

Titolo

Summary Tables for European Energy Technology Road Map

Descrittori

Tipologia del documento: Technical report
 Collocazione contrattuale:
 Argomenti trattati: Energy Technology Road Map

Sommario

The Strategic energy technology Plan (SET- Plan) is the technology pillar of the EU's energy and climate policy. The objective is to drive the improvement and development of the technologies necessary to adapt the current energy system into a more sustainable, competitive and secure one. The aim is to reduce carbon dioxide (CO₂) emissions by at least 85 % by 2050 compared to the 1990 levels. It responds to the challenge of accelerating the development of low-carbon technologies, leading to their widespread market take-up. This document summarizes the principal characteristics of each energy technology involved in the SET-Plan in order to identify the state of the art and the further potential improvements at medium and long-term of both technology and materials. The focus of this report is to provide a general framework for a comparative assessment of the impacts and the sustainability performance of renewable, fossil, and nuclear technologies.

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REV.	DESCRIZIONE	DATA		REDAZIONE	CONVALIDA	APPROVAZIONE

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Introduction

The European Union (EU) is tackling climate change, energy supply security and economic competitiveness through the transformation of the energy system, with far-reaching implications on how we source and produce our energy, how we transport and trade it, and how we use it. The aim is to reduce carbon dioxide (CO₂) emissions by at least 85 % by 2050 compared to the 1990 levels. There is no single energy technology that alone can sustain this transformation. Either the energy sources are not sufficiently abundant or they have drawbacks in terms of sustainability or security of supply. In other cases the technologies proposed are not yet competitive as compared to technologies using fossil fuels. Therefore, a broad portfolio of low-carbon technologies is required for coping with future uncertainty.

Since 2008, the EU implements the Strategic Energy Technology Plan (SET-Plan) with the aim to:

- a) accelerate energy technology development, technology transfer and up-take;
- b) maintain EU industrial leadership on low-carbon energy technologies;
- c) foster science for transforming energy technologies to achieve the 2020 energy and climate change goals; and
- d) contribute to the worldwide transition to a low-carbon economy .

The intent of this report is to set a general framework of European energy technologies as the basis for further comparative assessment of the impacts and the sustainability performance of renewable, fossil, and nuclear technologies. Although a wide range of technologies and methods exist to improve energy performance, supply renewable energy sources and reduce emissions, only some of these will be summarized herein. Much of the data are been taken up from two main documents: *2013 Technology Map* and the *Materials Roadmap Enabling Low Carbon Energy Technologies*. The first provides up-to-date information about the current European energy technology portfolio and the potential improvement that could be carried out by R&D; the second one complements and expands the technology roadmaps developed in the context of the SET-Plan as the basis for its implementation.

In order to provide a most detailed framework, the tables presented below have been divided in two main parts. The upper part composed of four fields: *Technology*, *Components*, *State of Art* and *Research Areas* and the bottom part composed of two fields *Materials Road Map* and

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Market. It has not been possible to bring up the *Components* field in all of the tables owing the complexity of some technologies. Furthermore in some of the tables below, the *Materials Road Map* field will be absent, because some technologies were not mentioned in the *Materials Roadmap Enabling Low Carbon Energy Technologies*.

The emphasis will be given on the following technologies:

1. Wind Power Generation;
2. Solar Photovoltaic Electricity Generation;
3. Concentrated Solar Power Generation;
4. Hydropower;
5. Geothermal Energy;
6. Marine Energy;
7. Carbon Capture and Storage in Power Generation;
8. Advanced Fossil Power Generation;
9. Nuclear Fission Power Generation;
10. Nuclear Fusion Power Generation;
11. Bioenergy- Power and Heat Generation;
12. Biofuels for the Transport Sector;
13. Hydrogen and Fuel Cells;
14. Electricity Storage in the Power Sector;
15. Smart Grid;
16. Cogeneration or Combined heat and Power
17. Heat Pumps;

Table 1: Summary of Wind Power Generation Technology

Wind Power Generation			
Technology	Components	State of Art	Research Areas
<p>HAWT (Horizontal Axis Turbines), are the most common turbine configuration used today, have the main rotor shaft and electrical generator at the top of a tower.</p>	Blades	<p>Composite Processing Technology: matrix composites (PMCs), ceramic matrix composites (CMCs) and metal matrix composites (MMCs)</p> <p>-Prepreg Technology (“pre impregnation”);</p> <p>-Infusion Technology.</p> <ul style="list-style-type: none"> • Wood/laminates • Glass fibre laminates • Carbon fibre laminates • Polymer matrix composite (PMC) • Fiber reinforced plastic (FRP). 	<p><u>Fibre-reinforced materials</u></p> <ul style="list-style-type: none"> • Materials modelling from micro-scale via phenomenological and subcomponent approach to full-scale modelling and extension; • Development of new/improved materials that combine high strength, stiffness, toughness and fatigue resistance for the production of very light blades; • Development of recyclable materials for blades such as thermoplastics as well as natural fibres and biopolymers <p><u>Sandwich core materials</u></p> <ul style="list-style-type: none"> • Development of cost competitive, very lightweight core materials that perform at least as good as the currently used balsa wood and PVC foams and that can be recycled and produced in an environmental sustainable manner. <p><u>Adhesives and joining/bonding materials</u></p> <ul style="list-style-type: none"> • Development of adhesives and joining/bonding materials suited for the newly developed structural blade materials; • Material characterization and modelling of adhesives and bonding materials to enable state of the art strength and fatigue analyses. <p><u>Coatings</u></p> <ul style="list-style-type: none"> • Development and testing of blade coatings to increase the biofouling erosion and UV light resistance, the self cleaning capability and the ice shedding efficiency; • Development and testing of blade coatings to reduce the detectability of static or rotating wind turbines by radars (“stealth” materials).
	Tower	<ul style="list-style-type: none"> • Still ; • Composite lattice (small turbines); • Pre stressed concrete; 	<p><u>Material developments and related joining technologies</u></p> <ul style="list-style-type: none"> • Development of high strength, heavy gauge, steels (thickness above 30 mm), with high toughness down to -50°C and with well suited welding technology; • Development of high efficient, in terms of productivity, welding techniques as submerged arc welding, laser welding and non-vacuum electron beam welding and hybrid-friction stir welding; • For onsite joining of parts the development of automatic or robotised gas metal arc welding procedures and the further development of bolted flange and friction connections; • Application of coatings and development of new protection methods for towers and substructures to reduce erosion, oxidation and biofouling. <p><u>Concrete</u></p> <ul style="list-style-type: none"> • Development and application of drilled concrete monopiles and gravity based support structures for deep water applications.
	Generator	<ul style="list-style-type: none"> • Induction generator • Asynchronous generator 	<p><u>Permanent magnet materials</u></p> <ul style="list-style-type: none"> • Reduction of use and substitution of rare earth elements in permanent magnet generators; • Development of stronger, lighter magnets with improved key magnet parameters including intrinsic coercivity and remanence. <p><u>High temperature superconducting materials</u></p> <ul style="list-style-type: none"> • Development of high temperature superconducting (HTS) generators for the application in large MW wind turbines; • This includes the development of robust, reliable and low maintenance cryogenic techniques required for generator cooling; • Reduction in the price of superconductor wire.

Materials Road Map

The materials roadmap for wind energy proposes a comprehensive research and development programme on blade materials such as fibre reinforced and sandwich core materials as well as bonding and joining technologies to improve the mechanical properties at reduced specific weight, to improve rotor performance and lifetime by intelligent use of materials and to reduce the manufacturing cycle times and production cost of blades; the development of new coatings for improved erosion resistance, self-cleaning and UV protection; the development of steel with enhanced properties for tower and support structures and related welding techniques, of concrete for mono-piles and gravity-based structures for deep water applications; the improvement of foundry technologies for dross-free ductile iron with high as well as lightweight composite structure to replace cast iron components.

The roadmap focuses also on materials used in generator, power electronics and transmission (shaft, gears and bearing) with research efforts to substitute rare earth elements in permanent magnets and develop stronger, lighter magnets; to develop high temperature superconducting (HTS) generators, new materials for power electronics to increase the working limit of junction temperatures and metal alloys for transmission components to ensure an effective lifetime equal to the design lifetime. To scale-up the material development to industrial scales, the roadmap puts forward up to 4 industrial manufacturing pilots to develop and produce concept blades at MW scale, to develop, manufacture and demonstrate lightweight (composite) hub, bedplate or generator gearbox housing as alternative for cast iron components, to design, produce and test large blades with a length of over 100 m that allows the economic design of >12 MW turbines as well as automated production techniques in a MW scale blade production line; up to 2 technology pilots to test gravity based support structure for large water depth and demonstrate a HTS generator at full scale. Finally the roadmap proposes the creation of Trans-European research field network facilitators to accelerate industrial development and the up-take of research results as well as a test rig for the testing of large (> 10MW) drive train units.

Market

There are two main market sectors: onshore and offshore wind. The differences include complexity of installation, working environment (saline and tougher at sea), and facility of access for installation and maintenance.

2013 was a record year for offshore installations, with 1,567 MW of new capacity grid connected. Offshore wind power installations represent over 14% of the annual EU wind energy market, up from 10% in 2012. A total of 117 GW is now installed in the European Union, a growth of 10% on the previous year and lower to the growth recorded in 2012 (+12% compared to 2011). Germany remains the EU country with the largest installed capacity, followed by Spain, the UK, Italy and France. Eleven other EU countries have over 1 GW of installed capacity: Austria, Belgium, Denmark, France, Greece, Ireland, The Netherlands, Poland, Portugal, Romania and Sweden.

Eight of the latter (Denmark, France, Germany, Italy, Portugal, Spain, Sweden, United Kingdom), have more than 4 GW of installed wind energy capacity.

Germany (34.3 GW) and Spain (23 GW) have the largest cumulative installed wind energy capacity in Europe. Together they represent 49% of total EU capacity. The UK, Italy and France follow with, respectively, 10.5 GW (9% of total EU capacity), 8.6 GW (7%) and 8.3 GW (7%). Amongst the newer Member States, Poland, with 3.4 GW (2.9%) of cumulative capacity, is now in the top 10, in front of the Netherlands (2.7 GW, 2%), and Romania is 11th with 2.6 GW (2%).

The wind power capacity installed by the end of 2013 would, in a normal wind year, produce 257 TWh of electricity, enough to cover 8% of the EU's electricity consumption – up from 7% the year before.

Table 2: Summary of Solar Photovoltaic Electricity Generation Technology

Solar Photovoltaic Electricity Generation			
Technology	Components	State of Art	Research Areas
Thin-film technologies; Multi-junction concentrator technologies	Solar Panel	<p>Materials: inorganic or organic. <u>Inorganic cells</u> : silicon (Si) or non-Si material.</p> <ul style="list-style-type: none"> • Wafer-based cells or • Thin-film cells. <p>Wafer-based Si is divided into two different types:</p> <ul style="list-style-type: none"> • monocrystalline • multicrystalline <p>In 2012, more than 85 % of new PV systems were based on crystalline Si technology that is highly matured for a wide range of applications.</p>	<p>Primary research issues are: reducing the costs and increasing the performance of PV technologies, the energy and materials consumption in manufacturing and installation and the energy pay-back time of systems; increasing the lifetime of PV system components, substituting the use of scarce, hazardous, rare and expensive materials.</p> <p>The main research areas are:</p> <ul style="list-style-type: none"> • Wafer-based crystalline silicon; in particular reducing the cell thickness and implementing advanced cells design, e.g. selective emitter, rear contact cells, etc.; • Existing thin-film technologies; in particular emphasising the research activities on bottlenecks such as interfaces, intra-grain defects, interconnections, etc.; • III-V multi-junction and concentrator technologies; in particular simplifying the multi-junctions formation, studying the mismatching and the tunnel layers. • Advanced inorganic thin-film technologies with emphasis on high growth rates, stable and reliable materials as well as increased cell efficiency through innovative device structures; • Organic solar cells, based on polymers, molecules, dye sensitized and hybrid cells; • Thermo-photovoltaics; • Novel PV-technologies; • Novel active layers; • Tailoring the solar spectrum to boost existing cell technologies; in particular, the use of nano-dots and nano-wires to improve photon conversion, i.e. down conversion, up conversion, multi-generation of excitons, and their implementation in conventional or advanced cells. • Thermo-photovoltaic (TPV) cells and systems.
Materials Road Map			
<p>Materials are key enablers in all PV systems. Crystalline Si-based systems are expected to remain the dominant PV technology in the short-to-medium term. Most of the 'novel' approaches can be categorised as high-efficiency approaches, in both cases nanotechnology and nano-materials are expected to provide the necessary toolbox to bring about these effects. The materials roadmap for PV energy proposes a comprehensive research and development programme on the optimisation of materials usage through predictive modelling down to quantum devices at the nanoscale, the improvement of intrinsic performance and reduction in layer thickness of constituent materials for both inorganic and organic PV cells and modules, the development of alternative manufacturing processes for specific solar grade materials, the development of thinner, higher strength, conformal, lower cost glass as well as flexible, light weight, low cost, long lifetime and high barrier encapsulants and optical glues.</p> <p>The roadmap focuses also on materials for light management (anti reflective, anti soiling, anti abrasion coatings, light trapping/guidance, spectral conversion and optical concentrators materials); the development of high through put, low cost manufacturing processes for film/layer deposition / thin film (epitaxial) growth; the development of materials for system-related devices such as inverters and trackers as well as the research into novel materials and processes. 3 manufacturing pilot projects on new solar grade materials, non vacuum deposition processes and PV high performance, thin, high strength glass; 1 field pilot to test new materials / device designs under real market conditions and to demonstrate the cost-effectiveness of combined High Concentrator PV and energy storage solutions for small-scale grid locations.</p>			

Market

Since 1990, annual global cell production has increased by three orders of magnitude from 46 MW to about 38 GW in 2012. This corresponds to a compound annual growth rate (CaGR) of about 36 % over the last 23 years. Statistically documented cumulative installations worldwide accounted for 100 GW in 2012. The total installed capacity of PV systems in the eU in 2012 was 68.8 GWp, representing approximately 8.5 % of the total eU electrical generation capacity. The electricity generated by PV systems that year was approximately 65 TWh. The highest shares were reported for Italy with 18.2 TWh and Germany 28.5 TWh, which correspond to 5.6 and 5.7 % of final electricity consumption, respectively. The annual installation of PV systems in 2012 in the eU was about 17.6 GWp and will likely remain in the first place of the ranking of newly built electricity generation capacity after it moved to this position in 2011. Europe is currently the largest market for PV systems with about 58 % of the annual worldwide installations in 2012. In terms of solar cell production, Europe has slipped behind China and Taiwan to third place, capturing about 6.5 % of the world market; but it is still a world leader in PV technology development.

Scenarios for the worldwide deployment of PV technology vary significantly between the 2010 IEA PV technology Roadmap scenario and the Greenpeace/European Renewable Energy Council (EREC) scenarios. The IEA scenarios range between 210 GW (298 TWh) by 2020 and 870 GW (1 247 TWh) by 2030, and the Greenpeace scenarios vary between 124 GW (158 TWh) by 2020 and 234 GW (341 TWh) by 2030 for the reference scenario, and 674 GW (878 TWh) by 2020 and 1764 GW (2 674 TWh) by 2030 for the advanced scenario.

(JRC, 2014), (EU Commission, 2011)

Table 3: Summary of Solar Photovoltaic Concentrate Solar Power Generation Technology

Concentrate Solar Power Generation (CSP)			
Technology	Components	State of Art	Research Areas
<p>Trough concentrators</p> <p>Linear Fresnel reflectors</p> <p>Central receivers (Solar towers)</p> <p>Dish systems</p> <p>The current CSP market is dominated by the parabolic trough technology. More than 80% of the CSP power plants in operation or under construction are based on this technology.</p>	<p>Collectors</p>	<p>Are usually subdivided into two types:</p> <ul style="list-style-type: none"> • <u>Line-focusing systems</u> : track the sun position in one dimension (one-axis-tracking) • <u>Point-focusing systems</u>: realize higher concentration ratios than line-focusing systems, these mirrors track the sun position in two dimensions (two-axis-tracking) 	<p>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.</p> <p>The industry is already focused on the R&D of the next stage of technology improvements, which shall have great impact on costs and efficiency of CSP plants. These improvements, which can be either technology specific or horizontal to most technologies, are centred on three main areas:</p> <ul style="list-style-type: none"> • Increase power generation efficiency, mainly through the rise of the operating temperature leading to higher turbine efficiency, but also through improvements in reflecting facets (Mirror’s capacity to reflect sun radiation) and receivers; • Reduce solar field costs by minimizing costs and through design optimization that can lead to more cost effective solar fields deployment; • Reduce internal resource consumption through reduction of needed water and auxiliary parasitic consumption (Plant operations require consumption of electricity, e.g. to pump fluids) <p>Key components to reduce the solar field cost are support structures, including foundations, mirrors and receivers. These costs will tend to decline over time as the overall volume increases.</p> <p>For mirrors, cost reductions may be accomplished by moving from heavy silver-backed glass mirror reflectors to lightweight front-surface advanced reflectors (e.g. flexible aluminium sheets with a silver covering and silvered polymer thin film), silver-backed glass mirrors are highly specular, that is to say they concentrate the sun’s rays into a narrow cone to intersect the receiver. Any new reflector solutions need to also be highly specular.</p> <p>The advantages of thin-film reflectors are that they are potentially less expensive, will be lighter in weight and have a higher reflectance. They can also be used as part of the support structure. However, their long-term performance needs to be proven. Ensuring that the surface is resistant to repeated washing will require attention. In addition to these new reflectors, there is also work underway to produce thinner, lighter glass mirrors.</p> <p>Currently operating parabolic trough plants use a synthetic aromatic fluid (SAF) as heat transfer fluid. This fluid is organic (benzene)based and as such cannot reach temperatures above 400°C with acceptable performance due to its decomposition at higher temperatures. This limited temperature range is capping overall steam cycle efficiency. To overcome this obstacle, developers are focusing on the development of alternative fluid technology, namely: molten salt, direct steam generation, nanotechnology improved fluids and alternative inorganic fluids.</p>
	<p>Receivers</p>	<p>They consist of a coated absorber tube and an encasing glass tube. The absorber is realized in the form of a coated steel tube surrounded by an evacuated glass tube which is highly transmissive for the sun light due to an anti-reflexive coating. Another concept is based on several parallel tubes forming a multi-tube receiver.</p> <p>In the solar tower plant the receivers use water/steam, air or molten salt to transport the heat, the upper working temperatures range from 250°C to 1000°C.</p>	

	<p>Support Structure</p>	<p>The metal support structure</p>	<p>For the support structures, developers are looking at reducing the amount of material and labour necessary to provide accurate optical performance (Flexing of the support structures in windy conditions can have a negative impact on the concentration of sunlight on the receivers.) and to meet the designed “survival wind speed”. Given that the support structure and foundation can cost twice as much as the mirrors themselves, improvements here are very important.</p>
	<p>Thermal Storage</p>	<p>To date, this has been primarily for operational purposes, providing 30 minutes to 1 hour of full-load storage. Plants are now being designed for 6 to 7.5 hours of full-load storage, which is enough to allow operation well into the evening when peak demand can occur and tariffs are high.</p> <p>Storage media include:</p> <ul style="list-style-type: none"> • Molten Salt • Steam Accumulators • Solid Ceramic Particles • High Temperature Concrete <p>Today's state-of-the-art thermal energy storage solution for CSP plants is a two-tank molten salt thermal energy storage system. The salt itself is the most expensive component and typically accounts for around half of the storage system cost, while the two tanks account for around a quarter of the cost.</p>	<p>Improving the performance of the thermal energy system, its durability and increasing the storage temperature hot/cold differential will bring down costs. For solar towers, increasing the hot temperature of the molten salt storage system should be possible (up to 650°C from around 560°C), but will require improvements in design and materials used. The development of heat transfer fluids that could support even higher temperatures would reduce storage costs even further and allow even higher efficiency, but it remains to be seen if this can be achieved at a reasonable cost. If direct steam towers are developed, current storage solutions will need to be adapted, if the capacity factor is to be increased and some schedulable generation made available.</p>

Materials Road Map

The materials roadmap for CSP proposes a comprehensive research and development programme on low-cost, spectrally selective, high mechanically stable absorber materials suited also for higher temperatures; and the development of higher reflectance and/or specularly, cost competitive, sustainable reflector materials. The roadmap focuses as well on heat transfer media to develop alternative synthetic fluids coupled with the improvement of molten salts and liquid metals to allow for higher temperatures, better heat transfer and better chemical stability; the development of more sustainable, reduced cost, corrosive-resistant structural materials such as steel, aluminium, fibre composites and the development of storage materials (heat storage materials and materials for thermo-chemical storage) to increase the performance and extend the operating temperature up to 600°C. To scale-up the material development to industrial scales the roadmap foresees up to 5 industrial 6 pilot projects to manufacture absorber coatings, profiled multilayer tubes, high temperature synthetic heat transfer fluids, catalyst materials and heat exchangers of ceramics or alloys; up to 5 technology pilots to test and validate material performances under real market

conditions in the areas of storage technologies, new molten salt mixtures, porous ceramic or metal structures for central receivers, fluidised bed materials as well as piping and tank structures. The roadmap puts also forward 3 test facilities (for coating technology, high temperature research and for advanced composites) to be developed in the framework of research infrastructure.

Market

At the end of beginning of May 2013, CSP plants with a cumulative capacity of about 2.05 GW were in commercial operation in Spain, representing about 69 % of the worldwide capacity of 2.95 GW. Together with those plants under construction and those already registered for the FIT, this should bring Spain's CSP capacity to about 2.3 GW by the end of 2013. Projects that have applied for interconnection have, all together, a combined total capacity of 15 GW. This is in line with the SEII, which aims at a cumulative installed CSP capacity of 30 GW in Europe, out of which 19 GW would be in Spain (eStela, 2009). In the US, about 1.2 GW of CSP are currently under construction and another 4.2 GW in the development stage. More than 100 projects are currently in the planning phase, mainly in India, North Africa, Spain and the US. The economic potential of CSP electricity in Europe is estimated to be around 1 500 TWh/year, mainly in Mediterranean countries (direct normal irradiance (dni) > 2 000 kWh/m²/year). Based on today's technology, the installed capacities forecasted in the EU-27 under the SEII are 830 MW by 2010, 30 GW by 2020 and 60 GW by 2030. This represents respectively, up to 2030, 0.08 %, 2.4 % and 4.3 % of projected EU gross electricity consumption. These penetration targets do not account for imports of CSP electricity. According to the SERTEC scenario, which assumes that a grid infrastructure will be built to connect Europe with North African Countries, CSP electricity imports of 60 TWh in 2020 and 230 TWh in 2030 could be realised. The penetration of CSP electricity for 2030 under these scenarios would be 10 % of the EU gross electricity consumption.

(MNA, 2011), (JRC, 2014), (EU Commission, 2011), (EU Commission, 2013)

Table 4: Summary of Hydropower Systems

Hydropower			
Technology	Components	State of Art	Research Areas
<p>Hydropower plants (HPP) are very diverse in terms of size and type of plant, size and type of generating unit, the height of the water fall (“head”), their functions (electricity generation, capacity or multi-purpose) and sizes.</p> <p>Three functional categories:</p> <ol style="list-style-type: none"> 1. Pumped hydropower storage (PHS); 2. Run-of-the-river (RoR) 3. Reservoir (or storage) HPP. 	<p>Pumps</p>	<p>There are two main types of PHS facilities:</p> <ul style="list-style-type: none"> - Pure or off -stream PHS (which rely entirely on water that were previously pumped into an upper reservoir as the source of energy); - Combined or pump -back PHS, which use both pumped water and natural stream flow water to generate power. <p>At state -of-the-art PHS system may achieve over 80% efficiency.</p>	<p>Many EU countries have introduced large economic support programs, such as feed-in tariffs. Some of these systems include smaller-scale hydropower projects, but most exclude larger-scale hydropower projects. In this context, reservoir HPP and PSP could facilitate the expansion of variable renewables.</p> <p>Many PSP projects are currently under development, in Europe. This includes modernization, upgrading or full redevelopment of 30- to 50-year-old PSP, and gradual expansion of recent plants.</p> <p>Technological drivers include increasing the efficiency of generation equipment above the current 85–95 %, and enhancing the control capacity of pumps for PHS through variable speed. Three main drivers are pushing developments in this field: erection of new large hydropower plants abroad; rehabilitation and refurbishment of existing hydropower facilities in Europe; and the need for the storage capability that would allow the electricity system to accommodate additional renewable power from wind and other variable sources. average efficiency improvements that can be expected from refurbishment are of the order of 5 %.</p>
	<p>Turbines</p>	<p>Small discharge, high-head installations are typically mountain-based dams and are equipped with Pelton turbines (impulse turbine). Large discharge, low-head installations are typically large RoR plants equipped with Kaplan turbines. intermediate flow rates and head heights are usually equipped with Francis turbines. (Kaplan and Francis turbines are reaction turbines).</p>	<p>R&D efforts address: load and fatigue analysis of turbine and generator components, in particular in a context of variable-speed and frequent stop–start operations; the integration of LHP with other renewable energies, for example through speed-adjustable generators; the development of hybrid systems, for example with wind, and minimising environmental impacts, for example turbine design with fewer blades and less clearance between the runner and housing to reduce injuries to and stress factors for fish, or oil-free Kaplan turbines to eliminate leak-related risks</p>
	<p>Dams</p>	<p>In cases where dams have been originally built for other purposes, such as for flood control and for water storage for irrigation and urban use, a hydropower plant may be added with a capital cost as low as EUR 400/kW.</p> <p>The impact of large hydroelectric facilities on the environment is often significant. Small installations, on the other hand, have minimal reservoir and civil construction work, so their environmental impact is</p>	

relatively low

Materials Road Map

Research in materials is focusing on cheaper alternatives to steel in some components and applications, such as fibreglass and special plastics. Developing more resistant materials to extend the lifetime of some components is also essential, for example steel alloys that are more resistant to turbine cavitation or high-voltage insulation systems able to sustain short-period operations to 180 °C.

Market

The global installed hydropower capacity at the end of 2012 was 990 GW, with 30 GW added during that year (Ren21, 2013). With 3 700 TWh generated worldwide in 2012, hydropower accounts for an estimated 16.5 % of the global electricity generation and 79 % of all electricity from renewable resources. This share is expected to increase to around 19 % in 2020 and up to 21 % in 2030. In Europe, in 2012, the 106 GW of hydropower plants generated 330 TWh of electricity, or 44 % of that one from renewable energy sources (RES) - down from 65 % in 2007. this is 10 % of the total electricity production in the EU-27. The global potential has been estimated at 9 770 TWh, although the growth expected is more modest but still doubling current generation to 7 000 TWh by 2050, including a three- to five-fold of PHS capacity. Nevertheless, in terms of the share in gross electricity generation, and due to increasing electricity demand, a share decrease to 9.2 % in 2020 and further down to 8.8 % in 2030 is expected. This estimation is based on the fact that the most favourable sites are already being exploited across the EU, while due to environmental restrictions it's unlikely that Europe could see much more expansion.

(JRC, 2013), (JRC, 2014), (IEA, 2012)

Table 5: Summary fo Geothermal Energy Systems

Geothermal Energy			
Technology	Components	State of Art	Research Areas
<p>Geothermal energy can be used for a wide range of applications from standard 12 kW_t heat pump systems in residential buildings up to geothermal power plants with electric capacities of 100 MWe and more. The application depends on the system's heat content and on the designated use of the geothermal source. Usually a minimum fluid temperature of 100°C is required.</p> <p>There are three types of conventional geothermal power plants:</p> <p>Direct Dry Steam</p> <p>Flash and Double Flash Cycle</p> <p>Binary Cycle</p> <p>Within each geothermal power plant category, the efficiency is mainly dependent upon the temperature (80–300 °C) of the geothermal working fluid.</p>	<p>Turbines</p> <p>Generators</p> <p>Transformers</p> <p><i>These components have the same characteristics of conventional energy systems.</i></p>	<p>The conventional geothermal power plants that are commercially available use hydrothermal resources that exist naturally in a particular location as their main supply of energy. There are three types of conventional geothermal power plants: dry steam, flash steam, and binary cycle and variations of them (e.g. combined-cycle or hybrid plants, combined heat and power). A typical geothermal dry steam/flash plant's capacity is 50–60 MWe but up to 300 MWe plants (Hellisheidi, Iceland, 7 power units) have been commissioned and are currently in operation. Within each geothermal power plant category, the efficiency is mainly dependent upon the temperature (80–300 °C) of the geothermal working fluid.</p> <p>Enhanced geothermal system (EGS) development is seen as an alternative for energy production with high production potential compared to the conventional geothermal power plants that presently rely on scarce natural hydrothermal reservoirs. EGS can provide energy supply almost everywhere, since almost any site at a specific depth can be considered a reservoir. In order to use this high potential, the EGS technology still needs to experience an intensified R&D phase in order to reach the stage of successful demonstration and commercially viable power plant by 2030</p>	<p>One of the main future challenges for the geothermal sector is the expansion of the EGS concept across the different regions and geological conditions of Europe. The construction of these types of novel power plants together with the development of more efficient binary cycle systems for low-temperature resources will preserve EU leadership in this area of geothermal technology and electricity production.</p> <p>EGS development is seen as an alternative for energy production with high production potential compared to the conventional geothermal power plants that presently rely on scarce natural hydrothermal reservoirs. EGS can provide energy supply almost everywhere, since almost any site at a specific depth can be considered a reservoir. In order to use this high potential, the EGS technology still needs to experience an intensified R&D phase in order to reach the stage of successful demonstration and commercially viable power plant by 2030.</p> <p>Several pilot projects are at the moment being conducted in Australia, Europe, Japan and the US. The basic concept is to drill two wells into the HDR with limited permeability and fluid content at a depth of 5–10 km. High temperature reservoirs (200 °C) have though been found as shallow as 3 km, where the temperature gradient is high (70–90 °C/km).</p> <p>The RD&D for ORC should focus on the new heat-transfer fluids to improve efficiency, and improve the manufacturing capabilities to develop modularity benefits; the balance of the plant can be determined before construction. One advantage of the modular design is that the maintenance of individual units can be performed without taking the entire plant offline.</p>
Materials Road Map			
<p>The R&D efforts proposed in the roadmap follow the different phases in the exploitation of a geothermal system. Focus is on innovative developments in accessing geothermal reservoir (including spallation drilling) that should work towards an increase of economic depth.</p>			

An important contribution would come by researching lightweight materials for drill bits to extend their lifetime in highly abrasive and corrosive environments at high temperatures and developing site specific materials for proppants in conjunction with stimulation techniques. Improved monitoring of the downhole requires materials developments to make fibre optic cables and power electronics withstand the hostile environment they should operate in. When assessing the heat reservoir and the subsequent production phase, the accumulated deposition of material inside the pipes (scaling) and the extreme corrosion and temperature problems need to be tackled from a materials' perspective. This involves the development of corrosion-resistant materials for the pipes, equipped with protective outer coatings and insulation, and inner liners.

Novel polymeric, ceramic or metallic membranes to separate and re-inject gases would make the operation of a zero emission plant possible. The roadmap furthermore contains several proposals for research infrastructures in realistic laboratory or even in situ conditions. Materials standardisation would be the topic of one facility. In a large scale autoclave heat exchangers and working fluids can be tested, while research wells are needed to test the structural materials for the drilling tools and well components.

Market

According to the Commission's forecast, the capacity of the geothermal power sector is expected to reach 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).

(JRC, 2014), (EU Commission, 2011), (EERE, 2013)

Table 6: Summary of Marine Energy Systems

Marine Energy			
Technology	Components	State of Art	Research Areas
<p>Wave energy</p> <p>The energy contained within the waves manifests itself in the form of kinetic motion of water particles, with the energy imparted to the waves from the wind. The particle motion varies relative to the water depth. Far offshore, particle motion is circular. As the waves approach the shore, interference from the seabed (drag) causes the water particle motion to become more ellipsoidal in shape. At the shore, waves break as the upper surface of the wave begins to travel faster than the water particles closer to the sea bed.</p> <p>Much of the European ocean wave energy resource lies in deeper waters, as wave energy levels increase predominantly with increasing westerly distance from shore.</p>	<p>Wave Energy Devices</p>	<p>Attenuator</p> <p>Are generally long floating structures aligned in parallel with wave direction, which then absorbs the waves. Its motion can be selectively damped to produce energy</p>	<p>Installed W&T capacity is likely to remain modest in the short term, for 2014–2015, only 61 MW of new capacity is expected on the global level.</p> <p>The cumulative capacity expected in 2020 is 140 MW, implying a total sector revenue of around EUR 500 million. This is a setback compared to the estimations of a few years ago predicting 1.3 GW cumulative capacity in 2020. An installed capacity of 15 GW in 2030 can be considered as realistic to optimistic.</p> <p>For the long term, an estimate that W&T energy would cover roughly 5 % of the EU power generation in 2050 is realistic</p> <p><u>Technology development:</u></p> <ul style="list-style-type: none"> • Prototype devices need to be very robust to withstand the marine environment • Demonstration and testing facilities • Research and innovation support and enabling technology support to facilitate cost reduction and performance improvement <p>Projects within a visible development pipeline are now underway, and several test centres have increased the availability for grid connected berths in which to test wave energy conversion concepts. Test centres include the European MarineEnergy Centre (EMEC), Wave Hub, Biscay Marine Energy Platform (BiMEP), and the Danish Wave Energy Centre (DanWEC). Several device developers have now experienced several months of at-sea testing, and certain devices are nearing a commercially viable stage.</p>
		<p>Overtopping</p> <p>Are a wave surge/focusing system, and contains a ramp over which waves travel into a raised storage reservoir.</p>	
		<p>Oscillating water column (OWC)</p> <p>In an OWC, a column of water moves up and down with the wave motion, acting as a piston, compressing and decompressing the air. This air is ducted through an air turbine</p>	
		<p>Point absorber</p> <p>Is a floating structure absorbing energy from all directions of wave action due to its small size compared to the wavelength.</p>	
		<p>Oscillating wave surge converter (OWSC)</p> <p>An OWSC extracts energy from the surge motion in the waves. They are generally seabed-mounted devices located in near shore sites.</p>	

<p>Tidal Energy Tidal device operation is synonymous to that of a wind turbine, albeit operating within a different fluid medium.</p> <p>There are three principal hydraulic mechanisms by which tidal currents operate: Tidal streaming, hydraulic current and resonant basins. Tidal streaming occurs as a result of the need for continuity within a fluid flow: As water flows through a constriction, the flow is accelerated.</p> <p>Hydraulic currents occur when two large bodies of water are connected, but are out of phase or have non-concurrent tidal ranges; the difference in water level in each body of water creates a pressure head, and the flow of water from one body of water into the other results.</p> <p>The third mechanism, a resonant basin, occurs when constructive interference between an incoming tidal wave and a reflected tidal wave generates a standing wave.</p>	<p>Tidal Devices</p>	<p>Horizontal Turbine</p>	<p>Horizontal axis turbines utilise lift generated by blades to turn a rotor. Energy is extracted from the tidal flow and causes the rotation of a turbine mounted on a horizontal axis. The rotation is converted to electrical energy through use of a generator.</p>	<p>Tidal energy converters are now experiencing large scale demonstration and testing; some manufacturers have progressed beyond their original design concept and are looking into engineering solutions that will help to further reduce their cost of energy. Tidal energy converters can be classified into different “generations” of design as device developers and technologies progress beyond the first prototype concept:</p> <p>“First” generation technology has experienced significant levels of testing in ocean conditions, such as the horizontal axis type tidal turbines. As a general rule, first generation devices are fixed on sea bed mounted foundation structures with one or, possibly, two devices per foundation.</p> <p>“Second” generation technology offers novel ideas and solutions to moorings (for example buoyant turbines or foundations), allowing access to the faster flowing water higher in the water column and reducing foundation costs. Second generation technologies may also achieve step change cost reductions by mounting multiple rotors on one foundation structure, maximising the energy output per marine operation. Second generation platforms are already under development, although not necessarily by companies with existing first generation technology.</p> <p>“Third” generation tidal devices consist of designs that radically change the way in which energy is harnessed by a given device, or allows access to many sites that were previously thought to be uneconomical. This may be a radical overhaul within the structure and PTO components of a device. Third generation technology may produce energy in tidal currents of much lower velocity than can be considered at present by moving the PTO through the current, rather than relying on an area</p>
		<p>Vertical Turbine</p>	<p>Vertical axis turbines, similar to the above, utilise lift generated by blades to turn a rotor. Energy is extracted from the tidal flow and causes the rotation of a turbine mounted on a vertical axis. The rotation is converted to electrical energy through use of a generator</p>	
		<p>Oscillating Hydrofoil</p>	<p>The oscillating hydrofoil device consists of a hydrofoil located at the end of a swing arm. Control systems alter the pitch of the foil to create either lift or downforce, moving the foil in an oscillatory motion. This motion can be used to pump hydraulic fluid through a motor. The rotational motion that results can be converted to electricity through a generator</p>	
		<p>Enclosed Tips (Ducted)</p>	<p>Enclosed Tips (Ducted) devices are essentially contained within a shrouded structure. The duct may be used to accelerate and concentrate the fluid flow, allowing the use of smaller rotor diameters. Other ducted structures could help to minimise turbulence and align the flow of water into the turbine.</p>	
		<p>Helical Screw</p>	<p>Helical screw type turbines are a variation on vertical axis turbines that draw power from the tidal stream as the water flows up through the helix.</p>	

		<p>Tidal Kite</p>	<p>Tidal kite designs, in which a tethered kite “flies” a small turbine through the flow, effectively increase the relative velocity entering the turbine. These dynamic devices could generate electricity from significantly lower-velocity currents, or use much less material than static TECs.</p>	<p>swept by a static prime mover.</p> <p>In the short to medium term, only areas in which the spring peak tide velocity exceeds 2.5 m/s will be economically suitable for development, utilising first generation devices.</p>
<p>Ocean thermal energy conversion (OTEC) ;</p> <p>OTEC plants use the temperature difference between surface and deep water in a heat cycle to produce electricity. Due to the low temperature difference of 20–25 °C the theoretical efficiency limit is a modest 7–8 %, while in practical terms an efficiency of 2–3 % would be realistic for a mature technology. Parasitic losses due to relatively intensive water pumping are relatively high.</p>	<p>Close-Cycle</p>	<p>Evaporator; Turbogenerator; Condenser; Working fluid pressurizer (boiler feed pump).</p>	<p>Closed-cycle OTEC system: the working fluid is vaporized by heat transfer from the warm sea water in the evaporator. The vapor expands through the turbogenerator and is condensed by heat transfer to cold sea water in the condenser. Closed-cycle OTEC power systems, which operate at elevated pressures, require smaller turbines than open-cycle systems.</p>	<p>Current Projects:</p> <ul style="list-style-type: none"> •OTEC Demonstration Plant: Marine corrosion research and heat exchanger performance testing in a complete OTEC cycle using surface (warm) and deep (cold) seawater flows. •Turbine: Installing a turbine on Makai’s heat exchanger test facility to become the only operational OTEC power plant using deep cold water in the United States. This project involves designing, testing, and optimizing the OTEC power system and seawater and ammonia flow controls. •Pipelines: Ongoing cold water pipe research and design. •Pilot Plant: Designs for the first offshore OTEC pilot plant in the range of 2 – 10MW net-power. •Environmental Effects: Multiple discharge water hydro- and bio-plume studies.
<p>Osmotic power (salinity gradient power)generation.</p>	<p>Open-Cycle</p>	<p>Vacuum chamber flash evaporator; Turbogenerator; Condenser; Vent compressor</p>	<p>In open-cycle OTEC, warm sea water is used directly as the working fluid. Warm sea water is flash evaporated in a partial vacuum in the evaporator. The vapor expands through the turbine and is condensed with cold sea water. The principal disadvantage of open-cycle OTEC is the low system operating pressures, which necessitate large components to accommodate the high volumetric flow rates of steam.</p> <p>Osmotic power generation is the energy available from the difference in the salt concentration. In this system, a semipermeable membrane separates the fresh water from the salty water. Due to the difference in osmotic pressure, the fresh water moves through the semipermeable membrane, generating a water flow under pressure, which can be converted into kinetic energy in a turbine. this power generation technology can be used in countries with abundant fresh water resources flowing into the sea.</p> <p>The technology RED as well as PRO</p>	<p>The main efforts are focused on the design and production of a semi-permeable membrane optimized for Osmotic Power.</p> <p>From economical calculations and estimations of the development in the energy market, a target for the efficiency of the membranes have been set at 5 W/m2 for producing Osmotic Power on commercial basis. The main challenges are related to the internal concentration polarization within the membrane. To exploit the driving force that the osmotic pressure differences represent, the membrane needs to be as thin as possible, but at</p>

membrane. A semi-permeable membrane is selective in its permeability, i.e. only specific substances can pass through the membrane. Both processes rely on ion-specific membranes.

is in the research and development phase.

Pressure Retarded Osmosis (PRO) uses the selective diffusion of water across a membrane in order to pressurize seawater. Freshwater and seawater are placed on either side of a membrane, and the seawater side is pressurized. As the seawater side increases in pressure and decreases in salinity, part of the water is discharged through a turbine while the rest is put in a pressure exchanger to pressurize the incoming seawater. The pressure difference across the membrane is the main supplier of energy and can be as much as 200 meters of hydraulic head (IEA, 2009). Membrane performance in the 4 - 6 W/m² range is currently the target range by the main research institution investigating PRO. The lifetime of the membrane also needs to increase to around 7 to 10 years before the technology can become commercial. Test modules have so far demonstrated energy densities of about 1.7 W/m² (IEA, 2009).

Reverse Electro Dialysis is another membrane-based technology that uses an electrochemical reaction rather than osmotic pressure. The form of the device is a stacked series of membranes, half of which are permeable to sodium and half chloride, with seawater and freshwater flowing alternately between each pair of membranes. The stack controls the diffusion of the sodium and chloride ions in the water, which then cause oxidation and reduction at the iron anode and cathode. Currently, the technology has been tested only at a very small (100 mW) scale.

the same time withstand the pressure difference. The water flux should be in the similar range as the common RO membranes and also the retention of salt is important.

Materials Road Map

Composites provide many advantages for manufacturing under-water structures such as tidal turbine blades, and wave devices. Composites offer strength, fatigue-resistance, corrosion resistance, buoyancy, and cost effectiveness. The needs of a young industry demand more than just a product or service provider. A wide variety of designs, many engineering and materials options, the unpredictable environment of sub-sea and the pressures of bringing new technology to market, require a partner who can see beyond the initial specification.

Market

Currently there are few MW of installed Wave and Tidal (W&T) energy systems on the global level. these installations are demonstration projects. Installed W&T capacity is likely to remain mod-est in the short term. The cumulative capacity expected in 2020 is 140 MW, implying a total sector revenue of around eUR 500 million. this is a setback compared to the estimations of a few years ago predicting 1.3 GW cumulative capacity in 2020. An installed capacity of 15 GW in 2030 can be considered as realistic to

optimistic. For the long term, an estimate that W&T energy would cover roughly 5 % of the EU power generation in 2050 is realistic. This implies 250 TWh of W&T power. Assuming 3500 annual full operation hours, the required W&T installed capacity in the EU would be 71 GW in 2050. European W&T energy stakeholders include: Marine Current Turbines (Siemens), Andritz Hydro Hammerfest, Tidal Generation limited (Alstom), Pelamis, Aquamarine Power, Fred Olsen, Scot Renewables, Vattenfall, Openhydro (EDF), Abengoa Seapower, Atlantis Resource Corporation, Voith Hydro, DEME Bluepower, IT Power, Tocardo, Ocean Energy Limited and Minesto, among others.

(Takahashi, 2001), (JRC, 2014), (Si Ocean, 2013), (Skilhagen, 2009)

Table 7: Summary of Carbon Capture and Storage Systems

Carbon Capture and Storage in Power Generation			
Technology	Components	State of Art	Research Areas
<p>CO₂ capture :</p> <p>Approaches to the capture of CO₂ can be categorised according to whether and how the production process needs to be modified to enable CO₂ separation:</p> <p>Post-combustion</p> <p>Pre-combustion</p> <p>Syngas/Hydrogen capture</p> <p>Oxy-fuel combustion;</p> <p>Chemical looping combustion</p> <p>For all applications where CO₂ separation is an inherent part of production, CO₂ capture processes are commercially available and in common use. In other applications, such as coal-</p>	<p>Absorber</p> <p>CO₂ is captured using a chemical solvent like an amine.</p>	<p>Involves removing the CO₂ from flue gases after fuel combustion with air. Flue gases are at low pressure, high temperature (around 120–180 °C) and CO₂ composition is between 3 and 20 % in volume. Post-combustion techniques are appropriate for CO₂ capture from industrial operations. Current post-combustion methods comprise chemical absorption, physical adsorption, gas separation membranes and cryogenic distillation. Chemical absorption with amines is the most mature technique.</p> <p>Concerning the adsorption processes, the utilized adsorbents are zeolites, activated carbon, amine functionalized adsorbents and metal organic frameworks. Membranes can be of organic or inorganic origin, a mixture of them, or use a combination of a membrane with an absorption liquid, like an amine. and finally, cryogenic distillation, analogously to air cryogenic separation into its components, separates CO₂ physically based on dew and sublimation points.</p>	<p>For the upcoming years, it will be important to:</p> <ul style="list-style-type: none"> • demonstrate integrated projects (regarding the complete value chain) to overcome unclear operational patterns; • support the deployment of CO₂ infrastructure; • define a specific business case for CCS deployment; • take advantage of knowledge sharing and of private–public partnerships; • maximise the benefits (and the development) of local communities, going for a societal point of view; • perform a clear (stable) legal framework; • gain public implication and acceptance . <p>Development of efficient solvent systems and processes for post- and pre-combustion capture. large-scale demonstration of oxy-fuel boilers for power plants and industry sectors and chemical looping are needed.</p> <p>Example of large-scale CCUS projects in Europe</p> <p><u>CCS Rotterdam Project</u> Implementation of a large-scale ‘CO₂ Hub’ for capture, transport, utilisation and storage of CO₂, with different point sources connected to multiple storage sites.</p> <p><u>Zero emission Porto tolle Project (ZePt)</u> It exemplifies a retrofitting example of a power plant of 660 MW with postcombustion techniques in 40 % of the flue gas. The storage place is a deep saline aquifer.</p> <p><u>Rotterdam opslag en Afvang demonstratieproject (Road)</u> The project includes capture of CO₂ from a coal power plant, pipeline transportation and offshore storage in</p>
	<p>Regenerator:</p> <p>the captured CO₂ is released from the solvent</p>		

<p>fired electricity generation, CO₂ separation processes are less advanced or require considerable redesign of traditional processes.</p>	<p>Oxy-fuel combustion</p> <p>Air separation unit; Oxy-Boiler; gas Heater; Dust elimination unit; Desulphurization unit;</p>	<p>Is a newer approach: the technology aims to produce a purer CO₂ stream after combustion using an O₂ /CO₂ stream instead of air. as a result, the flue gas contains CO₂ at higher proportions (75–80 %), water vapour and only traces of impurities; therefore, relatively simple purification of CO₂ is needed before storage. The process comprises air separation, combustion of the fuel and CO₂ recycling to dilute the pure oxygen. This process suggests high efficiency levels and offers major business opportunities, including the possibility of retrofitting existing plants, even if the higher temperatures obtained with the oxygen combustion can be an issue. The main disadvantage is the large quantity of oxygen required, which is expensive both in terms of capital costs and energy consumption. There are three main oxy-fuel combustion pilot demonstration plants in the eU: Schwarze Pumpe in Germany, CiUdenin Spain and Lacq in France.</p>	<p>a depleted natural gas reservoir.</p>
	<p>Chemical looping combustion</p> <p>Air reactor; Fuel reactor.</p>	<p>In chemical looping combustion the needed oxygen for the combustion is transferred by an oxygen carrier, generally an oxidised metal. as air is not used, the CO₂ produced contains water vapour and the reduced metal oxide. Therefore, purification only implies condensation of water. Some common metals used are iron, nickel, cobalt, copper, manganese and cadmium, driving to different working conditions of pressure and temperature. This technology is still in the R&D phase</p>	
<p>CO₂ Transport</p>	<p>Road tanker; Ship; Pipeline.</p>	<p>The pipeline is the most important means of transport for development of an integrated infrastructure. Even though hydrocarbons pipelines have been extensively used to transport CO₂, for instance for enhanced oil recovery (EOR) in the US, in the north Sea or in the Netherlands, it is necessary to requalify and inspect them for integrity assessment and materials evaluations. the CO₂ stream has impurities that need to be limited regarding its final use/storage. In addition, existing CO₂ pipelines work at 85–150 bar, while natural gas pipelines work at 85 bar or less.</p>	

CO2 Storage	<p>Different types of geological formations are being used and investigated:</p> <p>Oil/Gas reservoirs,</p> <p>Deep saline aquifer formations</p> <p>Unmineable coal beds</p>	<p>There is an estimated global storage potential of 10000 gigatonnes (Gt) CO₂, with 117 Gt in Europe nearly all of which is in depleted oil and gas reservoirs and saline aquifers.</p> <p>Current initiatives aim at creating a carbon atlas, to overlook sources, pipelines and storage sites' locations.</p>	<p>For the 2030 horizon, CCS will have to be routinely implemented; the estimated emissions stored will be in the amount of 2000 Mt CO₂/year. For the 2050 horizon, CCS will have to be further used, reaching 7 000 Mt CO₂/year stored (iea, 2013c). Compressed CO₂ is already injected into porous rock formations by the oil and gas industry, for eoR, and has been proven at commercial scale. typical storage costs per tonne of CO₂ range from EUR 1.0–7.0 for onshore storage in depleted oil and gas reservoirs with legacy wells, rising up to EUR 6.0–20.0 for offshore storage in saline aquifers.</p> <p><u>CO₂ STORE Project</u></p> <p>It aims at gaining knowledge on geochemistry and dissolution processes by monitoring CO₂ migration onshore and offshore. The result is the development of methodologies for assessment, planning and monitoring.</p>
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Materials Road Map

Capture of CO₂ requires functional materials that can separate efficiently CO₂ from a stream of flue and syn-gases. Increasing the efficiency of power plants, especially after the application of CCS, which is energy demanding, requires the increase of operating temperatures in boilers and burners, which in turn necessitates advanced materials that can operate in temperatures higher than those of today. In response to these needs, the materials proposes a research and development programme that focuses on the optimisation of functional materials for post combustion capture, such as solvents and advanced solvents, high temperature solid sorbents, other solid absorbers and membranes that could separate CO₂ with a low energy penalty.

Market

In the EU, 87.4 % of CO₂-eq. emissions correspond to fossil fuel combustion. energy industries generate 34.5 %, followed by transport (22.7 %), and manufacturing and construction industries (22.7 %). the remaining 12.6 % mainly comes from other industrial processes and solvent use (5.3 %) and from international maritime transport (3.9 %).

According to the eU energy Roadmap 2050, CCS from the power sector will contribute with 19–32 % of the GHG emissions reduction by 2050. The installed capacity will have to grow from 3 GW in 2020 to 3–8 GW in 2030, 22–129 GW in 2040 and 50–250 GW in 2050, depending on the energy system scenario. This would require about 20000 km of pipeline infrastructure. The IEA CCS technology Roadmap points out that the capture of CO₂ has to be successfully demonstrated in at least 30 projects from power and industry sectors by 2020.

(JRC, 2014), (EU Commission, 2011), (KBR, 2014), (IEA, 2013)

Table 8: Summary of Advanced Fossil Power Generation Systems

Advanced Fossil Power Generation			
Technology	Components	State of Art	Research Areas
<p>The technology for converting the chemical energy of the fuel to thermal energy :</p> <p>conventional thermal, fluidised bed, internal combustion or gasification;</p> <p><i>Today, they correspond to more than 80 % of the world energy production and they are expected to represent more than 40 % of capacity additions by 2035 (9 % in the EU), providing around 50 % of the electricity by 2035.</i></p>	<p>Gas Turbine</p> <p>Steam Turbine</p>	<p>COAL:</p> <p>Traditional power plants operate at sub-critical pressure, using different reactor designs: pulverised coal (PC), fluidised bed boilers and grate-fired boilers, water circulating through the boiler is heated to produce steam below its critical pressure, 22.1 megapascal (MPa). The thermal efficiency is around 38 % in terms of net lower heating value (LHV).</p> <p>Fluidised bed combustion (FBC) plants are intrinsically working at lower temperatures than PC plants (800–900 °C). This lower combustion temperature reduces the production of NOX compared to PC plants, but increases the amount of nitrous oxide (N2O). There is less production of sodium oxides (SOX) if limestone or dolomite is added to the feedstock.</p> <p>The Supercritical (SC) plants are high-efficiency plants, where the generated steam is above the critical point of water; typical conditions are 540 °C and 25 MPa and they can reach efficiencies up to 43 %. No water/steam separation is required during the cycle, and higher costs are expected due to the use of alloys and weldings to support high pressure and temperature. Overnight cost can be 10–20 % higher than the cost for a sub-critical plant.</p> <p>In the ultra-supercritical (USC) power plants, steam conditions of 600 °C and 25–29 MPa can be reached, resulting in efficiencies up to 47 % for bituminous coal-fired power plants the cost of this type of plants can be 10 % higher than that of SC units, since pressure and temperature conditions are higher.</p> <p>IGCC plants have higher efficiencies and produce lower emissions. The product gas, called syngas, is very versatile since it can be converted into a wide range of products (i.e. electricity, heat, and liquid and gas chemicals). Coal is gasified with oxygen and steam usually in an entrained bed gasifier. It has been successfully demonstrated at two large-scale power plant demonstration facilities in Europe. The syngas, mainly Co, H2 and CH4, is used in a combined cycle to produce electricity. Instead of being combusted, the syngas can be used to produce H2, chemical products like ammonia or small organic compounds. IGCC with CCS has been proven in different plants. Most state-of-the-art approaches aim at incorporating gas turbines able to tolerate 1 500 °C as inlet temperature to combust a H2 -rich syngas.</p> <p>Biomass combustion and gasification with coal are called co-combustion and co-gasification. A fraction of coal in conventional and advanced power plants is replaced by biomass, involving solution immediacy and direct reduction of Co2 emissions. In order to improve and homogenise the biomass source, to be closer to coal characteristics, pre-treatments like drying, chipping, pelletisation or torrefaction are needed. There exist different alternatives for biomass usage: co-combustion or co-gasification with coal and biomass mixed before going into the reactor or separate gasification for joint co-combustion. Biomass share in co-use is limited by technical constraints to 10–15 % of coal inlet thermal power. this option is very attractive for the disposal</p>	<p>The advanced ultra-supercritical (A-USC) power plant operating with steam temperatures at 700 to 760C (1292 to 1400F) will require nickel-based alloy materials in the steam generator, critical steam piping and steam turbine. Nickel-based alloy development from the United States (U.S.) . The full commercialisation is not expected before the decade 2020–2030.</p> <p>The goal for an NGCC is to attain a combined thermal efficiency of 63 % by 2020. In an analogous way as in co-firing options with coal, syngas can be obtained from biomass gasification, or biogas from biomass digestion, and be combined with natural gas or reformed natural gas.</p> <p>Unconventional sources of natural gas, such as shale gas, look very attractive after evaluating the big numbers of these in the US.</p> <p>Goals:</p> <ul style="list-style-type: none"> -New fossil fuel power plants should use advanced configurations; -Old plants with a reasonable lifetime should be retrofitted to implement CCUS, efficiency measures and/or co-use of biomass or organic wastes; -CH4 emissions from upstream oil and gas production may be minimised. <p>Power plants can be retrofitted to increase their efficiency, maximising heat integration, using bio-mass and CCUS technology or a combination of the two.</p> <p>Combined heat and power (CHP) aims at using waste heat to produce a valuable</p>

		<p>of organic wastes.</p> <p>NATURAL GAS:</p> <p>Open-cycle gas turbine (OCGt) plants only use the gas cycle. Natural gas Combined-cycle (NGCC) plants employ Brayton and Rankine cycles; the last uses exhaust gases to heat up water to produce steam. Typical efficiencies of gas turbines are around 35–46 %, while combined cycles can reach efficiencies of 55–60 %.</p> <p>Advanced air-cooled gas turbines can achieve combined-cycle thermal efficiencies of over 60 %, with more than 40 % efficiency in single-cycle operation (Siemens, 2010). the state-of-the-art tendencies in these plants are mainly focused on enhancements of the gas turbine.</p> <p>Shale gas is considered an unconventional source of natural gas. Technological advances, in particular the combination of horizontal drilling with hydraulic fracturing have made shale gas extraction technically possible.</p> <p>However, shale gas is still an uncertain source in terms of costs and availability, and the exploitation technology has to be carefully assessed in terms of environmental impact.</p> <p>Oil:</p> <p>Oil-fired power plants only represent 8 % of European electricity production; the available oil reserves are mainly used for transportation and in the petrochemical industry. The main reason why oil should be used for electricity generation is to secure electricity supply, since oil is more easily storable than gas.</p>	<p>contribution like electricity generation or pre-heating.</p> <p>New (and better) extraction methods are important to predict the impact as a whole of a power plant.</p> <p>It is crucial to develop super-alloys and reduce their cost in order to deploy A-USC plants.</p> <p>For the retrofitting of both existing PC plants and new PC combustion plants, oxy-fuel combustion is a promising option that will minimise the cost of the Co2 capture step since the flue gas contains around 90 % Co2.</p>
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Materials Road Map

Today, the majority of the European fleet of coal power stations still uses subcritical steam turbines that have thermal efficiencies of below 40% (LHV). No new deployment of this technology is expected in Europe apart from selected cases of retrofitting or reactivating mothballed stations. During the last decade, 92% of new coal plants in Germany and 53% of new coal plants in Poland were built using supercritical technologies reaching thermal efficiencies of 45% and 43% in case of hard coal and lignite fuel respectively. Outside Europe, subcritical technology still enjoys a market share above 50% of new builds in China, India and the United States. The next evolutionary step in the development of steam turbines for coal power stations is to raise the steam temperature to 700°C achieving a thermal efficiency of up 50%. The 700°C technology necessitates the switch from iron-based to nickel-based alloys as only the latter are able to withstand the higher temperatures. A number of pilot projects to test components under real life conditions have been initiated within projects funded by the EU and member states, such as e.g. the COORETEC28 program. The full commercialisation is not expected before the decade of 2020-30.

Market

Coal and gas fired power stations will likely remain in the European generation technology portfolio, with the latter having a higher potential if a safe and secure extraction of hydrocarbons from unconventional resources will become possible, even in scenarios with a very high share of RES-E generation (renewable energy sources). Their role will be to provide backup in times of no supply from variable RES-E as well as flexibility in case of rapid supply and demand changes. The technology portfolio consists of continuously improved steam and gas turbines (and combinations thereof as e.g. CCGTs). On a worldwide level, fossil fuels are expected to remain the most important source of power generation representing more than 40% of capacity additions by 2035 and providing well over 50% of electricity in 2035. Only 9% of these additions are expected to happen in the EU. Scenarios taking into account a decarbonisation of the European power system assume no more growth in global installed capacity post



2030 reducing the market to replacement installations which however remains significant. Roughly 1,300 GW of coal and 1,200 GW of gas plant capacity will be added between 2012 and 2035 representing about half of the then installed total capacity. The European and – to a lesser degree – the global fossil fuel mix are expected to continue shifting from coal to gas which is expected to overtake coal in terms of installed capacity by 2030.

(JRC, 2014), (EU Commission, 2013)

Table 9: Summary of Nuclear Fission Energy Technology

Nuclear Fission			
Technology	Components	State of Art	Research Areas
<p>1 PWR- pressurized water reactors(the large majority of all Western nuclear power plants)</p> <p>2 BWR- boiling water reactors;</p> <p>3 CGR-gas cooled reactor</p> <p>4 FBR- Fast Breeder Reactor</p> <p>5 VVER- Voda Voda Energo Reactor</p> <p>6 HTGR- High Temperature Gas Reactor</p> <p>7 EPR- European Pressurized Reactor</p>	<p>Fuel Elements:</p> <p>1-2 -5 -6 : Uranium Dioxide</p> <p>3: ^{235}U e ^{238}U</p> <p>4: ^{239}Pu, ^{238}U</p> <p>7: mixed uranium plutonium oxide</p> <hr/> <p>Coolant System:</p> <p>1-2-5-7 water</p> <p>3 Gas</p> <p>4 Sodium-Lead</p> <hr/> <p>Moderator System:</p> <p>1-2-5 -7 water</p> <p>4- No moderator</p> <p>3- 6 Graphite</p>	<p>The current state of the art of commercial nuclear power plants is the Gen-III reactor, which is an evolution of the Gen-II reactors with enhanced safety features and reliability. examples are areva's European pressurized reactors (ePRs), Westinghouse's AP1000, Canada energy inc.'s CandU6 and OKB Gidopress' VVER 1000 reactor designs.</p> <p>Two Gen-III reactors are under construction in Finland and France (both are EPR).</p> <p>Fast reactors can also be used to trans-mute high-level nuclear waste. the radiotoxic inventory can be reduced by more than a factor 100 and its heat load by a factor of 10, which would allow reducing the size of the final geo-logical repositories substantially</p>	<p>A new generation of nuclear reactors is being developed to achieve greater sustainable and environmental responsibility</p> <p>The small- and medium-sized reactors (SMRs) are now receiving more attention, especially in the US.</p> <p>New designs that are expected to be deployed by 2010-2030 include the Advanced Passive AP600 and AP1000 . These are considered as evolutionary designs offering improved safety and economics.</p> <p>Although the concept of fusion has been demonstrated, there are still a number of fundamental issues relating to the physics where understanding needs to be improved, including: plasma containment and operating modes, magneto-hydrodynamics and plasma stability, particle and power exhaust, and alpha particle physics. One of the most important technology areas is the development of materials that can operate for long periods and extended lifetimes in the extreme conditions of thermal load and neutron irradiation in close proximity to plasma, the so-called plasma-facing materials. A number of materials have been identified as candidates for future fusion power plants, but detailed experimental data is limited since there is presently no neutron source com-parable to a fusion power plant.</p> <p>Fourth generation: The fourth generation of nuclear reactors is expected to start being deployed by 2030. These new reactors are designed with the following objectives in mind:</p> <ol style="list-style-type: none"> 1.Economic competitiveness 2.Enhanced safety, 3.Minimal radioactive waste generation, 4.Proliferation resistance.
Materials Road Map			
<p>The materials roadmap for nuclear fission proposes a research and development programme on commercially available material (steel and Ni-alloys) for the prototypes and demonstrators; and advanced materials for the industrial scale systems. The focus is put on cladding application (Oxide Dispersion Strengthened -ODS- steels for liquid metal fast reactor and composites, for gas fast reactor an lead fast reactor) with the aim to improve high fuel burn-up capabilities and high temperature resistance; on coating technologies to enhance corrosion and erosion/wear resistance in liquid metal fast reactor and on novel materials based on Ti based alloys. Based on the research results developed above, the roadmap puts forward up to 4 pilot projects to validate manufacturing routes of 9Cr steel heat exchanger, of fuel cladding tubes with ODS and SiC_rSiC and coatings pilot plant(s) to treat relevant components for liquid metal fast reactor; 4 pilot projects to test 9Cr steel heat exchanger out of pile, fuel cladding tubes with ODS and composites (e.g. SiC_rSiC) out of pile and possibly in pile, and to confirm wear resistance and corrosion resistance of large scale coated components. This is complemented by the proposal to refurbish and/or built a series of research infrastructure in support: irradiation facilities, hot laboratories, high temperature testing systems and large scale facilities for out of pile testing of components. In addition, a modelling centre would be of high relevance for the materials performance assessment in a multiscale approach.</p>			
Market			
<p>In the energy Roadmap 2050 of the European Commission, seven policy scenarios were stud-ied. In the current policy scenario, the share of nuclear power in gross electricity production is projected to decrease from 30.5 to 20.7% in 2030 and to 20.6 % in</p>			



2050. For the five decarbonisation scenarios, the share of nuclear in gross electricity generation varies from 13.4 to 21.2 % in 2030 and 2.5 to 19.2 % in 2050. In other recent scenario studies, the share of nuclear in Europe is forecasted to be either stable or reduced by 2050 as compared to today. It should be kept in mind that even when taking into account successful life extension programmes of existing reactors, maintaining the share of nuclear energy in 2050 would require the construction of up to 120 new reactors.

(EU Commission, 2011), (JRC, 2014)

Table 10: Summary of Nuclear Fusion Technology

Nuclear Fusion			
Technology	Components	State of Art	Research Areas
Tokamak	<p>Coils</p> <p>Toroidal Room</p>	<p>The transient electric current that circulates in the primary coil of a tokamak induces a current in the plasma ring, which both heats the plasma and produces the poloidal magnetic field. The toroidal magnetic field, which is generated by electric currents circulating in the toroidal field coil rings around the torus. In addition, the currents circulating in the position control coils generate auxiliary magnetic field components that modify the poloidal field, equilibrating the plasma ring and controlling its position. It is the combination of toroidal and poloidal magnetic fields that leads to the improved confinement of tokamak plasmas.</p>	<p>Whilst ITER is being constructed and DEMO is in its conceptual phase, a number of fusion installations, with different characteristics and objectives, will continue to operate around the world, conducting complementary R&D in support of ITER. These include, in particular:</p> <ul style="list-style-type: none"> • the Joint European torus (JET), which will operate until at least 2017-18 and will include another major experimental phase using deuterium–tritium (d-t) as fuel, which follows the first D-T operation in the 1990s; • the experimental advanced superconducting tokamak (EAST) at the Institute of Physical Science in Hefei, China; • the Korea Superconducting Tokamak Advanced Research (KSTAR), in operation since 2008 at the National Fusion Research Institute in Daejeon, South Korea; and • the JT-60SA device in Naka, Japan, which is currently under construction with significant European ‘in-kind’ contributions under the Euratom-Japan Broader Approach agreement. JT-60SA operation is scheduled to start in 2019.
Materials Road Map			
<p>A dedicated neutron source is needed for material development. Irradiation studies up to ~30dpa with a fusion neutron spectrum are needed before the DEMO design can be finalized. While a full performance IFMIF (<i>International Fusion Materials Irradiation Facility</i>) would provide the ideal fusion neutron source, the schedule for demonstration of fusion electricity by 2050 requires the acceleration of material testing. The possibility of an early start to an IFMIF-like device with a reduced specification (e.g. an upgrade of the IFMIF EVEDA hardware) or a staged IFMIF programme should be assessed soon. A selection should be made early in Horizon 2020 of risk-mitigation materials for structural, plasma-facing and high-heat flux zones of the breeding blanket and divertor areas of DEMO, also seeking synergy with other advanced material programmes outside fusion.</p>			
Market			
<p>The obvious difference with all other low-carbon energy technologies is that fusion energy will not make any significant and commercial contribution to the electricity grid until around 2050. Current planning foresees fusion starting to be rolled out on a large scale sometime after the middle of the century following successful DEMO operation. There do not appear to be any resource issues that would prevent fusion being deployed at least as rapidly as fission power was deployed after the mid-20th century. Nevertheless, there will likely be a need for industry to progressively shift its role from that of provider of high-tech</p>			



components to that of driver of fusion development. this must already start with the design and construction of DEMO, with industry becoming fully responsible for a commercial fusion power plant.

(JRC, 2014), (IFERC, 2013)

Table 11: Summary of Bioenergi Power and Heat Generation

Bioenergy Power and Heat Generation		
Technology	State of Art	Research Areas
Biomass combustion	The technologies in use are largely based on mature direct combustion boiler and steam turbine systems for heat, electricity or CHP (<i>Combined heat and power</i>) at small- and large-scale for residential and industrial applications. Modern wood chips and pellet boilers have efficiencies as high as 90 %.	The Stirling engine (10–100 kWe) and the ORC (50–1 500 kWe) are promising technologies for small-scale and micro-scale CHP. (m-CHP), with electric efficiency of 16–20 %. Stirling engine technology is currently at the pilot-to-demonstration stage and the biomass ORC (organic Rankine cycle) process has been demonstrated and is now commercially available New CHP plants using MSW (Municipal solid Waste) are expected to reach 25–30 % electrical efficiency and 85–90 % overall efficiency in CHP.
Waste	Several technologies are available for organic waste conversion, including thermal (combustion, gasification and pyrolysis) or biological treatment (fermentation and anaerobic digestion (ad)).	Waste gasification is a promising option for electricity and heat production, as well as advanced fuels (e.g. through syngas upgrade, Fischer-tropsch synthesis, methanol synthesis, H ₂ extraction). New CHP (Combined heat and power) plants using MSW (Municipal solid waste) are expected to reach 25–30 % electrical efficiency and 85–90 % overall efficiency in CHP.
Biomass co-firing;	Biomass co-firing with coal in existing boilers is the most cost-effective and efficient option of heat and electricity production from biomass with small changes in the fuel feed systems. Direct co-firing in pulverised coal-fired boilers with up to about 15 % biomass has been successfully achieved, while fluidised bed boilers can substitute higher levels of biomass. Higher percentages of biomass (50–80 %) may be used in co-firing with extensive pre-treatment.	Current research includes: <ul style="list-style-type: none"> • Development of external gasifier/combustor- based indirect co-firing; • Torrefaction-based direct co-firing; • Techno-economic study of co-firing.
Anaerobic digestion (AD);	AD is the conversion of organic material to biogas by bacteria, in the absence of air. the biogas is a mixture of methane (50–70 %) and Co ₂ with small quantities of other gases, such as H ₂ S. this process is particularly suitable for wet feedstocks such as agricultural, municipal and industrial organic residues and wastes, sewage sludge, animal fats and slaughtering residues.	Several biogas upgrading technologies operate commercially, for example, water/chemical absorption and pressure swing adsorption (PSa); new systems using membranes and cryogenics are at the demonstration stage.
Landfill gas utilization;	Landfill sites are a specific source of methane-rich gas. CH ₄ emissions from MSW in landfills would be between 50 and 100 kg/t, can produce gas over a 20–25 year lifetime.	Due to the requirements to minimise land-filling of organic waste and to increase the levels of re-use, recycling and energy recovery, landfill gas is expected to decrease over time in the EU. The biomass-H ₂ route could be a promising technology for fuel cells.
Biomass gasification;	Gasification is the thermo-chemical conversion of biomass into a combustible gas (syngas) by partial oxidation at high temperatures. Biomass gasification is still in the demonstration phase and faces technical and economic	The BIGCC concept is a promising, high-efficiency technology, although more complex and costly, for generating a high-quality gas in a pressurised gasifier and conversion to energy in a combined gas/steam turbine cycle. The

	<p>challenges. Typical gasification plant capacities range from a few hundred kWe for heat production, 100 kWe to 1 MWe for CHP with a gas engine, to 30–100 MWe for Biomass Integrated Gasification Combined Cycle (BIGCC), or biomass integrated gas turbine (BiG-Gt) technology. Small gasifier and gas engine units of 100–500 kWe are available on the market.</p>	<p>biomass-H₂ route could be a promising technology for fuel cells (McKendry, 2002). Biomass gasification and solid oxide fuel cell (SoFC) or integrated gasification fuel cell (iGFC) systems could offer high-efficiency electricity production (50–55 %)</p>
Pyrolysis;	<p>Pyrolysis is the conversion of biomass to a liquid bio-oil, solid and gaseous components in the absence of air at temperatures around 450–600 °C. Fast pyrolysis (at 450–500 °C) and short residence times (< 5 s), for bio-oil production is of particular interest. the conversion efficiency of biomass to bio-oil is up to 80 %. More effort is needed to improve the quality of the pyrolysis oil, which includes hundreds of compounds. Bio-oils can be used as a feedstock for advanced biofuels and for future refineries.</p>	<p>Whilst pyrolysis and bio-oil upgrading technology is not commercially available, considerable experience has been gained and several pilot plants and demonstration projects are on the way. The main challenges concern the development of new techniques and catalysts for bio-oil upgrading. Pyrolysis can also be used as a pre-treatment step for gasification and biofuels production.</p>
Torrefaction;	<p>Torrefaction is a thermo-chemical upgrading process consisting of biomass heating in the absence of oxygen at temperatures typically ranging between 240 and 320 °C, releasing water and volatile compounds. Torrefaction produces a higher quality solid feedstock (bio-char) with high energy density and homogeneous composition. this decreases the costs for handling, storage and transport. torrefied biomass can be used in small- and large-scale applications as well as in higher shares of co-firing with coal. Biomass torrefaction can create new markets and trade flows as commodity fuel and increases the feed-stock basis. The drawback is that the torrefaction and pelletisation processes result in feedstock losses and increased cost.</p>	<p>Further development of torrefaction technology is needed to overcome certain technical and commercial challenges. No commercial torrefaction plant exists today, but the first demonstration projects are in operation (e.g. andritz-eCnat Stenderup (denmark), andritz aCB in Frohnleiten (austria), Stramproy at Steenwijk (the netherlands), topell at duiven (the netherlands), etc.).</p>
Biorefineries;	<p>A key factor in the transition to a bio-based economy will be the development of biorefineries, allowing highly efficient and cost-effective processing of biomass to a range of bio-based products (chemicals, materials, food and feed) and bioenergy (biofuels, biogas, heat and/or electricity). This allows a more sustainable and efficient use of biomass resources. The stage of development of biorefineries ranges from conceptual to large-scale demonstration, with the focus either on chemicals/materials or biofuels as the main products. A variety of biorefinery configurations are currently being developed with new products and routes still being identified. Biorefineries often rely on the concept of cascading use, where the highest value products are extracted first and biofuels and bioenergy are final products.</p>	<p>Biorefineries are a rapidly emerging concept and a promising integrated approach for the co-production of both value-added products (chemicals, materials, food and feed) and bioenergy (biofuels, biogas, heat and/or electricity).</p> <p>The deployment of the new biorefinery concepts will depend on the technical maturity of a range of processes to produce bio-based materials, biochemicals and energy the cost-effective production of advanced lignocellulosic biofuels (lignocellulosic ethanol, Fischer-tropsch diesel, etc.) is a major driver for the development of biorefineries</p>
Hydrogen from biomass	<p>A variety of routes exist for H₂ production, including thermochemical, electrolytic, photolytic and biological processes, all at different levels of development and not yet economically viable. Biological pathways are based on microorganisms, such as unicellular green algae, cyanobacteria and dark fermentative bacteria. Photo-biological processes are at a very early stage of development. H₂ storage options include compressed gas, liquid (cryogenic, borohydrides, organic liquids) and solid storage (nanotubes, nanofibres, zeolites, hydrides). Gaseous and liquid storage is commercially available, but cost efficiency is an issue.</p>	<p>Research is needed to identify more oxygen-tolerant enzymes and new strains that can convert organic material into H₂. There is a need for significant improvement of conversion efficiency, reliability and reducing capital costs. A key challenge is H₂ separation and purification.</p> <p>Solid storage is at a very early development stage</p>

Materials Road Map

Accelerating the commercial deployment of bioenergy technologies for widespread sustainable exploitation of biomass resources

in order to ensure at least 14% bioenergy in the EU energy mix by 2020, and at the same time to guarantee greenhouse gas emission savings of 60% for bio-fuels and bio-liquids.

The Materials Roadmap on bioenergy proposes a wide research and development programme covering 5 focus areas. In the first focus area, the emphasis is on high strength, wear- and corrosion-resistant structural materials such as steel, alloys and protective coatings, high durability polymers and ceramics to reduce the time to market and the life cycle costs of technologies and to improve their recycling. The second focus area covers the further development of catalysts, allowing for higher selectivity and yield, improved stability and functionality such as bi-/multi-functional catalytic systems. The third focus area includes the development of advanced ceramic, polymeric or metallic membranes for gas separation and separation of inhibitory or intermediary products from biomass pre-treatment.

Also the efficient separation/recycling of enzymes, the immobilization of cells, and downstream processing in continuous separation of fermentation products needs materials solutions for advanced membranes.

To advance the material and component development to industrial scales, the roadmap proposes up to 3 pilots: one pilot should develop the manufacturing of components with corrosion resistant steels, alloys and coatings; one on active coating application techniques and one on photosynthetic process materials.

A second pilot should test novel poisoning-resistant and long life catalysts. Testing the technical performance of polymeric, ceramic or metallic membranes and filters is proposed to be the topic of the third pilot. The last pilot is intended to test strains and vectors for screening and industrial scale production of strains and vectors for screening and industrial production of recombinant enzymes.

Market

Biomass plays an important role in energy generation in the eU, with 8.2 % of gross final consumption and more than two thirds (66 %) of renewable energy in 2010. In 2020, this is expected to remain above 57 % in 2020, although with a larger total production. About 2 090 TWh of biomass will be used to provide about 1 630 TWh as bioenergy in 2020, including biofuels. The installed bioenergy power capacity reached 29 GWe in 2010 and it is expected to reach 43 GWe in 2020, according to the NREAPs. In the reference scenario of the energy Roadmap 2050, the installed biomass capacity is expected to further rise to 52 GWe by 2030 and even 87 GWe in 2050. The growth in biomass capacity is much higher in different decarbonisation scenarios, which should reach between 106 and 163 GW in 2050.

Biomass electricity generation in the EU increased from 69 TWh in 2005 to 123tWh in 2010 and 133tWh in 2011 (eurostat, 2012). The contribution of biomass should be 232 TWh in 2020 in the reference scenario of the energy Roadmap, representing 19 % of RES-E. The biomass electricity should significantly grow to 360 TWh in 2050 in the reference scenario and to 460–494 TWh in 2050 in decarbonisation scenarios. Biomass electricity contribution could rise from a 2.6 % share in power generation in 2005 and 3.7 % in 2010 to 7.3 % in 2050 in the reference scenario and 9.3–10.9 % in decarbonisation scenarios.

Biomass use for heating rose from 470 TWh in 1997 to 860 TWh in 2010 and it is projected to have a contribution of 1 040 TWh (81 % of renewables) to heating in 2020. Currently, bioheat is the main bioenergy market accounting for 92 % of renewable heating and 13.1 % of total heat use in the EU in 2010. Direct use of biomass for heating is expected to rise from 13.5 % in 2010 to 33 % in 2050 in the high ReS scenario. In the EU, DH with biomass covers around 1.7 % of the heat demand and 20 % of dH in 2010. The share of DH heating is significantly higher in some Member States. Biofuel consumption in transport rise from 36 TWh in 2005, 150 TWh in 2010, 210 TWh in 2030 and it should reach 430–450 TWh in 2050 under current policy scenarios of the energy Roadmap 2050. The high RES (renewable energy sources) and diversified supply technology scenarios foresee biofuels increasing to 290–420 TWh in 2030 and 790–840 TWh in 2050. Future developments will depend on the adoption of the European Commission's proposal aiming to address the ILUC effects of EU biofuel consumption, to limit the use of food-based biofuels to 5 % of energy use in transport and to encourage the development of advanced biofuels

Table 12: Summary of Biofuel for the Transport Sector Technology

Biofuel for the Transport Sector		
Technology	State of Art	Research Areas
Bioethanol	<p>First-generation bioethanol production is a well-established and mature technology based on a fermentation process of starch and sugar-based food crops, followed by distillation. Bioethanol is produced from a wide variety of feedstocks, but is mainly produced from sugar cane (Brazil), wheat and sugar beet (EU), and maize (US). the ethanol productivity per land area in the EU is in the order of 42–84 GJ (1–2 tonnes of oil equivalent (toe)) ethanol/ha for cereals as feedstock, and 84–126 GJ (2–3 toe) ethanol/ha for sugar beet. However, one major problem with bioethanol production is the availability of raw materials for the production. The availability of feedstocks for bioethanol can vary considerably from season to season and depends on geographic locations.</p> <p>Second-generation, lignocellulosic biofuels are expected to deliver more environmental benefits and higher feedstock flexibility than first-generation biofuels, since many of the problems associated with first-generation biofuels can be addressed by the production of biofuels manufactured from agricultural and forest residues and from non-food crop feedstocks. Where the lignocellulosic feedstock is to be produced from specialist energy crops grown on arable land, several concerns remain over competing land use, although energy yields (in terms of GJ/ha) are likely to be higher than if crops grown for first-generation biofuels are produced on the same land. in addition, poorer quality land could be used.</p>	<p>Algae are likely to play an important role in third-generation biofuel production. Biofuel production from algae is presently at the R&D stage and pilot plants are up and running worldwide. There are technical challenges and a need for innovation and technical improvement in all steps of algal biofuels production. Further efforts are needed to develop the optimum strains of algae, With fast growth rates and/or high oil yields, in cultivation, algae harvesting and oil extraction.</p> <p>H2 production plays a very important role in the development of the hydrogen economy. One of the promising H2 production approaches is conversion from biomass. Several different routes are in the R&D stage and can play a role in the long term:</p> <ul style="list-style-type: none"> • fermentation of biomass to H2 (dark fermentation) or AD followed by CH4 reforming; • gasification followed by upgrading and reform-ing of syngas; • pyrolysis and reforming of bio-oil; • direct H2 production in a phototrophic environment (photo fermentation) through organisms. <p>The European advanced Biofuels Flight Path initiative was set up in 2011 to speed up the commercialisation of aviation biofuels in Europe, the actions foreseen include the following goals:</p> <p>On short term (0–3 years): make available more than 1000 tonnes of Fisher-tropsch biofuel; production of aviation-class biofuels in the hydro-treated vegetable oil (HVO); start construction of the first series of second-generation plants to become operational by 2015–2016.</p> <p>On midterm (4–7 years): make available more than 2000 tonnes of algal oils; supply of 1.0 Mt of hydro-treated oils and 0.2 tonnes of synthetic aviation biofuels; start construction of the second series of second-generation plants including algal biofuels and pyrolytic oils from residues to become operational by 2020;</p> <p>On long term (up to 2020): supply of an additional 0.8 Mt of aviation biofuels based on synthetic biofuels, pyrolytic oils and algal biofuels; further supply of biofuels for aviation, biofuels to be used in most EU airports; 2.0 Mt of biofuels are to be blended with kerosene.</p>
Biodiesel	<p>Biodiesel production from vegetable oil and fats is based on a relatively simple and established technology, and it is characterised by mature commercial markets and well understood technologies. Biodiesel is produced via transesterification. The feedstock can be vegetable oil, such as that derived from oil-seed crops (e.g. rapeseed, sunflower, soya bean, oil palm), used oil (e.g. frying oil) or animal fat. Rapeseed is the main raw material for biodiesel production in the EU, soya bean in the US and Brazil, and palm oil in Malaysia and Indonesia</p>	
Market		
<p>Biofuels production has increased continuously worldwide over the last years. At the moment, they represent the so-called biofuels of the first generation, while large research efforts are being undertaken to bring onto the market second-generation lignocellulosic biofuels. In 2011, global ethanol production reached 81.6 billion litres, in more than 50 countries. at the moment,</p>		

the US is the world's leading pro-ducer of bioethanol, with Brazil following. Global bioethanol production is projected to increase to above 3 800 petajoules (PJ) in 2021. the three major producers are expected to remain Brazil, the EU and the US, followed by China and India. It is expected that Brazil will remain the major bioethanol exporter, while global trade will increase from about 4 % to about 7 % of global production by 2021. Global biodiesel production totalled 24 billion litres worldwide in 2011, 57 % of biodiesel being produced in the EU. The EU is expected to be the largest producer and user of biodiesel. New biofuel mandates, such as the Renewable Fuels Standard (RFS) in the US, or the Renewable energy directive (RED) 2009/28/EC in the EU, and others in Asia and Latin America, provide perspectives for an increased production for biofuels across the world.

Mandates for blending biofuels into vehicle fuels have been set in at least 46 countries at the national level and in 26 states and provinces by early 2012. Most mandates require blending 10–15 % ethanol with gasoline or blending 2–5 % biodiesel with diesel fuel In the EU, RED set mandatory targets of 10 % share of renewable energy in transport for 2020 in each EU Member State, and 6 % reduction in GHG emissions from road transport fuels. In the US, the energy independence and Security act (EISA) of 2007 set overall renewable fuels targets of 36 billion gallons by 2022, with 15 billion gallons of ethanol and 21 billion gallons of advanced biofuels by 2022. In addition to the bioethanol programme, the Brazil biodiesel national programme was established and the biodiesel use mandate has been set at 5 % since 2010. The targets of China proposed for 2020 are to produce 12 Mt of biofuels, to replace 15 % of transportation energy needs. Currently, nine provinces have 10% ethanol mandate for transport . India's national Biofuel Policy, approved in 2009, encourages the use of renewable energy resources as alternate fuels to supplement fossil motor fuels and had proposed a target of replacing 20 % of fossil motor fuel consumption with biofuels (bioethanol and biodiesel) by the end of 2017.

The share of biofuel in the final consumption of energy in transport in the EU accounted for only 0.25 % in 2000, but increased to 138tWh (11.9 Mtoe; 3.9 %) in 2009, 155tWh (13.3 Mtoe; 4.3 %) in 2010 and 163tWh (14.0 Mtoe; 4.6 %) in 2011. The NREAPs estimate that biofuel use in transport in the EU-27 is likely to reach about 349tWh (30 Mtoe) in 2020. The greatest contribution in 2020 is expected to come from biodiesel with 251tWh (21.6 Mtoe), followed by bioethanol/bio-ethyl tertiary butyl ether (ETBe) with 85tWh (7.3 Mtoe) and other biofuels (such as biogas and vegetable oils) with 8.1tWh (0.7 Mtoe). According to the NREAPs' forecasts, the contribution made by biofuels produced from wastes, residues, non-food cellulosic material and lignocellulosic material is expected to reach 31.4tWh (2.7 Mtoe), representing about 9 % of the estimated biofuel consumption in the EU-27 in 2020. The NREAPs data show that in 2020 about 128tWh (11 Mtoe) of biofuels could be imported by all the Member States in order to reach the 10 % binding target. This should represent about 37% of the biofuel use in the EU in 2020.

These projections will dramatically change if the new Proposal for a directive of the European Parliament and of the Council amending directive 98/70/EC relating to the quality of petrol and diesel fuels and amending the directive 2009/28/EC on the promotion of the use of energy from renewable sources gets accepted. The proposal aims to increase the minimum GHG savings threshold for new installations to 60 % and to limit the amount of food crop-based biofuels to the current consumption level of 5 % up to 2020.

The share of biodiesel produced from vegetable oil is expected to decrease by 10 % down to 70 % in 2021. Second-generation biodiesel production is projected to increase slightly, mainly coming from the EU. It is expected that coarse grain will remain the dominating ethanol feedstock (44 %), followed by sugarcane (34 %). Cellulosic ethanol is projected to reach a global share of almost 9.5 % and will be produced predominately in the US.

(JRC, 2014), (IEA, 2013)

Table 13: Summary of Hydrogen Fuel Cells Technology

Hydrogen Fuel Cells Technology

Technology	State of Art	Research Areas
Hydrogen production and storage	<p>For on-board storage, the present storage technologies (liquid, high-pressure gas, solid-state) do not allow reaching the system targets in terms of performance that have been set by the U.S. doe.</p> <p>The majority of the fuel cells electric vehicles (FCEVs) today use high-pressure gas tanks for on-board storage. Pre-cooling H₂ to limit the maximum temperature during type IV tank filling may be required to obtain acceptable fill times.</p> <p>For off-board storage, mature gaseous or liquid storage systems have been developed in the chemical and refining industries.</p>	<p>In the future, also direct production of hydrogen e.g. by photocatalytic splitting of water or by employing bio processes (e.g. bacteria and algae, fermentation) might become feasible routes for low temperature / low energy hydrogen production.</p> <p>Storage of supercritical cryocompressed H₂ is currently under investigation, with a potential of achieving a 30 % density increase above pure liquid and more than 2.5 times that of compressed H₂.</p>
Polymer electrolyte or Proton Exchange Membrane Fuel Cell (PEMFC)	<ul style="list-style-type: none"> - Electrolyte: water-based, acidic polymer membrane; -also called polymer electrolyte membrane fuel cells ; -use a platinum-based catalyst on both electrodes ; -generally hydrogen fuelled ; -operate at relatively low temperatures (below 100°C) ; -high-temperature variants use a mineral acid-based electrolyte and can operate up to 200°C; -electrical output can be varied, ideal for vehicles. 	<p>Large stationary fuel cell installations will also be needed for reconverting stored renewable energy, either decentralised or connected to a (smart) grid system.</p> <p>Most of the current research on catalysts for PEM fuel cells is focused on the cathode. The general objectives are: to reduce PT content (and thereby cost); to obtain higher catalytic activity than the standard carbon-supported platinum catalysts; and to increase the durability of the catalyst/support system, especially during transients and shutdown/startup cycles.</p>
Solid Oxide Fuel Cell (SOFC).	<ul style="list-style-type: none"> -Electrolyte: solid nonporous ceramic materials, such as stabilised zirconium oxide; - a precious metal catalyst is not necessary; - an run on hydrocarbon fuels such as methane; - operate at very high temperatures, around 800°C to 1000°C. 	<p>Technology objectives up to 2020:</p>
PAFC – Phosphoric Acid Fuel Cells	<ul style="list-style-type: none"> -Electrolyte: concentrated liquid phosphoric acid in a bonded silicon Carbide matrix - use a finely dispersed platinum catalyst on carbon - quite resistant to poisoning by carbon monoxide - operate at around 180°C. - electrical efficiency is relatively low, but overall efficiency can be over 80% if the heat is used; - used in stationary power generators (100 kW to 400 kW) 	<p>Transport : Contribution of 500,000 Fuel Cell Electric vehicles (FCEVs) and 1,000+ hydrogen refuelling stations towards the transition of the transport sector towards electric drives;</p> <p>Energy production: Contributing to the transformation of the European energy mix by producing 50% of H₂ used for these applications from renewables energies or from zero-CO₂ emission sources</p>
MCFC- Molten Carbonate Fuel Cells	<ul style="list-style-type: none"> - Electrolyte: melted carbonate salt suspended in a porous ceramic matrix; - a precious metal catalyst is not necessary; - can run on hydrocarbon fuels such as methane; - energy conversion efficiency about 60%; - operates at about 650 C°; - no precious metal is required as the fuel catalyst; - most fuel cell power plants of megawatt capacity use MCFCs, as do large combined heat and power plants. 	<p>Energy Storage: Contributing to the integration of intermittent renewable energies (wind, solar) by applying hydrogen storage capacity up to 500 MV as part of a grid scalable storage.</p> <p>Early Markets: Contributing to the demonstration of cost-efficient solutions with clean and sustainable FCH technologies for material handling vehicles, back-up power and portable power applications.</p> <p>Heat & Power generation: Contributing to the transformation of the energy sector by providing heat and power to more than 50,000 households using stationary fuel cell systems.</p> <p>Technology objectives up to 2050:</p> <p>In the EU, anticipating an estimated 10–15 % of II cars manufactured in the EU to be fuel cell-based by 2040–2050</p>

Materials Road Map

The roadmap for hydrogen and fuel cells proposes a comprehensive research and development programme for the development

of low cost, high conductivity ionic and electronic conductors operating at a wide range of temperatures and pressures and stable under different chemical and mechanical conditions with long cycle life; the development of low-cost enhanced catalysts for both low and high temperature applications that withstand corrosion and exhibit a tolerance to impurities; the development of low-cost functional materials for hydrogen purification, storage and thermo-chemical cycles technologies with improved chemical and mechanical properties; the development of low cost, reliable and corrosion resistant structural materials for pressurised and cryogenic hydrogen storage, hydrogen transport, coal gasification, thermo-chemical cycles as well as sealant materials to maintain hydrogen tightness and to withstand thermal cycles. This programme focuses as well on developing novel materials with enhanced performances for electrolytes, catalysts, photo-materials and hydrogen storage materials.

To reduce the time-to-market of these materials and associated manufacturing processes, the roadmap puts forward up to 4 industrial manufacturing pilots for proton exchange membranes and solid oxide fuel cells and water electrolysis applications, photo-electrochemical cells for hydrogen production and hydrogen storage tanks for automotive applications to demonstrate at scale and verify the reproducibility and durability of their performance, up to 3 industrial pilots to test and qualify 10 the resulting manufactured components and systems in real operating conditions.

These research and pilot activities are underpinned by the proposal of up to 3 (or network of) testing facilities at European level in the field of fuel cells for automotive applications, large scale hydrogen production by water electrolysis and hydrogen purification and storage materials.

Cross-technology pilots and testing facilities are recommended for structural materials.

Market

FCH technologies have a very high development potential because of the substantial contribution they can deliver towards eU energy and climate change policy goals and for enabling the transition towards low-carbon energy and transport systems across a wide power range.

Hydrogen: over the last years, hydrogen's capacity to enhance fuel security in transport, to balance the electricity grid and to enable enhanced penetration of RES (renewable energy sources) in transport and heat applications has resulted in a positive market outlook for FCH technologies. Additionally, demand in the refining and chemical industries will likely increase because of lower crude oil quality, the need for cleaner petroleum-based fuels and the increasing demand for fertilisers.

Market revenues from H₂ for European mobility could amount to several billions of euros by 2030. Next to its use in FCEV, H₂ has been earmarked as a suitable alternative propulsion fuel for other transport modes, with the exception of long-distance heavy-duty road, aviation and sea shipping. The global demand for hydrogen fuel (FCEVs, buses, forklifts, uninterrupted power supply, scooters) is expected to reach over 0.4 Mt/year by 2020, reflecting a 2010–2020 growth rate of 88. The second major growth area is in industrial combustion where H₂ (potentially blended with natural gas) reduces emissions at a similar cost and with less complication than post-combustion retrofit CCS. Longer term, there are H₂ opportunities in distributed CHP. By 2050, H₂ should be produced through carbon-free or carbon-lean processes. H₂ production by electrolysis is expected to considerably grow because of its ability to contribute to grid stability through both supply management (by providing dispatchable power when coupled with large-scale fuel cells or H₂ turbines) and demand management (through fast response time and good partial load performance). The latter is particularly attractive for small-scale electrolyzers sited at refuelling stations and has the added advantage of not requiring a distribution infrastructure.

Table 14: Summary of Electricity Storage in Power Sector Technology

Electricity Storage in Power Sector		
Technology	State of Art	Research Areas
Mechanical energy storage	<p>Pumped hydro storage (PHS): is a mature technology, the oldest and the largest of all available energy storage technologies. The basic principle of a PHS system is to store energy by means of two reservoirs located at different elevations. In times of low demand, electricity from the grid is used to pump water to the higher reservoir, while in times of peak demand the water is released to generate electricity, hence operating a reversible cycle of grid electricity. Costs for pumped hydro stations are in the range of EUR 500–3 600/kW for the power production equipment and eUR 60–150/kWh for the reservoir</p>	<p>The goal of R&D is to overcome limitations given by very high or very low head and to extend the range of services that PHS can deliver to the power system. Further developments concern challenges to the technology of using seawater with only one scheme built. Alternatives to conventional geological formations are PHS plants using underground reservoirs or former opencast mines.</p>
	<p>Compressed air energy storage (CAES): is a mechanical storage technology made of mature building blocks. The concept consists in compressing air by means of electric energy, storing the compressed air in an underground cavern and expanding the air in a combustion chamber to drive a gas turbine. The technology is suited for time shifting but can also deliver reserve power to the grid. The costs of this technology are given by the compressor and turbine and the excavation of the storage cavern. Estimates range between eUR 400 and 1 150/kW for the power conversion unit and EUR 10 and 120/kWh for the storage unit.</p>	<p>One option for improving the technology is the adiabatic CAES, where the expanding air recovers the heat generated during compression from a thermal storage so no natural gas is needed in the process. Demonstrating the adiabatic CAES on large-scale is the main goal of ongoing RD&D. Based on the results of the ongoing engineering phase, an investment decision could be made in 2016. Isothermal CAES, of which a 1.5 MW prototype has recently been deployed in the US, is a further technological option</p>
	<p>Flywheels: Flywheel systems store kinetic energy of a rotating mass. Charging is reached by accelerating the flywheel, and it is discharged when it is slowed. The main elements of a flywheel are the rotating mass, which is connected to a main shaft (rotor) powered by an external source of energy. Flywheels are designed to charge or discharge at their rated power level within seconds but usually not for more than 15 minutes. The technology is thus best suited for grid application, in particular frequency control. Flywheels are expensive in terms of energy costs of eUR 3 500–4 000/kW. Power-related costs of flywheels are between eUR 600 and 700/kWh.</p>	<p>Increasing the energy density of the flywheel is key for reducing the currently high investment costs. This could be achieved by raising the rotational speed of the flywheels and further increasing the reliability of these by improving disc materials, bearings and power electronics.</p>
Chemical energy storage	<p>Hydrogen storage and power-to-gas: electrical energy enables a chemical reaction with the resulting compound storing the energy (e.g. the electrolysis of H₂). H₂ can be produced using electricity via reversible water electrolysis. It can be stored and transformed back into electricity by means of a fuel cell or a combustion engine/turbine. Even though H₂ does not play a significant role in the current electricity system, it offers the broadest spectrum of potential applications of all storage technologies: from stand-alone systems comprised of electrolyzers and fuel cells to integrated power-to-gas concepts providing new degrees of flexibility by connecting the electricity and gas sectors. The high energy density and the possibility to store large quantities of H₂ in underground caverns make the technology ideally suited for seasonal storage. Projects demonstrating electrolyzers with several hundred kW of power combined with RES-E have been</p>	<p>Further promising technologies are currently in the R&D or early demo stage. Redox-flow batteries separate the electrolyte, which is stored in a tank, from the electrodes and thus could be scaled up to very large energy capacities. A large-scale demonstration project of 40 MWe is planned in Japan. Further possible battery systems currently being investigated are based on Na-nickel-chloride, zinc bromide and iron-chromium.</p>

	<p>carried out, for example, in Norway. An alternative approach is to store and transport H₂ in natural gas grids either by blending or by creating synthetic CH₄. The injection of H₂ from electrolysis into the gas grid is currently tested to the scale of several MW in, for example, Falkenhagen, Germany</p>	
<p>Electrochemical energy storage : Electrochemical batteries store electricity through a reversible chemical reaction. The essential components are the container, the electrodes (cathode and anode), and the electrolyte. By charging the battery, the electricity is transformed into chemical energy, while during discharging it is restored into electricity.</p>	<p>Lead-acid batteries (Pb-acid): provide a mature and scalable technology base for providing short-term storage, in particular frequency control. Grid-scale Pb-acid batteries have power costs of around eUR 400/kW and energy costs of less than eUR 300/kWh₂₀. The largest Pb-acid batteries installed so far have been in the range of 10–20 MW_e.</p>	<p>The goal for 2020–2030 is to increase the battery lifetime to 10000 cycles at 80 % depth of discharge and to decrease the energy costs to EUR 100–150/kWh. Technological approaches consist of materials innovations for the electrodes and electrolyte reducing the detrimental effects of deep discharging.</p>
	<p>Li-ion batteries: represent the state of the art in small rechargeable batteries. They are widely used in consumer electronic devices and more recently in electric vehicles, but they are equally well suited to provide scalable and fast short-term storage. Power costs of Li-ion batteries are comparable with Pb-acid technology, but energy costs range between about two and four times those of Pb-acid systems. The total global installed stationary capacity is estimated at 100 MW_e. Li-ion systems in the range of up to several 10 MW_e have recently been installed in Japan and the US. Stationary Li-ion batteries are currently being installed by several European distribution system operators to provide frequency control in regions with a high penetration of renewable energy. Several battery projects are currently installed in Europe, mainly to provide frequency control in power grids with a high penetration of renewable energy.</p>	<p>The main goal for this technology is to reduce the costs.</p>
	<p>NAS batteries are a commercial storage technology originally designed in Japan for providing grid-scale power storage. The sole manufacturer currently offers modules with a storage capacity of approximately 7 hours. The technology has relatively high power costs of above EUR 2 000/kW but more attractive energy costs of around eUR 300/kWh. Self-discharge can be significant during longer periods of no utilisation, due to the required operating temperature of ~ 300 °C. This makes this technology particularly well suited for daily storage. In Japan, the technology has been promoted as a means to stabilise output from RES-E the global installed capacity exceeds 300 MWe. In Europe, the Italian transmission system operator (TSO) TE RNA has signed an agreement with NGK, the provider of the NAS storage technology, for up to 70 MW of capacity.</p>	<p>Costs reduction and enhanced cyclability are the main goals for this technology.</p>
<p>Electrical storage</p>	<p>Differs from the other categories as no transformation of electrical energy to another form is required. Capacitors and super-conducting magnetic storage are examples for this category. These technologies currently do not contribute to the grid-scale storage of electricity.</p>	

Thermal energy storage	Mainly electrical heating systems with attached thermal storage, usually lacks the capability to reconvert the energy into power but offers some of the functionality provided by other storage systems technologies.	
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Materials Road Map

The materials roadmap for electricity storage proposes a comprehensive research and development programme on low-cost, safe and sustainable electro-chemistry, electrolytes and structural materials with superior electro-chemical, thermal and mechanical properties under severe operating conditions and long cycle life, new and innovative cell/system design and manufacturing processes for both energy oriented technologies (e.g. lithium-ion batteries, red-ox batteries, compressed-air energy storage, pumped hydro-storage) and power technologies (e.g. electrochemical capacitors, superconducting magnetic energy storage and flywheels) of industrial potential at European level. This programme focuses as well on developing new electrochemical paths and proofs of concept for emerging technologies such as metal-air batteries, solid state batteries, liquid-metal systems etc. In parallel, the roadmap puts forward up to 4 industrial pilots to demonstrate at industrial scale high-speed and low cost manufacturing processes for electrical double layer capacitors, lithium-ion, flywheels rotor and motor as well as for materials for high temperature compressors and high thermal and pressure resistant media for thermal storage and containers with application in compressed air energy storage; up to 5 pilot projects to test and verify the reproducibility and durability of the performance of these advanced storage technologies including alternative to all vanadium red-ox systems at MW or above scale, under realistic operating conditions in different market environments. This is complemented by the proposal to establish trans-European research and innovation networks that pool industrial and research resources together on a wide range of technologies and research and innovation activities and to set-up a European network of safety testing organisations for stationary applications. Recommendation is also made to establish education and training centres in the field of electrochemistry and storage.

Market

The market for electricity storage can be broadly divided in two segments: *large scale storage* used for energy time shifting on transport grid level and *decentralised storage* supporting services on distribution grid level. Currently, the market is comprised mainly of the first segment which is dominated by the mature technology of pumped hydro. The equally mature compressed air energy storage (CAES) has not yet been deployed on a large scale. Roughly 42 GW of pumped hydro storage are currently installed in Europe (EU combined with Switzerland, Norway and Turkey) with an additional capacity of 5.5 GW under construction. Only two CAES facilities exist worldwide of which one is located in the EU; and the second one was built in Alabama, USA in 1991. Three new grid scale CAES projects, one of which in the EU are in an advanced state of development or have secured financing. The potential for new pumped hydro or compressed air energy storage in Europe could be more than four times the current capacity. Market needs however are likely to be smaller if competing sources of flexibility are taken into account: studies see an additional 50% to 100% of installed capacity by 2050 i.e. 20 – 40 GW of additional bulk storage for Europe.

The currently less developed market for decentralised storage technologies such as batteries is driven by developments on the level of power distribution and consumption. A trigger for the mass deployment of (Li-ion) batteries would be the electrification of road transport. This could make battery storage available for grid applications: both directly in the form of vehicle-to-grid concepts or in form of grid-connected Li-ion (or more conservative lead acid) batteries. Other technologies such as NaS

batteries, Redox-flow batteries, or flywheels are currently deployed in pilot projects competing with lead-acid and Li-ion systems for provision of grid services. Even though hydrogen does not play a significant role in the current electricity system, it offers the broadest spectrum of potential applications of all storage technologies: from stand alone systems comprised of electrolyzers and fuel cells to an integrated power-to-gas concept allowing the transport and storage of wind energy from coastal regions to the inland consumption centres

(IEA, 2013), (JRC, 2014)

Table 15: Summary of Smart Grid Technology

Smart Grid		
Technology	State of Art	Research Areas
Generation	<p>Individual or company generating electricity: traditionally, the energy provided to the electricity system comes from large installations. The smart grids technology and market regulation included in the “3rd energy legislative package” facilitates the integration of electricity from distributed generation. The distributed generation plants have small capacity but they can be located near the consumption; in that case, local consumption may be encouraged and network costs may be reduced. When the distributed generation is a co-producer of heat and electricity (CHP), due to its proximity with the residential load the transfer of the heat is facilitated, improving the business cases of CHP plants.</p>	<p>The RD&D priorities of the electricity grids stakeholders are described in the SRAof the european technology Platform SmartGrids emphasis in terms of R&dis placed on, among others, further developing the thematic topics of:</p> <ul style="list-style-type: none"> • integration of truly sustainable, secure and economic electricity systems; • smart electricity distribution systems; • smart electricity transmission systems;
Transmission	<p>EU regulation (EU, 2013) defines the priority electricity corridors for transmission. The northern Seas offshore Grid (NSOG) was established with the intent to support the transmission of electric energy produced from RES in the northern Seas and to increase the cross-border electricity exchange. The North-South electricity interconnections in Western Europe (NSIWest electricity) define a corridor connecting continental Europe with Scandinavia and the UK. The target includes the integration of RES and to integrate the markets in Europe. The third and fourth corridors are the north-South electricity interconnections in Central eastern and South eastern Europe (NSI east electricity) and the Baltic energy Market interconnection Plan in electricity (BeMiP electricity), respectively.</p> <p>From a technology perspective, high-voltage direct current (HVDC) multi-terminal grids technology has the potential of transmitting electricity over long distances is more efficiently than by using alternating current lines or cables. This is particularly the case for offshore grids. To deliver offshore wind power from a multiplicity of sites to several landing points, a multi-terminal approach appears as an optimal long-term solution. HVDC lines could also prove more efficient in transmitting large amounts of power over long land distances, the so-called “electricity highways”. These have also been identified as a priority in the eU infrastructure regulation. today, almost all HVDC systems have two terminal connections that exchange electric power.</p>	<ul style="list-style-type: none"> • smart combined electricity transmission and distribution systems; • smart retail and consumer technologies; • socio-economical and ecosystem smart grids barriers and opportunities. <p>At the level of the EU, R&D is based on the responsibilities allocated to different entities or programmes. The European Energy Research Alliance (EERA) operates a joint pro-gramme on smart grids giving emphasis to the disciplines of network operation, energy man-agement, control system interoperability and electrical storage technologies. Up to September 2013, 329 FP7-supported energy projects on different sub-disciplines were funded to support the integration of smart grid technologies.</p> <p>The Competitiveness and innovation Framework Programme launched the Intelligent Energy Europe (IEE) programme, which supports those organisations willing to improve their environmental foot-print. KIC innoEnergy targets the exploitation of knowledge that has been already created from the research of academic structures and the industry catalysing their cooperation. Smart Grids ERA-Net funds specialised proposals on smart grids and develops an articulation between national pro-programmes. the european Research Council (ERC) supports high-profile individuals in their research.</p> <p>The European industrial electricity Grid initiative brings together representatives principally from industry and member states to plan and develop the research and innovation activities to develop and deploy smart grids in Europe.</p>
Distributed energy storage systems	<p>The manufacturing industry offers a variety of concentrated and distributed energy storage products, which are increasingly being tested in different configurations; combined with generation, connected to the grid or combined with loads. The electric energy storage modules may relieve potential congestions of the grid and thus delay the need for network upgrade, and increase the ability of the grid to absorb the energy pro-duced from intermittent renewables. Also, they may improve the efficiency and reliability of the system, but today high installation costs do not justify the business case in most configurations. in addition, regulation may not allow network operators to own and operate storage as this would interfere</p>	<p>The European industrial electricity Grid initiative brings together representatives principally from industry and member states to plan and develop the research and innovation activities to develop and deploy smart grids in Europe.</p>

	with the market.	The JRC's institute for energy and transport (JRC-iet) has been mapping the European Smart Grid projects and a respective report has been released for projects collected up to 2012 (JRC, 2013). The current initiatives, based on the information provided, include large publicly funded projects, in particular the first group of projects funded by the low Carbon network Fund (ICNF)
Consumption	<p>As part of state-of-the-art smart grid technology, a distributed control approach focuses on the implementation of platforms that harmonize the load and the intermittent production of electricity from RES (renewable energy sources) as well as optimize the internal consumption.</p> <p>The transition of the traditional metering to smart metering equipment is an important element in the implementation of smart grids. Smart meters are the measuring devices that can record real-time detailed electric energy consumption data, and communicate these measurements to the energy providers for billing.</p>	<p>(total investment of around eUR 120 million) from the UK, and a significant number of large-scale demonstrators financed under FP7 (e.g. Grid4eU, linear, Green eMotion) or with European regional funding (particularly a large-scale grid automation project for RES integration in the south of Italy).</p>

Materials Road Map

The objective of the SET-Plan on electricity grids is to enable the transmission and distribution of up to 35% of electricity from dispersed and concentrated renewable sources by 2020 and a completely decarbonised electricity production by 2050. The materials roadmap on electricity grids proposes a research and development programme on the development of high temperature superconductor materials (HTS) and manufacturing processes for DC and AC cables to ensure uniform critical current and enhanced magnetic field performance and to reduce cost at least by a factor of 10; the development of advanced composites for cables (including new carbon fibre and plastic core composite material and metal matrix composite) with enhanced mechanical, electrical and thermal performance; the development of polymer based insulating materials and their manufacturing processes for high voltage insulated cables, on line and station insulators; the development of wide band gap semiconductor materials for 20 kV power electronics devices for high injection operation. The roadmap focuses also on the development of enabling structural materials for advanced packaging for power electronic devices at high temperatures as well as on the thermal behaviour of materials at cryogenic temperatures. In addition, to accelerate the transfer to market, the roadmap puts forward one technology pilot project to simulate, qualify and test new HTS materials and components and their interaction with the grid; and one pilot to improve significantly the manufacturing processes of HTS materials. This is complemented by the proposal to establish a European (or network of) grid testing facility on HTS and to set up a European research infrastructure for pre-stress application for advanced composites.

Market

The European electricity grid is the largest synchronous operating system with more than 660 GVA of installed capacity, according to ENTSOE (European network of transmission System operators for electricity). To upgrade and modernise the European network, conservative estimates forecast an investment need of EUR 56 billion by 2020–2025, EUR 390 billion by 2030 and eUR 480 billion by 2035.

The energy Roadmap 2050 estimates the infrastructure requirements with different energy technology scenarios. Decarbonisation scenarios require more sophisticated infrastructures than the reference scenario. For example, the scenario with high share of renewables would require extra HVDC lines to transport electricity from the North Sea to the centre of Europe and also more storage.

(JRC, 2014), (EU Commission, 2011)

Table 16: Summary of Cogeneration or Combined Heat and Power (CHP) Technology

Cogeneration or Combined Heat and Power (CHP)		
Technology	State of Art	Research Areas
Reciprocating engines in the form of spark or compression-ignited ICEs	The technology is mature and available in a wide range of sizes, with electrical efficiencies of 25–48 % (typically rising according to size) and total efficiencies of 75–85 %. Electrical output is 1–3 000 kW _e . The investment cost for small-scale reciprocating engines is up to EUR 10000/kW _e , and for large-scale engines it is from EUR 1000/kW _e .	<p>Cogeneration is a mature technology. Several European initiatives concern the integration of CHP in the future energy system. The EII on Smart Cities supports cities and regions that take pioneering measures to reduce GHG emissions by 40 % by 2020. To reach this goal, measures to improve energy efficiency, low-carbon technologies, and smart management of supply and demand will be needed. This also includes high efficiency co- or trigeneration and dH and cooling systems. Also, the Smart Cities and Communities innovation Partnership includes cogeneration and DH (District Heating) as a means to improve the energy efficiency of cities and communities. Several projects in FP7 were studying cogeneration and/or its integration in the future energy system. For example: FC-DISTRICT is about optimising and implementing an innovative energy production and distribution concept for new 'energy autonomous' districts, exploiting decentralised cogeneration coupled with optimised building and district heat storage and distribution network; E-HUB concerns an energy Hub, which is similar to an energy station where energy and information streams are coordinated, and where different forms of energy (heat, electricity, chemical, biological) are converted between each other or stored for later use; DIGESPO aims to research and build a modular 1–3 kW_e, 3–9 kW_{th}-CHP system based on innovative CSP and Stirling engine technology; and aRCHeR (aRCHeR, 2013), which studies the system integration of nuclear cogeneration units coupled to an industrial process.</p>
Gas turbines use high-temperature	High-pressure hot gases to produce electricity and heat. They can produce heat and/or steam as well as electricity. Typical electrical efficiency is 20–45 %, while overall efficiencies are 75–85 %. The capacity is in the MW range and therefore generally not used for normal building heating applications, but for hospitals, leisure centres, hotels and other such establishments, which are characterised by a steady, year-round demand for domestic hot water supply. Investment cost for large-scale gas turbines is EUR 800–1500/kW _e .	
Combined-cycle gas turbines (CCGTs)	With heat recovery can be used at large industrial centres for chemical works, and at oil refineries, industrial drying facilities and food processing plants. Such industrial centres often have a common energy centre where large amounts of both heat and electricity are generated. The heat demand follows the industrial processes and tends to be fairly predictable and continuous on a year-round basis. Total efficiencies can be above 90% and the electrical efficiency can remain at high levels regardless of the heat production level.	
Micro turbines	Are smaller versions of gas turbines, typically 1–250 kW and therefore more suited for different types of buildings like a house or a small commercial building. Such engine-based units currently have relatively low electrical efficiency (from around 10 % for Stirling engines up to 25 % for ICEs (Internal Combustion Engine)). There are several m-CHP (Combined Heat and Power) units commercially available, for example, Honda make a modified gas engine unit and several European manufacturers are making or are about to make a unit based on a Stirling engine. Investment costs are in the range of EUR 1 500–2 100/kW _e .	
Fuel cells	Use an electrochemical process that releases the energy stored in natural gas or H ₂ fuel to create electricity and heat. Heat is a by-product. Fuel cells that include a fuel reformer can utilise the H ₂ from any hydrocarbon fuel. Fuel cells offer the advantage of nearly 1-to-1 electricity-to-heat ratios, making them well suited for modern low-energy buildings. More information about fuel cells can be found in Table 13.	
Market		
Industrial heat demand is expected to increase substantially for all likely scenarios, whereas households and tertiary sectors are		

expected to need less heat in the future. The decarbonisation scenarios of the energy Roadmap 2050 project that the share of electricity production from CHP will increase from 473tWh in 2005 to around 1 050tWh in 2030 and then decline to about 700tWh in 2050. The growth until 2030 is driven by support policies based on the CHP directive (now the energy efficiency directive) and the EU ETS. The support from the latter is partially due to the fact that high-efficiency CHP plants are allocated some emission rights for free. This free allocation of emission rights is reduced with time. DH is expected to decline from its 2000 levels of 190tWh to 109tWh in the reference scenario and to 29–52 tWh in the decarbonisation scenarios in 2050. It is also stated that DH systems reduce emissions in the short and medium term when using fossil fuels, but in the longer term the heat source has to be biomass or another suitable low-carbon source in order to reduce GHG emissions sufficiently. This is valid for the CHP plants too. It should be noted that other scenario studies claim that the energy Roadmap 2050 significantly underestimates the potential of CHP and dH. It is claimed that more detailed mapping between heat sources and demands are needed for modelling a more accurate prediction of heat demand. Cogeneration can be used to balance the electricity production from variable renewables. Fluctuations in heat supply can be smoothed out by the use of heat storage technologies. It is relatively easy to store low-temperature heat for up to 48 hours. Low temperature heat is useful for many applications, for example, DH and about 30 % of the industrial applications. Storing higher-temperature heat is technically possible but more complex. The Cogeneration directive has been in place since 2004, and has now been replaced by the energy efficiency directive. The progress reports on the implementation of cogeneration revealed that the growth of electricity production from CHP has been slower than anticipated in most Member States. Some of the explanations for the slow progress are presented in the following section where barriers are discussed Key European players in supplying installations include Siemens and Alstom, which manufacture across the range except for the very small sizes. There are several industrial gas engine manufacturers such as Jenbacher, MTU, MAN and Wartsila. Outside Europe, there are several large manufacturers, for example, Caterpillar from the US for engines and smaller turbines, Mitsubishi from Japan and General Electric from the US offer large power stations.

(JRC, 2014), (EU Commission, 2011)

Table 17: Summary of Heat Pumps Technology

Heat Pumps				
Technology	Components	State of Art	Research Areas	
Air/air Air/water Water/air Water/water	Compressor	<p>Heat pumps are based on a mature technology that transfers thermal energy from a heat source to a heat sink using a compression cycle that takes advantage of temperature gradients. They can be driven by electricity or by thermal energy.</p> <p>The main difference between conventional heat pump technology and thermally activated heat pumps: compression heat pumps employ a mechanical compressor (driven by an electric motor or combustion engine), while thermally activated heat pumps achieve compression by thermal means.</p>	<p>Challenges still remain in order to enhance overall performance and operation. The use of alternative materials will help to reduce the cost of equipment and components.</p> <p>The main R&D effort is the optimisation of operational plans, control systems, and the design of load management strategies and installing protocols.</p> <p>Optimal integration of heat pumps with alternative heat and cooling technologies (in particular, conventional boilers and solar technology) constitutes one of the main challenges in order to achieve large-scale deployment in the near future.</p>	
	Pumps	<p>Thermally driven heat pumps can further be differentiated into:</p> <ul style="list-style-type: none"> • absorption, which use high-temperature heat for the process; and • adsorption heat pumps, which incorporate low-temperature energy and convert it to a higher temperature. 	<p>Integrated solutions will have a relevant role in increasing the use of renewable and low-carbon technology in building renovation applications.</p>	
	Fans			
	Heat exchangers			
	Expansion valves	<p>Different working fluids are available, choosing the correct working fluid will depend on the specific application and no single fluid is preferred in all applications.</p>	<p>Small heat pumps with low investment and installation costs could either supply most of the annual heating demand being supported only by existing boilers at low ambient temperatures or cover peaks in demand.</p>	
	Inverters			
	Condenser	<p>Fluorinated gases (F-gases), which have a high global warming potential (GWP), are still widely used in air conditioning and heat pump equipment.</p>	<p>Another area of R&D, involves: the performance of heat pumps in cold and/or warm climates, and the selection of refrigerants capable of maximising performance while minimising GWP.</p>	
	Evaporator	<p>CO₂ (for applications with temperatures up to 90 °C) and ammonia (capable of reaching temperatures up to 100 °C) are currently the two main refrigerants used for high-capacity heat pumps.</p> <p>In absorption systems, which use liquids or salt to absorb vapour, the most common combinations of working fluid and absorbent are water/lithium bromide and ammonia/water.</p> <p>Heat pump efficiency is characterised by the coefficient of performance (CoP): the ratio between energy delivered and energy consumed.</p>	<p>There is considerable effort put into the analysis and efficient use of natural refrigerants (CO₂, ammonia and hydrocarbons) and into the development of new synthetic refrigerants.</p>	
			<p>The most common heat pumps used in the residential sector are air/air units and split-air conditioners for air conditioning.</p> <p>Water/water and water/air heat pumps have higher efficiencies than air/air units, they require a water source situated close to the end user.</p>	

Market

The main factors that have been identified as having a significant influence in the European heat pump market are the price of primary energy sources, the building and construction market, and the implementation of policies.

The EU market is dominated by air/air and air/water units, followed by geothermal units mainly used for heating. The choice of energy source largely depends on national and regional factors. While in countries with warm climates there is a higher use of reversible air/air units, colder climates demand a more stable source temperature, which implies a larger share of ground-coupled units. Overall, the air-source segment, including reversible heat pumps and exhaust air heat pumps, remains the largest. In recent years, the share of sanitary hot water (SHW) has greatly increased and it currently represents 9 % of the total market. This technology is particularly associated with the building renovation sector and the use of hot water heat pumps with fossil fuel boilers and in combination with PV systems.

Heat pump sales in households in the period from 2005 to 2010 showed a considerable market penetration in the Scandinavian countries, followed by Austria, Estonia, Italy and Switzerland. The market for multi-family residences and services is currently under development with a lower market penetration (around 10 %). The rest of the European countries have lower market penetration values, which indicates potential for further exploitation.

In recent years, the European heat pump market has undergone major changes with a clear trend towards the creation of medium- and large-sized enterprises capable of offering global solutions for the heating and cooling sector. It should also be noted that traditional air conditioning manufacturers, including Japanese and Korean suppliers, have expanded into the combined heat and cooling sector.

(JRC, 2014)

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Conclusions

In Europe is growing a pressing need to make low-carbon technologies affordable and competitive in order to transform the entire energy system, and reduce the greenhouse gas emissions. This is the core idea behind the European Strategic Energy Technology Plan (SET-Plan) aimed at accelerating the large scale deployment of selected low carbon energy technologies by intensifying research and development (R&D) and demonstration activities, which in turn would advance their commercialisation.

In this report we have presented the state-of-the-art and the potential improvements of a portfolio of energy technologies which can have possible roles in the post-2020 European energy system, as foreseen in the Energy Roadmap 2050. From the collected data, it is clear that the implementation of the long term sustainability goals, such as the decarbonisation of the society and economic growth, primarily depend on the continuous innovation on energy technologies.

Scientific and economic data show that the power sector needs structural change: it needs to achieve significant reductions in greenhouse gas emissions already in 2030 (57-65%) and to reach near-complete decarbonisation by 2050 (96-99%). The projected structure of the energy system for two of the scenarios is shown in Figure 1 (EU Commission, 2013).

In both the ‘Reference’ scenario (*Res*, which reflects a business-as-usual trajectory for the energy system) and the ‘Diversified Supply Technologies’ scenario (*DST*, which is the most technology-neutral amongst the decarbonisation scenarios considered in the Roadmap), electrification of the energy system is a major trend, resulting in much larger electricity generation capacities by 2030 and 2050 compared to today.

Fossil-fuel capacity without carbon capture is slowly phased out and growth at the 2030 horizon is concentrated in solar, biomass/waste and wind and some other renewable energy sources (RES). By 2050 there is also a substantial role for carbon capture and storage (CCS). Of all the technologies addressed by the SET-Plan only wind and solar power in favorable locations can currently compete in the market without some form of economic incentive for power generation or grid access.

Therefore, in order to reduce costs and realize the economics of scale associated with large scale deployment, high technological know-how and advanced manufacturing processes will be needed (EU Commission, 2013).

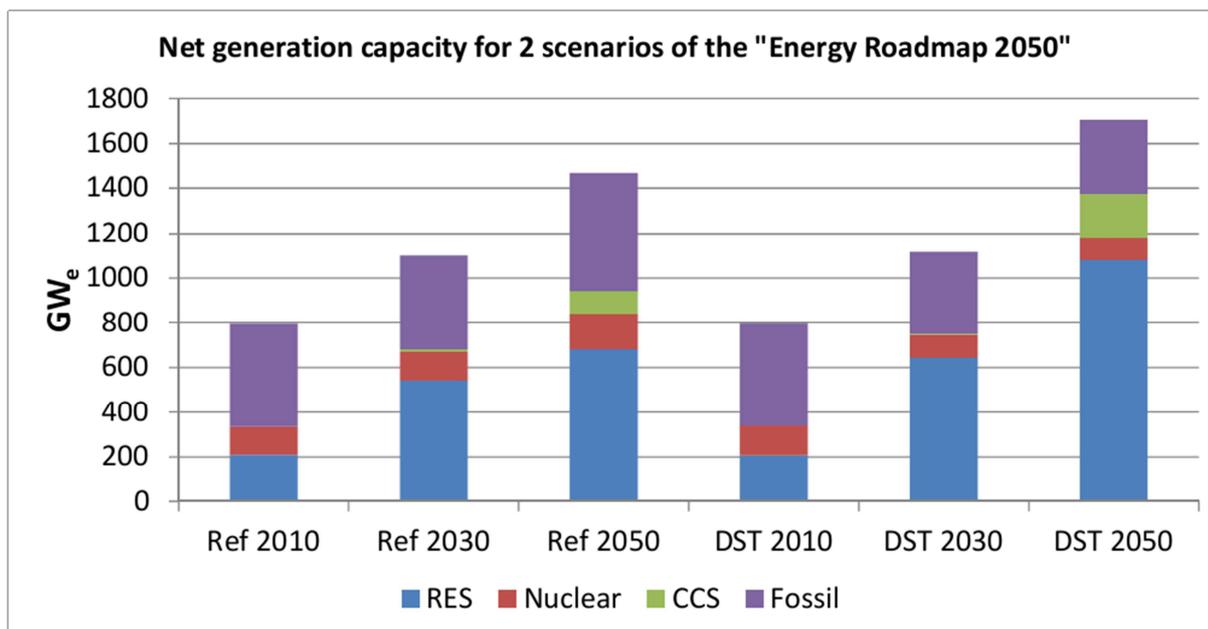


Figure 1: Evolution of net electricity capacity in the EU between 2010 and 2050 according to two scenarios from the Energy Roadmap 2050: The reference (Ref) and the 'Diversified Supply Technologies' (DST) scenarios (EU Commission, 2013).

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