of common interest, are progressing in all MS with major civil nuclear programmes, and the first deep geological repositories will become available towards the end of the next decade. In the longer term, Gen-IV technology will help to reduce the waste burden by significantly limiting the volume, toxicity and heat load of the ultimate waste for disposal, though this will require a considerable R&D effort and investment in new infrastructure. The other main challenges in the development of Gen-IV reactors are related to achieving the required performance, competitiveness and enhanced levels of safety, for which research and large investments are needed in order to preserve Europe's position, even though much of the required basic research will be carried out within the framework of the Gen-IV International Forum. Another significant potential barrier for nuclear fission is the availability of qualified engineers and scientists with reduced output from universities over the last decade. Presently the preservation of nuclear knowledge remains a major issue, especially since most of the current generation of nuclear experts are nearing retirement.

12.5. Needs

The high initial capital investments and sensitive nature of the technology involved means that renewed deployment of currently available nuclear technology can only take place in a stable (or, at least, predictable) regulatory, economic and political environment. Apart from this overriding requirement for a clear European strategy on nuclear energy, a new research and innovation system is needed that can assure additional funding, especially for the development of Gen-IV technology, thereby enabling Europe to preserve its lead in the longer term. The timescales involved, and the fact that key political and strategic decisions are yet to be taken regarding this technology, mean that a significant part of this additional funding must be public, especially in the short to medium term. Later, with the development of first-of-a-kind demonstrators or prototypes, the participation of industry can of course be expected to increase markedly. Joint Undertakings are a possible model for the construction and operation of these demonstrators and prototypes, as well as experimental reactors. In the meantime, an enhanced research effort is needed to ensure Europe's leadership in sustainable nuclear energy technologies that include continuous innovation in LWRs, closed fuel cycle with U-Pu multi-recycling in conjunction with fast neutron reactor development, recycling of minor actinides, and (very) high temperature reactors and related fuel technology. Breakthroughs are especially sought in the fields of materials to enhance safety, solutions to the nuclear waste problem, nuclear fuels and fuel cycle processes. Additionally, there is a need for harmonisation of European standards and a strategic planning of large communal research infrastructures which need to be continuously available for nuclear fission R&D, with also the possibility of opening national installations to the European research community. More effort is needed to inform and interact with the public and other stakeholders, and the education and training of a new generation of nuclear scientists and engineers needs urgent attention.

As examples of required major investments, 2 billion € is estimated for the new large infrastructures for the sodium fast reactor prototype and related fuel fabrication pilot plant; 600M€ for the alternative design fast experimental reactor; 1.5÷2 billion € to demonstrate cogeneration technology based on a VHTR. Numerous other smaller infrastructure (test loops, etc.) are also required. Though this investment and the related roadmaps represent a necessarily ambitious yet realistic R&D scenario, a more detailed analysis of Gen-IV goals and research potential would indicate where additional funding could accelerate deployment of key technologies.

12.6. Synergies with other sectors

Interactions are anticipated with other Technology Platforms in the energy sector such as that on "Hydrogen Energy and Fuel Cells" and possibly also on "Bio-fuels". In the field of materials and numerical simulation, there are synergies with research in non-nuclear R&D (EXTREMAT in the EC's 6th Framework Programme), and mechanisms should be put in place to ensure that current opportunities can be developed further. In addition, the opportunities for important common research with the fusion programme, especially in the area of materials, need to be fully exploited. All cross-cutting research would benefit from more clearly defined channels of interaction, responsibilities and increased flexibility regarding funding and programming.

13. NUCLEAR FUSION POWER GENERATION

13.1. Technological state of the art and anticipated developments

In assessing the potential for global and sustainable energy production in the long term it is clear that the diminishing availability and rising cost of energy based on carbon combined with the increased emphasis on low environmental impact energy sources generally, emphasizes the notion that nuclear fusion is one of very few candidates for the large-scale carbon-free production of base-load power. Fusion has many potential attractions, as it is considered to be essentially unlimited, intrinsically safe, widely available, using cheap fuel with no production of CO_2 or atmospheric pollutants and producing relatively short-lived waste. It has been demonstrated to work successfully, the Joint European Torus (JET) having produced 16 MW of fusion power.

Big challenges must, however, be faced to make 'magnetic confinement' fusion work reliably on the scale of a power plant, including sustaining a large volume of hot plasma for long periods at pressures that allow a large net energy gain from fusion. Such a plant needs materials designed into complex components capable of resisting the extreme conditions required for continuous high power outputs.

The integrated European/Euratom fusion development programme is addressing these challenges and fusion power plant conceptual studies including full lifetime and decommissioning costs suggest that, if they are met, fusion could be economically competitive with other low carbon sources of electricity. Agreement to construct ITER, which should demonstrate the technical and scientific feasibility of mastering fusion in 'burning' plasmas on the scale of a power plant, is a major step forward for fusion. The Broader Approach agreement between the EU and Japan, which includes final design work and prototyping for IFMIF, a device that will subject small samples of materials to the neutron fluxes and fluences that will be experienced in fusion power plants, is another important step. The goal beyond ITER and IFMIF is to demonstrate the production of electricity in a demonstrator fusion power plant (DEMO for short) with its first demonstration of electricity production in ~ 30 years after which it is hoped that fusion will be available for deployment on a large scale. Nevertheless, there are still many issues and challenges to be resolved, e.g. in relation to reliability.

The most recent development centres around the proposal of a 'new paradigm' in which electricity production would be demonstrated much sooner (in about 25 years) by a relatively modest performance 'Early DEMO' or 'EDEMO'. It would not be required to produce electricity at a stipulated cost, and would use already known low-activation materials such as Eurofer that are expected to survive under fusion power plant conditions. With this approach the timing link between DEMO, ITER and IFMIF would be relaxed and interest of the industry could be gained earlier if fusion feasibility is demonstrated. An EDEMO fusion power plant could be producing electricity by 2030, but fusion will not be a significant player in the nuclear energy market at that time, as it is expected that Generation III and IV nuclear fission plant will be providing much of base load electricity. It is premature to speculate about the situation in 2050, but the current European fusion development plan (which the proposed 'new paradigm' could speed up very significantly) foresees fusion starting to be rolled out on a large-scale around the middle of the century. There do not appear to be any 'resource/feedstock availability' issues that would prevent fusion being deployed at least as rapidly as fission was deployed after the mid 20th century, given the wish and the funding to do so.

13.2. Market and industry status and potential

There is of course no obvious market positioning for a technology needing another 30-40 years to reach maturity, especially in view of the current uncertainties in predicting the contributions from other, mainly renewable, energy sources over that time-scale. Nevertheless after the transition from the laboratory R to the industrial R&D stage, industrial take-up is already manifesting itself with respect to the construction of ITER and to increased contributions towards the underpinning European programmes. This industrial involvement would be expected to accelerate should the decision to speed up the programme on the basis of a decision on the new paradigm being taken within the next few years. It is essential that industry contributes strongly to the DEMO design team from an early stage in addition to its key role in ITER construction and operation. Industry rarely commits itself to projects with a 30-40 year time horizon and a decision to launch EDEMO with accompanying Component

Testing facilities may indeed provide the impetus to trigger industrial involvement in spite of the traditional caution.

13.3. Impacts

The potential impact of the introduction of nuclear fusion technology can be summarised through 3 main statements:

– Fusion has outstanding environmental characteristics (no CO_2 or other atmospheric pollutants).

– Together with renewable energy sources, fusion is unrivalled for security of supply because the fuels (water and lithium) are inexpensive and very widely available.

– Fusion development represents a potentially outstanding opportunity for improving the competitiveness of European industry.

The impact of the introduction of fusion technology will also directly depend on the competitiveness of such technology. A quantitative assessment of the efficiency and availability of future fusion power plants, which will largely determine competitiveness of fusion energy, is not yet possible and in fact requires the operation of the DEMO plant before a final realistic estimate can be made. However each stage of the Fusion Development Plan will bring elements with it which can be used to refine the cost evaluation. In any case, efficiency and availability should not be considered as a blocking issue for the use of fusion as it would contribute to reducing both the overall CO_2 emission and the depletion of resources. It should also be emphasised that at present there is no other sustainable and environmentally interesting alternative for base load heat and electricity production for the second half of the 21^{st} century.

13.4. Barriers

Now that the green light has been given for ITER, there are currently no political barriers to nuclear fusion development. This is not to say that political obstacles will not resurface in the future due to the globalised nature of fusion development. The public perception, in particular concerning safety and waste, will mainly come into play once a commercially viable plant is planned for construction. Even this may not present difficulties if the conventional nuclear energy production behaves well and sets a good example. The availability of suitably trained scientists and engineers may pose problems over the lengthy time frames foreseen and even such excellent initiatives as the European Fusion Training Scheme need to be made sustainable. Financial barriers are certainly in place as funding is derived from national and international sources but with limited industrial contributions due to the long term nature of the programme. Increased funding would speed up the Programme and would also allow major changes such as the introduction of the new paradigm, but raising the necessary resources will undoubtedly be difficult. However, as for many first-of-a-kind plants, the costs are very high, with some hundreds of million Euros required to accelerate the research and complete the DEMO design. The capital costs of EDEMO and the Component Test Facility are estimated as a few billion and the cost of the planned DEMO at 10 billion Euros. With such figures the potential financial obstacles are obvious. There are also scientific and technical barriers, which manifest themselves in all very large projects, but which are particularly resistant in new frontier technologies. Although the areas where problems will have to be overcome are numerous, plasma physics and materials engineering will figure high on the list at all stages of the development of fusion technology, just as in the Fusion Road Map. The lack of appropriate harmonized European Codes and Standards may delay the necessary developments although some recently developed EN Codes for example for component design may reduce the height of the hurdle.

13.5. Needs

There is no doubt that the availability of an EU policy for Nuclear Energy would be a boon as a framework on which the necessary development programmes could be attached. Although the Fusion Development community is well organised there is a need to strengthen this organisation with industrial partners to complement the research institutes and universities who currently form the majority. EU Member States should be encouraged to contribute more including those who absent themselves from traditional nuclear technologies. Dissemination of information supporting nuclear fusion through targeted PR should be employed, although only benefit will accrue if the general public is regularly addressed. Education and training should be reinforced, academic and research centres brought into line earlier and campaigns of recruitment into the field should be coordinated.

The Experts are convinced of the need to reinforce all aspects of the present EU programme, with a view to ensuring success and minimising risk in particular during the construction phase of ITER and the design phase of DEMO. They also recommend that Europe should set up a DEMO design group, with substantial industrial involvement (technical and managerial), as soon as resources (manpower and money) allow this to be done without a negative impact on ITER. This group would design a buildable DEMO and consider whether EDEMO should be built without waiting for (full) results from ITER and IFMIF. This work would, *inter alia*, give clear direction to future R&D, including the ITER programme. The group should also evaluate the potential of a Component Testing Facility and the challenges of constructing such a device and, if it seems desirable, proceed to a detailed design. All these proposals obviously have a resource need as outlined above but also a political will should be sought from an EU unified in its desire to shorten the timescale to see fusion as a reality.

13.6. Synergies with other sectors

There are important interactions, both at strategic level and in specific technical areas. Strategically, there is obviously an interaction with climate change strategy. Fusion, if as successful as hoped, will make a major contribution to the security of energy supplies, and will also contribute to reconciling lowering emissions with continued economic development. It is also important to benefit from synergies and the exchange of know-how with other technology programmes, ranging from the application of fusion power for hydrogen production to materials development programmes. Scientific and technical synergies already exist with several fields and through the SET Plan these should be further developed:

– Although fusion and fission power are very different in many respects, there are a number of technical areas where there should be synergies and substantial opportunities to mutually benefit from collaborative programmes, with foci that include: the design and application of high-temperature (radiation-resistant) alloys, safety and licensing issues, helium and liquid metal cooling systems, irradiation facilities, and codes and standards. This synergy becomes even more important when the developments specifically required for GEN III and GEN IV, in particular materials requirements, are elaborated in comparison with those needed for fusion. The EU has introduced some relevant programmes (e.g. PERFECT, which brings together multiscale modelling work in fission and fusion, and EXTREMAT, which is focussed on high-heat flux materials), and there is scope for further initiatives on a European scale;

– Similarly, developments for advanced fossil-fuel power plants in the Zero Emissions Technology platform require high temperature materials, and work on high heat-flux materials for a variety of applications;

– The potential for fusion based production of hydrogen emphasizes the need for a link to the hydrogen and fuel cell activities;

– Fusion research requires high performance computing; developments are being prepared in contact with other communities, taking into account the projects of new European infrastructures;

– There are synergies with a number of other scientific domains (including some in the energy sector), e.g. in the areas of turbulence studies, diagnostics techniques (e.g. spectroscopy), and atomic physics (plasma edge phenomena).

14. ELECTRICITY NETWORKS (SMART GRIDS)

14.1. Technological state of the art and anticipated developments

Flexible, coordinated and adequate electricity networks - designed according to new architectural schemes and embedding innovative technological solutions - are key to address major challenges in the liberalised EU energy systems: mounting network congestions, increasing deployment of renewables-fed and more efficient electricity generation units and diffusion of dispersed generation installations.

In order to make the transmission and distribution grids work together efficiently and safely, an increased coordination in their development and operation must be actively pursued. Both transmission and distribution need to be further developed, not only in terms of carrying capacity but also in terms of advanced Information and Communication Technologies (ICT) infrastructure and communication and control platforms.

Since building or upgrading conventional overhead lines to increase the transmission capacity is progressively more difficult, alternative technologies are either being deployed or are under development: a) HVDC (High Voltage Direct Current) systems, already mature for long distance and undersea transmission (also suitable for connecting off-shore wind-farms) may contribute to regulate the current flowing through the network. b) Flexible AC Transmission Systems (FACTS), gradually more deployed, are power electronics-based devices aiming to increase the control over voltages and power flows in the grid; c) New types of conductors - including Gas Insulated Lines (GIL), High Temperature Superconducting (HTS) wires and high-current composite conductors - are installed at demonstration level with encouraging results in terms of lower electricity losses and higher transfer capacities. A major drawback of such new technologies is the higher investment cost in comparison with traditional solutions.

Software and ICT can contribute as well to increase the adequacy and robustness of the system - thus reducing the need for building new infrastructures - and to augment its observability and governability: a) Dynamic thermal power rating techniques intend to exploit favourable ambient conditions (low temperatures) to temporarily overload conductors without risks of mechanical and thermal stress. b) Wide Area Monitoring Systems (WAMS) aim to monitor, assess and optimise the power flows across the whole system, by means of large-scale satellite-based measurements.

Improving the monitoring and control of selected network's areas via computational intelligence is also conducive to a more secure and reliable grid operation with increased share of Distributed Generation (DG) resources, Renewable Energy Sources (RES) and cogeneration (CHP) installations. Integration of large amounts of intermittent renewables requires enhanced data exchange, with dedicated ICT platforms supervising the information flows between the electricity system players. This may strengthen the capabilities of real-time trading, fault prevention, asset management, generation control and demand side participation. In particular, installation of smart meters coupled with demand side energy management measures may rationalise energy consumptions and make the load more responsive and flexible.

The development and improvement of cost-effective and coordinated high-power energy storage systems, based on different technologies, may also play a vital role in facilitating a larger penetration of DG resources and CHP plants.

14.2. Market and industry status and potential

The bulk power system expansion - in terms of new large scale generation and added transmission capacity, both needed to adequately meet the buoyant electricity demand increase - is curbed by techno-economic, environmental and social issues. The European average investment on transmission infrastructure from 1996 to 2004 has been around 3.1 b€ per year. The largest part was devoted to substations (40%), internal lines (33%) and other assets (23%), such as telecommunication, protection and control, special equipment. Amounts invested in cross-border electricity infrastructure in Europe appear significantly low: only 200 million € yearly, mainly concentrated on HVDC submarine cables. This means that more than 60% of the projects declared of European Interest face significant delays.

On the other hand, at distribution level, given the steady technological progress in cogeneration and renewable power generation, small- or medium-sized power plants (with capacity up to several tens MW) are increasingly installed close to the consumers. These small-scale power plants are the main elements of the Distributed Generation architecture. The DG penetration in 2020 is not expected to exceed an EU average value of 20-25% (with respect to the generation capacity), which is already recorded in some forerunner countries. In 2030 this share may stabilise at around 30-35%, with large variation between EU Member States (a few countries may reach 40%).

14.3. Impacts

One of the crucial benefits of a coordinated development of the transmission and distribution grids and the integration of efficient/renewable generation in the network is the relief of cost-effective generation constrained by network bottlenecks. This benefit is taken into account throughout this document by supposing that targeted network reinforcements are put in place in order not to cap the energy output from the new efficient and/or renewable generation technologies. Further benefits may be represented by: transmission and distribution capacity investment deferral due to development of small-scale DG facilities; reduction of outages; increase in quality of supply.

The electricity losses reduction is the benefit here translated both in terms of CO_2 emission reduction (sustainability advantage) and fossil fuel avoidance (security of supply gain). It is estimated that efficiency gains on the transmission network may bring about a 1% decrease in electrical losses (compared to electrical energy demand) in 2020. This assumes that some of the planned reinforcements of the extra high voltage transmission grid are completed and considers increased connection of generating units to lower voltage networks closer to customers. In 2030 a 2-2.5% diminution of losses is expected, with a considerable share coming also from the distribution systems, significantly evolved towards Distributed Generation schemes.

14.3.1. Carbon Dioxide Emissions

If the maximum potential is realised, the electricity grids could avoid up to 30 Mt/year CO_2 in 2020 and 60 Mt/year CO_2 in 2030. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be up to 600 $MtCO_2$.

The construction of new lines and the installation of innovative equipment may also allow the replacement of lower efficiency power units - at present needed for providing ancillary services especially in constrained portions of network - with more efficient power production fed by less costly primary energy sources. This may be conducive to further CO_2 emission avoidance.

14.3.2. Security of Supply

Efficiency gain in the grid operation (i.e. losses reduction) could lead to avoiding up to 10 Mtoe of fossil fuel use in 2020 and 25 Mtoe in 2030, with a maximum cumulative fossil fuel avoidance of 250 Mtoe, for the period 2010 to 2030. EU electricity grid systems may further contribute to security of supply in terms of: primary energy sources exploitation and diversification; reliability and quality of networks operation; capacity (adequacy) to deliver electrical power.

14.3.3. Competitiveness

A European integrated electricity grid system is crucial to contribute to the competitiveness of the EU market, in terms of low impact on electricity prices and support to the liberalisation process. Strengthened interconnected networks and a well-coordinated electricity system may support inter-regional trade, thus leading to effective competition and reducing the scope for market power abuse.

14.4. Barriers

The main barriers hindering the development of the present grids and the design of future electricity networks are to be found in the inadequacy of the current regulatory framework, the low degree of technical and research coordination and the increasing social opposition to new installations.

Investments appear distorted as a result of insufficient unbundling: the network operators have few incentives to develop the grid in the overall market interest and investment decisions of vertically integrated companies are biased to the needs of supply affiliates.

Regulations and standardisation covering grids issues are either not harmonised or lacking in national laws and codes. EU research is fragmented and driven by short-term profit visions.

Streamlined and simplified cooperation procedures and tools between different stakeholders - e.g. RES producers, Transmission System Operators (TSOs), Distribution System Operators (DSOs), research institutes - are missing. Coordinated procedures and common tools (e.g. on the development of reliability and probabilistic security criteria, on network management and planning techniques) are sometimes not shared and agreed upon by the same TSOs.

Social acceptance of electricity infrastructures is steadily declining. Additionally, a shortage of qualified workforce is recorded in the EU.

14.5. Needs

EU Member States will need to spend at least 400-450 b€ in network infrastructures over the next three decades, some 25% for transmission and 75% for distribution networks; a 30% share is planned to come from public funding. The expected share of yearly R&D effort on transmission and distribution issues would amount to 13 b€. For example, before 2013 at least 6 b€ are to be invested on electricity transmission to address the priorities outlined in the Trans-European Networks Guidelines.

Depending upon the location and the distance of the new installed generation from an adequate grid (e.g. off-shore wind farms, concentrated solar power plants), a further 10 to 25% share of connection costs has to be added to the total network investment mentioned above. Connecting more electricity generated from renewable sources and internalising balancing costs for intermittent generators are estimated to require almost one billion € yearly. How to draw a border between investments required for grid reinforcement and for generation connection and how to share such costs between stakeholders is still subject to debate.

There is a need to set out standard rules and guidelines on one side and a need for removal of administrative barriers (harmonisation/certification schemes) on the other, to control the system evolution from the present numerous and varied national-based networks towards a common European electricity system. Market structure and mechanisms should be implemented to support innovative technology deployment (e.g. Smart Metering, FACTS).

Social acceptance of electricity infrastructures should be improved. A greater number of electrical engineers is also required to ensure new knowledge and expertise to EU research and industry.

14.6. Synergies with other sectors

The electricity network stakeholders and all the energy production technology sectors should work together in conceiving a future European system that takes into account the needs of all its users.

With increasing shares of RES energy (wind in particular) injected into the grid, system operation and development philosophies have to be modified accordingly. RES penetration in the network can be amplified, as soon as common regulations governing the European electricity systems (e.g. grid access and operation rules) are put in place and real-time monitoring mechanisms aiding the transmission and distribution operators are set up.

EU-wide research collaboration on RES integration enablers, such as storage, ICT and metering, is essential to make these technologies viable from the technical/economic point of view. The diffusion of information technologies throughout the electricity system may profoundly change the assumptions on which the traditional system was built. Control and generation of electricity may be distributed throughout the power network, with a fleet of properly coordinated smart appliances and loads able to adjust to grid conditions, hence optimising the system operation.

15. BIOFUELS

15.1. Technological state of the art and anticipated developments

Bio-ethanol and bio-diesel are the most common biofuels used in transport worldwide. Other biofuels are also in use such as pure vegetable oil and biogas, although with a more limited scope at present. Nonetheless, there is an important potential of agricultural feedstock for biogas and/or synthetic natural gas production which can lead to an increased used of "green" natural gas in the transport sector in the future. Agricultural biomass in the EU is the dominating feedstock with rapeseed being the main raw material for bio-diesel production while cereals and sugar beets are the main sources for bio-ethanol. Forestry biomass is currently mainly dedicated to power and heat markets. Bio-ethanol production is currently based on a fermentation process of starch and/or of sugar. The ethanol productivity per land area is, in the EU, of the order of 1.2 $toe_{ethanol}$/ha for wheat grain as a feedstock. Investment costs for the production plant are of the order of €700 to €1200/$kW_{ethanol}$. The production of bio-diesel is currently based on extraction, refining and esterification processes of plant oil, e.g. rapeseed and sunflower. The bio-diesel productivity per land area order of 0.9 to 1.2 $toe_{biodiesel}$/ha with investment capital cost about €200 to 300/$kW_{biodiesel}$. New technology developments, such as hydrogenation processes can help diversify raw material feedstock used to match the foreseen rising demand for bio-diesel.

At present, bio-fuels blending limits in the EU are set according to conventional fuel standards. Up to 5% in volume can be made for pure bio-ethanol and 15% for ether (e.g. Ethyl-Tertiary-Butyl-Ether (ETBE)). In the case of fatty acid methyl esters (FAME), the limit is up to 5% in volume. These standards are mostly designed to ensure a compatibility with conventional power trains and refuelling infrastructure. However, the revision of the fuel quality directive may change these blending limits. It is considered that bio-ethanol and bio diesel can be blended up to 10% and 25% respectively without significant changes on vehicle engines or delivery infrastructure. Flexible fuel vehicles as commercialised since 2002 in Sweden can operate with ethanol blending levels of 85%.

The use of ligno-cellulosic materials as a feedstock for bio-fuels production (2nd generation biofuels) has been prioritised by the Biofuels Technology Platform. A direct production pathway for bio-ethanol production, currently under investigation, consists of mobilising the cellulosic components of different plants through a saccharification stage prior to the fermentation process. On a well to wheel basis, these processes could bring GHG savings of about 90% with regards to conventional fuels. Capital investment costs reported in the short term are of the order of € 1 800 to €2 100/$kW_{ethanol}$. Fischer-Tropsch fuel production via biomass gasification is another important pathway, notably for diesel replacement. Capital investment costs reported in the short term are in the range of €2 500 to 2 800/$kW_{FTfuels}$. About 90% more GHG savings can be gained with regards to conventional diesel, in addition to a high compatibility with conventional power trains. It is noted that second generation processes mostly involve a co-generation of electricity. The second generation biofuel productivity is of the order of 2 to 4 $toe_{biofuels}$/ha. These advanced biofuel processes are still under development, with demonstrations taking place for instance, in Germany and in Sweden. Market entry for these advanced biofuels production processes is foreseen around

2015-2020. In addition, biomass based DME (dimethylether), which can be produced from synthesis gas resulting from the gasification of biomass and/or black liquor, is currently under development, and being demonstrated as a transport fuel, for instance, in heavy duty vehicles. Transport, storage and distribution of DME are similar to that of LPG (Liquefied Petroleum Gas). With the requirement for better economics, integrated concepts named as bio-refineries are currently investigated based on economies of scale and multiple products strategies. At present, different pathways and portfolio of products are studied. Efforts are under way to shortlist the most interested options, with market entry scheduled by 2030. Finally, hydrogen produced from biomass- referred as 3rd generation biofuel- is expected to play a significant contribution in passenger car and urban transport markets as of 2030.

15.2. Market and industry status and potential

Today, almost 4% of the EU gross energy demand is covered by biomass resources. Nearly two-thirds of all renewable energy sources (RES) used in Europe comes from biomass. In 2005, about 5% of the biomass consumption for energy purposes was dedicated to biofuel production, a total production of biofuels of about 4 Mtons. In March 2007, the European Council agreed on a 10 % binding minimum target to be achieved by all Member States for the share of biofuels in overall EU transport petrol and diesel consumption by 2020 This target complements the overall goal of the 2003/30/EC Directive to achieve a 5.75% biofuels share by 2010. By 2030, the Biofuels European Technology Platform considers that up to one quarter of the EU transport fuel consumption could be met by biofuels. The market shares of biofuels in the overall EU-27 transport petrol and diesel consumption, assumed in the baseline are: 7.5% in 2020 and 9.5% in 2030. The maximum estimated market shares of biofuels in the EU-27 are up to: 14% in 2020 and 20% in 2030.

15.3. Impacts

15.3.1. Carbon Dioxide Emissions

If the maximum market shares are achieved, biofuels could potentially avoid up to 40 Mt/year CO_2 in 2020 and 75 Mt/year CO_2 in 2030, with respect to the baseline. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be up to 0.81 $GtCO_2$.

15.3.2. Security of Supply

Achieving the maximum market shares for biofuels could lead to the use of up to 25 Mtoe of biofuels in 2020 and 40 Mtoe in 2030, displacing roughly the same amount of oil, with a maximum cumulative fossil fuel avoidance of 450 Mtoe, for the period 2010 to 2030.

15.3.3. Competitiveness

The market penetration of biofuels to its maximum potential will bring about an increase of the overall transport fuel costs up to 3.5% in 2020 and in 2030 with respect to the baseline.

15.4. Barriers

The cost competitiveness of biofuels with regard to conventional fuels remains a key barrier in the deployment of biomass in the transport sector. Advanced technologies hold the promise to deliver more environmental benefits per product output, better economics and higher front-end feedstock flexibility than 1st generation processes. At present, process development and scale-up for these advanced technologies are still necessary, in parallel to the need for an overall R&D investment in feedstock and biomass supply logistics. Demonstration projects at a relevant industrial scale are crucial to acquire feedback on and to validate cost and technical performance. However, they are capital intensive. A strong coordination between biomass suppliers, car manufacturers and the automotive fuel industry is essential to balance the evolution of the EU vehicle fleet and the delivery infrastructure against higher penetration of biofuels. This should be backed-up with standards and administrative procedure harmonisation across the EU-27. The sustainability of biomass production along with the allocation of these resources between electricity, heat and transport fuel production, and the competition for biomass resources with non-energy sectors are critical issues that are currently being addressed and debated. The European Environmental Agency estimated that about 295 Mtoe could be exploited in a sustainable manner by 2030 in the EU-25. Certification schemes and policy goal oriented support schemes will be key in ensuring that biomass supply meets sustainability criteria. In parallel, feedstock markets need to be optimised towards energy markets, with a balance between domestic biomass production and international trade to be found.

15.5. Needs

A better coordination of and more focused research, development and demonstration (R&D, D) efforts at the EU and national levels is important to advance new technologies, including system integration, and to overcome current technical and cost barriers. The build-up of a knowledge community on bioenergy at the EU level is an important priority. For 2nd generation biofuels, the R&D, D infrastructure and promotion instruments are not mature. There is a crucial need to demonstrate the technology at a relevant industrial scale prior to a mid-term commercialisation target. These operations are costly. A long term and coherent policy framework and innovative financing mechanisms that pool together government, industrial and investor resources need to be put in place. Equally, more R&D, D efforts should be devoted to upstream areas, e.g. land use and bio-energy production. The biomass energy sector involves many stakeholders from different horizons. A cross-sectoral coordination between agriculture, forestry, oil industry and car manufacturers is essential. In parallel, an overall harmonisation of incentives and regulations across the EU as well as the set-up of sustainability certification schemes in view of avoiding market distortion and competition, and the development of resources mapping and life-cycle analysis tools are of prime importance. A better communication to society on the benefits of using biofuels will also ensure a wider social acceptance.

15.6. Synergies with other sectors

Biofuels developments interact strongly with the Common Agricultural Policy (CAP) and Forestry policies, as well as development, trade and industrial policies. There is a need for a harmonised and coherent policy framework as underlined in the EU Biomass Action Plan and in the EU Strategy for Biofuels. Coordination with non-energy based biomass industry is of prime importance. In the long run, synergies with hydrogen are foreseen in the advent of fuel cells and hydrogen large scale deployment in the energy sector.

16. HYDROGEN AND FUEL CELLS

16.1. Technological state of the art and anticipated developments

16.1.1. Hydrogen production, transmission and distribution

16.1.1.1. State of the art developments

The use of hydrogen in industrial applications is an established market with significant quantities and industrial know-how at the European Level. In 2003, it is estimated that around 6 million tonnes of hydrogen was consumed in Europe for industrial applications, of which 46% was in Ammonia production and 31% in petrochemical applications. For large scale hydrogen production, natural gas (NG) steam reforming is currently the predominant technology. Steam NG reforming processes commonly used are in the range of 50 to 200 MW_{H2}. Energy efficiencies are of the order of 70% to 80%, with capital investment costs in the range of €300 to €400/kW_{H2}. Heavy oil and coal gasification are the second main pathways in hydrogen production. These processes have energy efficiencies around 50% to 65%, with capital investment costs of the order of €900 to € 1 000/kW_{H2}. At small scale (~a few MW_{H2}), natural gas steam and auto-thermal reforming processes are still at a demonstration/commercialisation phase. Energy efficiencies are in the range of 45% to 68%. Investment costs are in the range of €700 to €2000/kW_{H2} for power capacities ranging from 600 kW_{H2} to 6 MW_{H2}. Water electrolysis is a well established modular process. Alkaline technology is the state-of-the-art technology. Today, the largest electrolyser module – an atmospheric electrolyser- develops a capacity of approximately a few MW_{H2}. In the case of future central hydrogen production, a scale-up in the size of electrolyser modules will be required. Energy system efficiencies range from 45% to 65%, including auxiliaries. Capital investment costs are of the order of €800 to €1 500/kW_{H2}. Electrolysis is a key technology to enable a high penetration of renewable electricity in the transport sector.

16.1.1.2. Anticipated developments – decarbonisation of hydrogen streams

At a large scale, fossil fuel based hydrogen production can only be envisaged along with a high degree of decarbonisation of the production stream. With capture and storage technologies (CCS) the emissions can be cut down by a factor 3 to 5. Overall, a decrease in efficiency of 6 to 8 efficiency points is expected, while the hydrogen production cost could increase by 20 to 30%. Hydrogen and electricity co-production with an Integrated Gasification Combined Cycle along with CO_2 capture and storage is a promising alternative to maximise the economics for coal based processes. Demonstration projects are currently being investigated in the US and the EU. Market entry of CCS based technologies is expected around 2020. At a small scale, a strong focus is currently placed on hydrocarbon (natural gas, biofuels) reforming/partial oxidation technologies for on-site hydrogen generation with the goal of improving energy efficiencies, flexibility to load variation as well as to lower the investment capital cost. Efficiencies around 70% can be expected in the future with capital cost of the order of €700 to 900/kW_{H2}. On-site based production units are expected to play an important role in the transition period until hydrogen demand in the energy sector reaches a level for which investment in a dedicated hydrogen centralised infrastructure is justified.

For low temperature electrolysers, the major line of development is the pressurisation of the electrolyser, the improvement of the overall electro-chemistry and a simplification of the balance of plant. Improved and mass manufacturing can lead to significant decrease in the equipment cost. Pressurised electrolysers up to 3 MPa are state of the art. Capital cost investment for pressurised systems is of the order of €900 to €2200/kW$_{H2}$ for capacities ranging from a few 100 kWs to a few MWs, with prospects of €500 to €700/kW$_{H2}$. Higher pressures have been demonstrated at a prototype scale level. Achieving higher energy efficiencies can also be done by raising the operating temperature. High temperature electrolysers are currently in the development stage with a strong need for advanced materials. Expected efficiencies are above 80% with capital cost of the order of €800 to €1000/kW$_{H2}$. Market entries for the latter are foreseen after 2020.

At present, biomass-based gasification applications for hydrogen production, are at the demonstration stage, with market entry foreseen between 2015 and 2020. In theory, it can be implemented at large scale. However biomass supply can be a limiting factor. Energy efficiencies of the order of 45% to 65% are expected. Capital investment cost in the near term is of the order of €900to 1500/kW$_{H2}$ with an expected decrease to €700 to €1000/kW$_{H2}$ due to economies of scale and process integration. Biomass gasification can avoid 7 times more CO_2 emissions compared to steam methane reforming without CCS. In the longer term beyond 2030, at large scale, high temperature thermo-chemical and electrolytic water splitting processes using concentrated solar thermal and nuclear energy as process heat and electricity are currently being investigated. The efficiencies of most investigated thermo-chemical cycles are expected to be around 40% - 50%. Capital investment for nuclear technologies in the range of €2000/kW$_{H2}$ is expected at these time horizons. At small scale, biogas production through anaerobic digestion is a mature technology. Its conversion into hydrogen is largely based on the same technologies as natural gas. Biochemical fermentation either in an anaerobic environment (dark fermentation) or in a phototrophic environment (photo-driven fermentation) is under experimental development for hydrogen production. Preliminary calculations report an overall efficiency of around 50% for a hybrid dark and photo-driven fermentation process.

Large scale transport of hydrogen is already commercialised. Liquefied hydrogen as well as gaseous hydrogen is commonly delivered every day in industrial facilities. Around 1500 km of gaseous hydrogen pipelines are currently operated in the EU. The capital cost for pipelines are between 500 k€/km to 1 500 k€/km for transmission and 100 k€/km and 500 k€/km for distribution. Medium term targets for large scale hydrogen delivery infrastructure are to increase pipeline operating pressure for gaseous transport and to increase the size of liquefaction plants. Today's investment cost for a refuelling station is about €1 000 to €1 200/kW$_{H2}$. Today's research is mainly focused on increasing the delivery pressure to 70 MPa and improving the overall durability, load flexibility, spatial requirements and safety of refuelling technologies. In mid 2007, 39 filling stations were in operation in Europe, and 26 planned to be in the coming years. Most of them are located in Germany. Finally, large and medium scale above-ground and underground (e.g. depleted gas field, aquifers, caverns or buried tanks) stationary storage is a key element of a future centralised - decentralised large scale hydrogen transmission and distribution infrastructure. Geological premises are the most widely studied types of systems for large scale storage of hydrogen, with significant synergies with natural gas storage. For underground tanks – with less storage capacities than geological storage-, liquefied hydrogen tanks are already in use for space applications. This option has been first operated for a bus refuelling station by BP in London. Compressed hydrogen tanks are mature for above-ground storage, and in development for underground applications. Further developments are required in view of a wide scale deployment of hydrogen use, to increase their performances in terms of cost, space requirements, safety, operability and durability etc. For tank-based hydrogen storage technologies, there are important synergies for joint developments with on-board storage.

16.1.2. Fuel Cells

Three main technologies of fuel cells are currently developed for transport and stationary applications in Europe: Proton Exchange Membrane Technologies (PEMFC), Molten Carbonate Fuel cell (MCFC) and Solid Oxide Fuel Cell (SOFC). The two latter are focussed mainly on industrial and residential applications, while the main focus for PEMFC are automotive applications. A fuel consumption of 0.27 kWh/km is expected for PEMFC based transport vehicles running on hydrogen by 2015. This is nearly 40% less than the fuel consumption of an advanced internal combustion engine for a similar vehicle size. Capital investments costs for stationary fuel cells are expected to be of the order of €1 500 to €6 000/kW_e by 2010-2015, while, by 2015-2020, €100/kW_e for PEMFC stacks is targeted for transport applications. Sixty Mercedes-Benz A class fuel cell vehicles have been operated in a demonstration project since 2003, in 2006 achieving more than 705 000 km with a total running time of 21 600 hours.

The development of performing and cost-competitive hydrogen storage technologies is key for all applications. At present, gaseous and liquefied technologies are commercially available. An increase in the tank operating pressure, and a reduction of the boil-off rate for liquefied storage are the main development trends. Gaseous hydrogen storage tanks at 70 MPa are currently in the demonstration stage. A medium cost target (about 2020) is around €10 to 30/kWh_{H2}, that is a decrease by about a factor 3 to 10 with respect to currently available technologies. To meet all these targets, alternative solid-state hydrogen storage technologies are being developed, still requiring further research. The market entry of the latter technologies is expected post-2020.

Combined heat and power is the targeted mode of energy conversion for fuel cells in stationary applications. Hydrocarbon fuels (natural gas, biofuels) are expected to be the dominant fuel in the near to medium term (up to 2030). MCFC are currently the most mature technologies available for demonstration/commercial projects above 100 kWe. Electrical efficiencies of the order of 45% and overall energy efficiencies of 75% to 80% have been achieved with a cumulative running time of 10 000 to 20 000 hrs. PEMFC have been developed and tested mostly in a scale range below 50 kWe with electrical efficiencies around 30 to 40%. SOFC technologies are currently less mature and are mainly at the prototype demonstration stage. The capital investment for stationary fuel cell applications is currently around €10 000/kWe. By 2015-2020, a ten-fold decrease to €1000 - €1500/kWe with overall energy efficiencies of 90%, is expected for sizes above 100 kWe with a medium term lifetime goal above 30 000 hours. For sizes below 100 kWe, a cost of €6 000/kWe with electrical efficiencies of 34 to 40% and lifetime above 12 000 hrs are targeted. Between 10 to 30% CO_2 equivalent reductions are reported compared to conventional technologies for heat and electricity production. It is noted that at present, 2/3 of cost is attributed to balance of plant components for fuel cell based stationary applications. Finally, although the main focus of this document are hydrogen supply technologies and fuel cells, combustion engines either for automotive applications or power and heat generation can use hydrogen as a fuel. Hydrogen ICE vehicles are an important technology option for the transition to building up a hydrogen infrastructure. Similarly, hydrogen fuelled gas turbines are being developed for combined cycle with CO_2 capture and storage for near zero carbon emission power plants.

16.2. Market and industry status and potential

In the last decades, a research and industry community in the field of hydrogen energy and fuel cell technologies has been formed across the EU, with a strong commitment from the EU research base and industry to advance hydrogen and fuel cell technologies jointly, as illustrated by the on-going proposal for a Joint Technology Initiative on Fuel Cells and Hydrogen. The EU industry base is comprised of large multinational companies and innovative small and medium enterprises (SMEs). For instance, most of automotive OE&Ms are currently developing hydrogen power vehicles. More and more SMEs are involved in the component supply chains, although there is a strong need to strengthen it at the EU level. This is of importance as it can provide significant job opportunities and economic growth.

Hydrogen and Fuel Cells are medium and long term energy technology options. The transitioning from today to 2020 is described in the Snapshot 2020 of the HFP. By 2020, mass market roll-out is expected to be kick-started in the transport sector. By then, 1 million to 5 million vehicles would be on the road with annual sales of the order of 0.4 million to 1.8 million vehicles. Hydrogen supply infrastructure would be coupled to transport developments. Refuelling platforms would be available across the EU, and infrastructure expansion initiated. Markets for stationary applications are expected to be established by 2015. By 2020, 8 to 16 GWe would be produced by combined heat and power (CHP) fuel cells mostly running on hydrocarbon fuels, with annual sales of the order of 2 to 4 GWe. Markets in premium applications (e.g. portable generators, specialty vehicles), micro-fuel cells for handheld electronic devices would already be established. About 6 GWe are forecasted to be in operation in these premium market segments at that time. Methanol is expected to be the primary fuel for the micro fuel cell market segment.

Two scenarios are considered for hydrogen penetration in the passenger car market in the EU-27 derived from the Hyways project findings[2]. The limitation of the analysis to the passenger car market segment is to investigate the potential contribution to EU policy goals of a combined deployment of hydrogen and fuel cells in a mass market environment. Stationary applications are an important mass market for fuel cells. However, other fuels than hydrogen are expected to play a role in the near to medium term. . CHP stationary fuel cells are analysed in the co-generation chapter. It is assumed that no deployment of hydrogen fuelled vehicles in the passenger car market segment is forecasted in the baseline scenario. Depending on the combined implementation of a supporting and regulatory framework and the realisation of significant investments in R&D and D in the next 7 years, the maximum estimated market shares of hydrogen vehicles in the EU-27 are up to 1.4% in 2020 and 12% in 2030 of the passenger car fleet.

16.3. Impacts

16.3.1. Carbon Dioxide Emissions

If the maximum market shares are achieved, Hydrogen vehicles could potentially avoid up to 5 Mt/year CO_2 in 2020 and 60 Mt/year CO_2 in 2030, with respect to the baseline. The corresponding maximum cumulative avoided CO_2 emissions for the period 2010 to 2030 would be up to 0.33 $GtCO_2$.

16.3.2. Security of Supply

Achieving the maximum market shares for hydrogen vehicles could lead to up to 2.5 Mtoe avoided fossil fuel use in 2020 and 20 Mtoe in 2030, with a maximum cumulative fossil fuel

2 www.hyways.de

avoidance of 135 Mtoe, for the period 2010 to 2030. Natural gas dependency can be increased in the short term. Nonetheless, the gradual introduction of other feedstocks such as renewable sources in the medium term will reduce it in the long run.

16.3.3. Competitiveness

The market penetration of hydrogen vehicles to its maximum potential will bring about an increase of the overall cost of usage of passenger cars up to 0.3% in 2020 and 0.7%in 2030 with respect to the baseline.

16.4. Barriers

The major barrier to hydrogen penetration as a fuel in the transport sector, but also for stationary applications, is the cost and durability of fuel cells. For both hydrogen production and fuel cell technologies a significant amount of research and demonstration is still needed on materials, process integration including balance of plant components to lower system costs and to meet customer performance requirements. Another barrier facing the hydrogen energy economy is the supply-demand investment dilemma for the infrastructure build-up. Important up-front investments in hydrogen production and delivery only make sense when it is synchronized with hydrogen demand. For instance, for transportation, 10 to 20% of the retail stations will have to deliver hydrogen once hydrogen fuelled cars start to be significantly introduced. In addition, many EU companies that have been established in the past decades in the fuel cell business are small and medium enterprises. These companies are facing an equity dilemma. It is imperative to support these companies in the market establishment phases. In order to raise the energy security and greenhouse gas emission reduction levels, it can be expected that alternative feedstocks than natural gas from fossil fuel origin will have to be used to produce hydrogen. The whole issue of the hydrogen production and its originating feedstock is still an open and debated question, which can become a crucial barrier when several sectors of activity are competing for the same resources, driving prices up (e.g. biomass). Finally, the set up of a long term regulatory framework is critical to back-up these emerging markets. Safety issues are critical for both public acceptance and mass market deployment of hydrogen technologies, which may have an impact on technology developments and their cost-competitiveness. Hence, regulations, codes and standards and public acceptance play a crucial role as market development enablers. Hydrogen fuel quality standards are another key issue that should be developed with the specification of end-use applications.

16.5. Needs

Currently there is a strong international competition in hydrogen vehicles and fuel cell based combined heat and power in stationary applications. EU stakeholders are well positioned to compete, nonetheless, the market entry of hydrogen and fuel cell technologies needs to be accelerated if the EU does not want to lose out to the international competition. Coordination and focus of available funding at the EU, national and regional levels on research and development to overcome residual technical, social and cost barriers is needed. Supporting large scale demonstrations and broad introduction to mass markets are critical as visibility raisers, test beds for developments and future infrastructure expansion nuclei. Of equal importance, upstream research and developments are still needed to ensure the mid-term technology cost-competitiveness and to build up new knowledge for long term options. Supporting market instruments should be developed in parallel to technology developments. Furthermore, research capacities for infrastructure transition planning need to be strengthened across the EU, including organisational and behavioural research and the development of socio-economic modelling tools. There is a need for continuous monitoring of costs and technology improvements to provide investors with confidence in hydrogen and fuel cells and to design specific support schemes tailored to the different elements of hydrogen and fuel cells chains. For instance, to strengthen the EU SMEs industry base, innovative financing and demand pooling schemes will be required in the short term. The establishment of harmonised regulations, codes and standards (RCS) at national and international levels as well as the introduction of more stringent carbon reduction policy measures are important issues.

16.6. Synergies with other sectors

Hydrogen as a universal energy carrier can be an integral part of electricity systems. Hydrogen can play a role in balancing power grids (e.g. via electrolysers as an additional load), in back-up power generation as an alternative fuel to diesel. Above all, hydrogen can be used as a storage media to cope with stochastic power generation (e.g. wind electricity production). Autonomous renewable energy sources-based energy networks as can be envisaged for remote areas are early markets for these concepts. Beside transport applications, fuel cell systems can play an important role in the development of micro co-generation in Europe. The possible competition for primary resources for hydrogen production and other sectors of activity indicates a need for coordination and synergies between policies and industrial sector strategies. Biomass is a prime example, but wind, coal and nuclear energy are equally important issues due to their forecasted medium to long term role both for power generation and hydrogen production. Attempts to synchronise the agenda of these sectors are currently being undertaken.

17. SUMMARY TABLE OF THE TECHNOLOGY MAP

The summary table of the technology map presents an overview of the key conclusions of the assessment of the addressed technologies. The table includes:

- A description of each technology (energy sector, current market share of the technology and technological state of the art);
- The potential share of the each technology to the future European energy system (considered in the baseline scenario, estimated potential of technology penetration in the energy system by 2020 and 2030 and the potential technology breakthroughs);
- The quantified impacts of penetration of each technology:
  - Environment: annual CO_2 emissions avoided in 2020, 2030 and cumulative 2010-2030 (Mt of CO_2; relating to the additional energy generated by the technology),
  - Environment: carbon mitigation cost in 2020, 2030 and average for 2010-2030 (Euros per tonne of CO_2 avoided),
  - Security of supply (SES): annual fossil fuel savings in 2020, 2030 and cumulative 2010-2030 (Mtoe of fossil fuel; relating to the additional produced energy),

  - Competitiveness: additional cost of energy (percent) as a result of the technology penetration in 2020 and 2030;

- Main barriers to penetration in the European energy market for each technology;

- Needs to realise potential of each technology.

TECHNOLOGY AVENUE	DESCRIPTION	POTENTIAL	ADDITIONAL IMPACT				BARRIERS	NEEDS
			Environment		SES	Competitiveness		
	1) Sector 2) Current market share 3) State of the Art	1) Baseline scenario 2) Potential penetration 3) Potential breakthroughs	CO_2 avoided (Mt)	Mitigation cost (€/t CO_2)	Fossil fuel savings (Mtoe)	Additional cost of energy (%)		
WIND POWER	1) Power generation 2) 3% of demand ~50 GWe installed capacity 3) Onshore wind: commercialised Offshore wind: Starting deployment	1) 2020: 120 GWe 2030: 148 GWe 2) 2020: 120÷180 GWe 2030: 168÷300 GWe 3) Large scale testing to commercialisation, particularly for offshore environments	0÷100 (2020) 2÷250 (2030) 10÷2400 (2010-2030)	(-5)÷0 (2020) (-20)÷5 (2030) (-10)÷5 (2010-2030)	0÷35 (2020) 1÷75 (2030) 5÷700 (2010-2030)	(-0.3)÷0 (2020) (-2)÷0 (2030)	Inflexible grid infrastructure Lack of large-scale testing facilities Under-developed storage mechanisms Disparate level of financial support Lack of social acceptance Lack of skilled professionals	Upgrading of grid infrastructures and appropriate EU regulations for grid integration Large-scale test facilities / RD&D for upscaling Better coordination of financial support schemes across the EU Specialised education programmes Support of innovation in SMEs
			Need (with increasing levels of wind) for increased use of reserves and additional back-up capacity not taken into account in calculations					
SOLAR PHOTOVOLTAICS	1) Power generation 2) 0.1% of demand 3.4 GWp installed capacity 3) Small scale: commercialised Large scale: Development Thin films: Development	1) 2020: 9 GWp 2030: 16 GWp 2) 2020: 65÷125 GWp 2030: 300÷665 GWp 3) Integration of thin films in buildings High concentration devices for large systems	30÷60 (2020) 140÷320 (2030) 980÷2230 (2010-2030)	240 (2020) 125 (2030) 160 (2010-2030)	9÷20 (2020) 42÷100 (2030) 300÷690 (2010-2030)	3÷7 (2020) 8÷17 (2030)	High cost of electricity Techno-economic issues Building integration Lack of skilled professionals Access to grid Regulations and administration	R&D Development of a liberalised market Financial incentives Framework to facilitating exports
CONCENTRATED SOLAR POWER	1) Power generation 2) 0% of demand < 100 MW installed and/or under construction capacity 3) Parabolic trough : commercialised Central receiver: commercialised Dish receiver: Demonstrated	1) 2020–2030: 0 GWe 2) 2020: 1.8 GWe in EU27 → 1.8 GWe with 55 TWhe imports 2030: 4.6 GWe in EU27 → 4.6 GWe with 216 TWhe imports 3) Higher temperature systems, low cost heat storage Process scale-up > 100 MWe Trans Mediterranean Grid infrastructure	5÷35 (2020) 15÷130 (2030) 145÷1035 (2010-2030)	15÷55 (2020) 5÷45 (2030) 10÷50 (2010-2030)	2÷10 (2020) 5÷40 (2030) 45÷315 (2010-2030)	0.2÷0.3 (2020) 0.3 (2030)	High cost of electricity Lack of feed-in support in most EU country Equity shortage for demonstrating first of a kind project Investments in grid infrastructure	Expansion of feed-in tariffs for CSP in the EU Risk sharing financing mechanisms for large scale demonstration and commercialisation projects R&D and Demonstration Open EU market to CSP imports Investment in a trans-European and trans-Mediterranean Super grid Framework to build-up a global market

TECHNOLOGY AVENUE	DESCRIPTION	POTENTIAL	ADDITIONAL IMPACT				BARRIERS	NEEDS
			Environment		SES	Competiti-veness		
	1) Sector 2) Current market share 3) State of the Art	1) Baseline scenario 2) Potential penetration 3) Potential breakthroughs	CO_2 avoided (Mt)	Mitigation cost (€/t CO_2)	Fossil fuel savings (Mtoe)	Additional cost of energy (%)		
SOLAR HEATING AND COOLING	1) Heat generation 2) 2% of demand 13 GWth installed capacity 3) Small scale for hot water: commercialised Combi-systems: Demonstrated Cooling systems: Development Medium temperature industrial systems: development	1) 2020: 52 GWth 2030: 135 GWth 2) 2020: 90÷320 GWth 2030: 200÷700 GWth 3) Integration in buildings Cooling Medium temperature systems for industrial applications	4÷30 (2020) 8÷65 (2030) 80÷600 (2010-2030)	270÷330 (2020) 80 (2030) 170÷220 (2010-2030)	25÷35 (2020) 50÷55 (2030) 65÷480 (2010-2030)	0.3÷2 (2020) 0.1÷ 1 (2030)	Heat storage Lack of financial incentives Building integration Lack of skilled professionals Regulations and administration	R&D in energy storage and materials research Financial incentives for the deployment of the technology
HYDROPOWER GENERATION: **LARGE HPP**	1) Power generation 2) 9% of demand about 95 GW installed capacity (non pumped storage) 3) Large scale: commercialised	1) 2020: 100 GW 2030: 100 GW 2) 2020: 101÷108 GW (refurbishment from 2005 park: 25÷50%) 2030: 104÷112 GW (refurbishment achieved from 2005 park: 55÷85%) 3) Large scale refurbishment of existing facilities Power electronics for dynamic operations (e.g. pumped hydro storage)	3.5÷15 (2020) 7.5÷20 (2030) 70÷270 (2010-2030)	25 (2020) 10÷20 (2030) 20÷25 (2010-2030)	1÷5 (2020) 2÷6.5 (2030) 20÷80 (2010-2030)	0.05÷0.2 (2020) 0.04÷0.2 (2030)	Lack of institutional support Complex regulations and administration Lack of support for R&D and Demonstration Equity shortage for R&D development and Demonstration Social acceptance	Increased R&D and Demonstration public support Focussed and co-ordinated R&D and Demonstration programme at the EU level Coherent, harmonised and conducive regulation and administration frameworks across the EU

TECHNOLOGY AVENUE	DESCRIPTION	POTENTIAL	ADDITIONAL IMPACT				BARRIERS	NEEDS
	1) Sector 2) Current market share 3) State of the Art	1) Baseline scenario 2) Potential penetration 3) Potential breakthroughs	Environment		SES	Competiti-veness		
			CO_2 avoided (Mt)	Mitigation cost (€/t CO_2)	Fossil fuel savings (Mtoe)	Additional cost of energy (%)		
HYDROPOWER GENERATION: **SMALL HPP**	1) Power generation 2) 1% of demand 11 GW installed capacity 3) Small scale: commercialised Very small scale: Development	1) 2020: 14.5 GW 2030: 15.5 GW 2) 2020: 14.5÷18 GW 2030: 16.5÷19 GW 3) Advanced low/very low head turbines Power electronics	0.5÷7.5 (2020) 1.5÷6.5 (2030) 15÷110 (2010-2030)	5÷10 (2020) 5÷7 (2030) 5÷8 (2010-2030)	0.2÷2.5 (2020) 0.4÷2 (2030) 3.5÷35 (2010-2030)	~0 (2020) ~0 (2030)	Lack of institutional support Complex regulations and administration Lack of support for R&D and Demonstration Equity shortage of SMEs for R&D development and Demonstration Social acceptance	Increased R&D and Demonstration public support Focussed and co-ordinated R&D and Demonstration programme at the EU level Coherent, harmonised and conducive regulation and administration frameworks across the EU
GEOTHERMAL	1) Heat and power generation 2) Less than 1% of demand 3) Heat pumps commercialised DH commercialised Enhanced geothermal power system RD&D	1) 2020: 1,0 GWe 2030: 1,3 GWe (heat not available) 2) 2020: 1÷6 GWe 2030: 1÷8 GWe 2030: 38÷42 GWth 2030: 60÷70 GWth	15÷35 (2020) 20÷50 (2030) 300÷700 (2010-2030)	0÷100 (2020) (-10)÷80 (2030) (-10)÷90 (2010-2030)	5÷12 (2020) 8÷16 (2030) 100÷200 (2010-2030)	0.2 (2020) (-0.3)÷ 0.3 (2030)	Lack of appropriate legislation Lack of financial incentives Lack of clarity in administrative procedures, long permit time Lack of skilled professionals Lack of social acceptance Fragmentation of existing knowledge	Coherent financial support mechanisms Additional incentives Appropriate regulations, standards, permit procedures RD&D support International collaboration and centralisation of existing knowledge Vocational and training programmes
OCEAN WAVE POWER	1) Power generation 2) Null 3) Large scale systems : Demonstrated < 1 MW, on-going up to a few MWs	1) 2020: 0,9 GWe 2030: 1,7 GWe 2) 2020: 5÷10 GWe 2030: 10÷16 GWe 3) Large scale testing to commercialisation Off-shore grid infrastructure	10÷15 (2020) 15÷25 (2030) 140÷275 (2010-2030)	70÷150 (2020) 70÷150 (2030) 70÷150 (2010-2030)	2÷5 (2020) 5÷10 (2030) 40÷80 (2010-2030)	0.5 (2020) 0.7÷0.9 (2030)	Cost competitiveness of ocean electricity High cost of technology learning Lack of dedicated engineering capacities and of private investments Cost of off-shore grid and unavailability of on-shore grid Administrative and legislative Coastal use	R&D and Demonstration Coordinated approach at EU level Long term feed-in tariff and capital investment support Coastal management at EU level

Technology Avenue	Description	Potential	Additional Impact				Barriers	Needs
			Environment		SES	Competitiveness		
	1) Sector 2) Current market share 3) State of the Art	1) Baseline scenario 2) Potential penetration 3) Potential breakthroughs	CO_2 avoided (Mt)	Mitigation cost (€/t CO_2)	Fossil fuel savings (Mtoe)	Additional cost of energy (%)		
Cogeneration of Heat and Power	1) Power generation / District heating / Industry 2) 10% of demand ~95 GWe installed capacity 3) Large/medium scale: commercialised Micro-CHP, fuel cells: R&D evaluation	1) 2020: 160 GWe 2030: 169 GWe 2) 2020: 165÷185 GWe 2030: 195÷235 GWe 3) Large/medium scale overhaul/replacement with higher electrical and overall efficiency Biomass based CHP Heat storage/cooling	50÷85 (2020) 50÷95 (2030) 1000÷1400 (2010-2030)	15÷30 (2020) 30÷70 (2030) 15÷40 (2010-2030)	20÷30 (2020) 20÷35 (2030) 400÷500 (2010-2030)	0.5÷1 (2020) 1÷3 (2030)	Lack of coherent policies in some MS Market liberalisation exposes short term profitability projects Market uncertainties about fuel and electricity prices Many (older) installations now operate with lower efficiency and uncompetitive costs level Correlation of heat and electricity demand Slow progress on micro-CHP development	Improved efficiency across the sectors, especially electrical Improvements in bio-CHP technology Innovations on thermal (heat) storage technologies and improved cooling systems Performance improvement (technology & economics) for heat distribution infrastructure for DH R&D, demonstration and financing small scale CHP (fuel cells and micro-CHP) that lead to their mass introduction Support transition to decentralised energy supply
Zero Emission Fossil Fuel Power Plants	1) Power generation 2) Null 3) Individual components commercialised in smaller scales Overall, in advanced research and validation phase, ready to embark on large scale demonstration	1) 2020: 0 GWe 2030: 0 GWe 2) 2020: 5÷30 GWe 2030: 90÷190 GWe 3) Successful large scale demonstration projects by 2015	20÷120 (2020) 330÷700 (2030) 1800÷4700 (2010-2030)	30 (2020) 16÷18 (2030) 18÷20 (2010-2030)	(-3)÷(-15) (2020) (-40)÷(-90) (2030) (-230)÷(-600) (2010-2030)	0.3÷2 (2020) 2÷6 (2030)	Technology not demonstrated at large scale High cost of first-of-a-kind plants Unfavourable market and regulatory conditions Lack of supportive fiscal measures Lack of CO_2 transmission and storage infrastructure Public acceptance	Research and development Large scale demonstration projects Development of a suitable regulatory and market framework Development of CO_2 transport and storage infrastructure

Technology Avenue	**Description**	**Potential**	**Additional Impact**				**Barriers**	**Needs**
			Environment		SES	Competitiveness		
	1) Sector 2) Current market share 3) State of the Art	1) Baseline scenario 2) Potential penetration 3) Potential breakthroughs	CO_2 avoided (Mt)	Mitigation cost (€/t CO_2)	Fossil fuel savings (Mtoe)	Additional cost of energy (%)		
Nuclear Fission Power	1) Power generation (Gen-IV with heat generation) 2) 31% of demand ~135 GWe installed capacity 3) Gen-III: Mature technology. Gen-IV: depends on concept. Basic research still required for all designs leading to strategic decisions by 2012 at the latest. First of a kind and demo plants (VHTR and SFR) by 2020	1) 2020: 114 GWe 2030: 100 GWe 2) 2020: 127÷150 GWe 2030: 127÷200 GWe 3) To maintain market share requires c. 100GWe new build over next 25 years (Gen-III) Development of fast reactors and fuel cycles will enable much greater sustainability	55÷160 (2020) 100÷400 (2030) 1100÷3800 (2010-2030) No account taken of possible market insertion of VHTR (process heat) Current annual savings by existing nuclear plants accounts for about 800 Mt of CO_2 and 250 Mtoe of fossil fuel (not included in above figures)	(-5) (2020) (-10) (2030) (-10)÷(-5) (2010-2030)	15÷50 (2020) 35÷125 (2030) 300÷1200 (2010-2030)	(-0.5)÷(-0.1) (2020) (-2)÷(-0.5) (2030)	Lack of overall EU nuclear strategy Lack of harmonised regulations and standards Public/political acceptance Insufficient public R&D funding for Gen-IV Future availability of suitably qualified scientists and engineers	A stable and predictable regulatory / economic / political environment. Clear EU nuclear strategy Increased support for RDD&D on Gen-IV; more public funding, public-private partnerships, Joint Undertakings, etc. Better public and stakeholder information and dialogue on nuclear energy Promote education and training in scientific disciplines in general and nuclear technology in particular
Nuclear Fusion Power Generation	1) Power generation 2) None 3) Committed construction of ITER as prototypic experiment aimed at demonstrating the technological feasibility of fusion energy	1) N.A. before 2030 2) After 2030 3) Operation of DEMO as demonstration fusion power plant	N.A. No CO_2 or other air pollutants during operation Huge potential fossil fuel savings with water and lithium as largely available inexpensive fuels Cost of energy is expected to be balanced by the outstanding improvement of the competitiveness of European industry	N.A.	N.A.	N.A.	Limited industrial contributions to the financial sources due to the long-term nature Low availability of suitable trained engineers and scientists S&T challenges on frontier technologies	Strengthen the organisation of fusion development with reinforced industrial participation, in particular within the DEMO design group Reinforcement of education and training programmes Strong political will for shortening the timescale of fusion development through EU and international resources

TECHNOLOGY AVENUE	**DESCRIPTION**	**POTENTIAL**	**ADDITIONAL IMPACT**				**BARRIERS**	**NEEDS**
	1) Sector 2) Current market share 3) State of the Art	1) Baseline scenario 2) Potential penetration 3) Potential breakthroughs	Environment		SES	Competitiveness		
			CO_2 avoided (Mt)	Mitigation cost (€/t CO_2)	Fossil fuel savings (Mtoe)	Additional cost of energy (%)		
ELECTRICITY NETWORKS (SMART GRIDS)	1) Power transmission / distribution 2) 75÷85% of generation at transmission level 7÷10% of electricity consumed lost at transmission and distribution levels 3) Long overhead lines Centralised network control	1) New generation partially constrained by network bottlenecks 2) 2020: 1% losses reduction 2030: 2.5% losses reduction 3) HVDC, FACTS,WAMS Active network management of distributed generation systems	20÷30 (2020) 50÷60 (2030) 500÷600 (2010-2030)	N.A. N.A. N.A.	5÷10 (2020) 15÷25 (2030) 150÷250 (2010-2030)	N.A. N.A.	How to define/share reinforcement and connection cost between stakeholders under discussion Regulatory framework Social oppositions Lack of coordinated research efforts	EU Member States need to invest at least 400-450 b€ in transmission and distribution infrastructures over the next three decades Depending upon distance between new generation and a robust grid (e.g. off-shore wind, concentrated solar power), a further 10 to 25% share of connection costs may add to the global grid investment Shared design for integrating new generation technologies ICT for control and monitoring Standard rules and guidelines
			An integrated electricity grid fosters EU market competitiveness, in terms of impact on electricity prices and support to liberalisation The mitigation costs are not evaluated here because it is not quantifiable which part of the investments results in losses reduction and which part in the below listed further benefits Key benefit of grids coordinated and integrated development is the relief of cost-effective generation capped by bottlenecks. In this assessment it is assumed that each generation sector can inject into a reinforced grid nearly the maximum power Further benefits include network investment deferral, reduction of outages, increase in quality of supply					
BIOFUELS	1) Transport 2) 3.9 Mt of biofuels in 2005 3) 1st generation: Commercialised 2nd generation: pilot scale demonstrated	1) 2020: 7.5% of transport petrol & diesel demand 2030: 9.5% of transport petrol & diesel demand 2) 2020: 10÷14% of transport petrol & diesel demand 2030: 15÷20% of transport petrol & diesel demand 3) 2nd generation large scale demonstration by 2015	15÷40 (2020) 45÷75 (2030) 375÷810 (2010-2030)	150÷160 (2020) 90 (2030) 120÷125 (2010-2030)	10÷25 (2020) 20÷40 (2030) 190÷450 (2010-2030)	1.5÷3.5 (2020) 2.0÷3.5 (2030)	No structural barriers Biomass availability and sustainability (including allocation between energy sectors and competition with non-energy sector)	Reinforced and focused public support for R&D at national and EU levels Funding mechanisms for large scale demonstration initiatives Harmonisation of markets, regulations and policies at EU levels

TECHNOLOGY AVENUE	DESCRIPTION	POTENTIAL	ADDITIONAL IMPACT				BARRIERS	NEEDS
			Environment		SES	Competiti-veness		
	1) Sector 2) Current market share 3) State of the Art	1) Baseline scenario 2) Potential penetration 3) Potential breakthroughs	CO_2 avoided (Mt)	Mitigation cost (€/t CO_2)	Fossil fuel savings (Mtoe)	Additional cost of energy (%)		
HYDROGEN AND FUEL CELLS	1) Transport and Power generation 2) Null 3) Large scale hydrogen production: commercialised or under development Small scale H_2: Demonstra-tion/Commercialised Fuel cells: Demonstration	1) 2020 – 2030: 0% of passenger cars 2) 2020: 1.5% of passenger cars 2030: 6% to 12% of passenger cars 3) Low cost, reliable and durable fuel cells High capacity hydrogen storage Low cost and large scale carbon free/lean H_2 supply	5 (2020) 30÷60 (2030) 185÷330 (2010-2030) Impacts only for passenger cars	475 (2020) 100÷240 (2030) 145÷290 (2010-2030)	2.5 (2020) 10÷20 (2030) 80÷135 (2010-2030)	0.3 (2020) 0.7÷0.8 (2030)	Long term and disruptive mitigation option Lack of end-use deployment support Regulation and Code and Standards High up-front infrastructure investments for hydrogen production and supply Shortage of equity for SMEs High cost of fuel cells Pending issue of primary resources allocation for hydrogen production	Focussed R&D and large scale Demonstration and market preparation efforts at EU level Long term public and private partnership Establishment of regulatory and financial support schemes Education