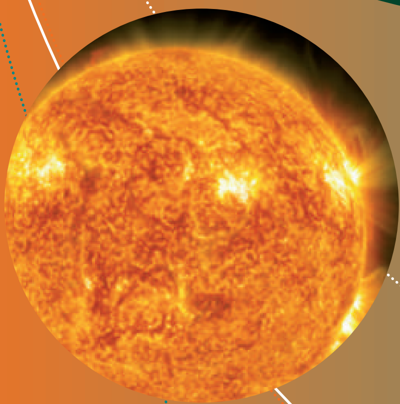
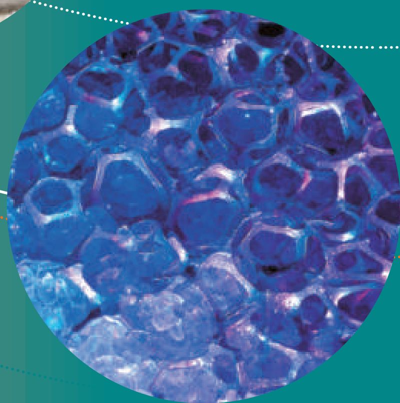
Strategic Research and Innovation Agenda for Renewable Heating & Cooling

European Technology Platform on Renewable Heating and Cooling





RHC Renewable Heating & Cooling
European Technology Platform

European Commission

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Executive Summary

This Strategic Research and Innovation Agenda (SRA) is the first of its kind for the Renewable Heating and Cooling (RHC) sector. It provides stakeholders with a structured and comprehensive view of the strategic research priorities to enable an increasing share of heating and cooling to be supplied by Renewable Energy Sources (RES). The contribution of RHC to the EU energy targets by 2020 and beyond will be determined by the availability of reliable, efficient and affordable technology. Expanding the market for biomass, geothermal and solar thermal applications, achieving significant breakthroughs through targeted, collaborative research and development activities-in RHC technology are all fundamental to achieve on time the European Union's energy and climate objectives.

The heating and cooling sector plays a crucial role with respect to our primary energy demand. In 2010, heat accounted for 47% of the final energy consumption in the EU. For the purposes of this RHC-SRA, three profiles of heating and cooling demand are identified: residential sector (Chapter 3), non-residential buildings (Chapter 4), and industrial processes (Chapter 5). Local constraints such as the relative abundance of different forms of renewable energy but also the required temperature, the consumption profile, the thermal demand density[i], etc. affect the choice of technology.

Alongside the description of demand characteristics, the RHC-SRA presents the strategic research and innovation priorities for renewable energy technologies able to meet these diverse profiles of demand in the short-term (by 2020), and medium- to long-term (2030 and beyond). Priorities for District Heating and Cooling (DHC) technology are presented separately (Chapter 6) because advancements are likely to bring benefits to all types of users and to have a positive impact on the entire range of renewable energy supply technologies. Other cross-cutting technologies (CCT) like energy storage, hybrid systems and heat pumps are looked at within the individual chapters (Sections 3.5, 4.5 and 5.5).

According to the Common Vision for the Renewable Heating & Cooling sector in Europe (RHC-Platform, 2011), the potential of RHC technologies is vast: in 2020 over 25% of heat consumed in the European Union could be generated with renewable energy technologies and by 2030 RHC technologies could supply over half the heat used in Europe. To realise such potential will require a holistic view, identifying the pathway to commercial exploitation of the results of research, development and demonstration activities.

[i] Thermal energy density refers to the amount of heat or cold required in a certain area (e.g. in a city, industry, or rural area).

The most important aims, which are common to all RHC technologies, can be summarised as follows:

- Significantly reduce the cost of RHC technologies for different applications and for different capacities.
- Enhance RHC system performance and reliability.
- Reduce RHC system payback time.

Efficiency and cost reduction targets by 2020 are provided for each technology within the detailed discussion of research and innovation priorities in the main body of the report (Chapters 3-6). In general, it is acknowledged that prices and generation cost values for RHC systems in Europe vary widely, reflecting differences in the cost of components as well as of installation, operation and maintenance.

Albeit some of the results of the RHC-SRA priorities are expected to be used in commercial applications after 2020 (and in some cases after 2030), it is essential to provide as of today the appropriate R&D support framework to ensure the transition to tomorrow's energy systems. The benefits of strategic planning of investments in research infrastructure usually ripen over a long time frame. A number of technologies such as thermochemical energy storage and EGS which are unlikely to be cost-competitive by 2020, are expected to realise their full potential in the following decade and to become key drivers to realise the RHC-Platform's Common Vision until 2050. Curiosity-driven research in renewable energy technology for heating and cooling, which in the current economic climate has suffered non-negligible budget cuts, holds the potential to lead to a new generation of energy technology options, able to cost-compete with and possibly outperform fossil fuels.

All R&D activities on cross-cutting technologies must be accompanied and supported by additional research on Information and Communication Technology (ICT) and materials science (Chapter 7). As heating and cooling technologies become more intelligent, the flexibility available to the energy system is increased and the associated costs lowered. ICT plays an increasing role in reducing the energy intensity of our applications, therefore enabling renewable heating and cooling systems to satisfy a higher share of the energy demand. Materials research is at the core of sustainable technologies for and solutions to our thermal energy needs. Research and development of new materials as well as the understanding and use of their properties is crucial to enable scientists and engineers to enhance energy systems and to realise the full potential of RHC technologies.

Tomorrow's energy systems are defined by the policy and legal framework we adopt today (Chapter 8); these must provide the right conditions to attract large scale public and private investments. The market for heating and cooling systems is characterised by asymmetric information. Policies are required that ensure that prospective customers are provided with standardised information about the technological solution that best meets the thermal energy needs of the individual building, district or industrial process. It is a priority to ensure that building sector professionals are aware of the entire spectrum of RHC solutions to make decisions based on life-cycle cost and benefit analyses which take into account future energy prices and CO_2 emissions. It is important to address proactively the shortage of skills and any financial barriers that might set back the progress of RHC technology.

This publication provides recommendations to policy makers, funding bodies as well as to industry and research stakeholders on how to prioritise the allocation of resources for research, development and demonstration of RHC systems (Figure A). In particular, the RHC-SRA can be used as input for the identification of the most appropriate areas to fund under Horizon 2020, the successor programme to the Seventh Framework Programme for Research and Development of the European Union. Failure to provide sufficient support to scientific and technological research for RHC in the next EU Budget (2014 – 2020) would put at risk some of the energy industries with the highest potential of growth, mitigation of climate change and job creation in the EU today – and the transition towards a clean, secure and affordable energy supply.

Chapter 9 provides an overview of the total resources required for the successful implementation of this RHC-SRA in Europe. **The RHC-Platform estimates that 4,032 million Euro are required for the successful implementation of this Strategic Research and Innovation Agenda in Europe** (Figure B). **Over the period 2014 - 2020, on average 576 million Euro should be allocated annually to RHC research and innovation activities**. The information provided is based on a quantitative analysis of funding for RHC research, development and demonstration from the public and private sectors in the period 2007-2012 and the expected funding trends to 2020, which rely on a number of assumptions developed by the RHC-Platform. It must be noted that available data is incomplete and the information concerning public investments in R&D for several Member States was not available.

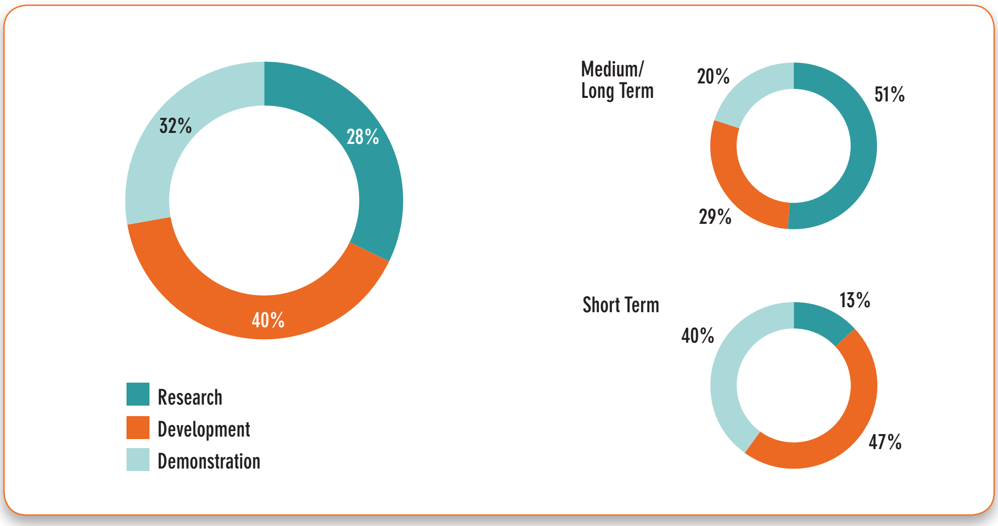

Figure A: Estimated distribution of resources by type of activity, distinguishing between priorities with impact in the short-term and medium- to long-term (based on the analysis of all priorities in the RHC-SRA).

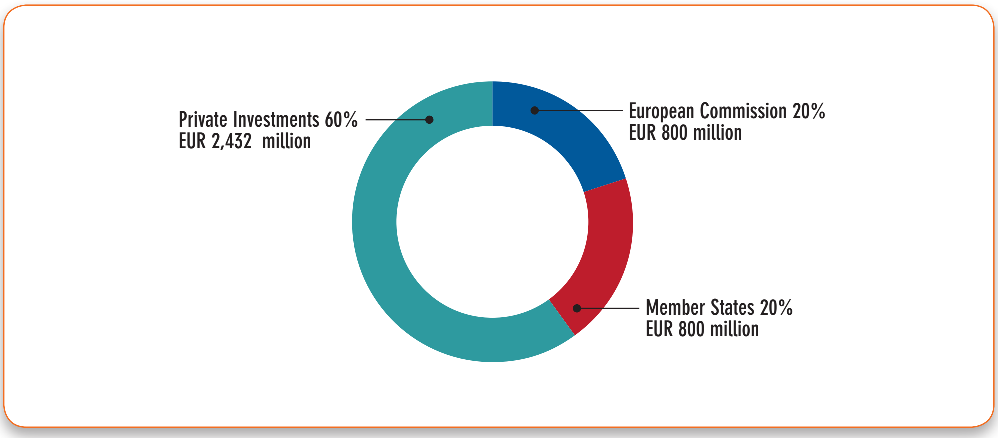

Figure B: Estimation of total resources required to implement the RHC-SRA between 2014 and 2020, in million Euro and in % by sector.

The RHC-SRA has been prepared by the RHC-Platform's Horizontal Working Group on Shared SRA, it was edited and coordinated by the Secretariat of the RHC-Platform and ultimately approved by the Board of the RHC-Platform. Numerous experts provided useful insight directly to authors or through the open consultation carried out in February and March 2013. This publication was made possible thanks to the support of the European Commission through the Seventh Framework Programme for Research and technological Development (Grant Agreement n. 268205).

The Strategic Research and Innovation Agenda for Renewable Heating & Cooling (RHC-SRA) in a nutshell

1. The RHC-SRA clearly identifies the R&D activities and investment areas needed to make RHC technologies cost-competitive in all market segments (residential, non-residential, and industrial) by 2020 (in some cases by 2030).

2. Specific, measurable targets are identified for each research and innovation priority. These technology-specific targets are often expressed in terms of cost reduction and/or efficiency gain; however the implementation of the RHC-SRA in its entirety requires a systemic approach to produce innovative integrated solutions.

3. The total volume of resources required to implement the RHC-SRA until 2020 is estimated at around 4 billion Euro, approximately 60% of which is expected to come from the European industry. For each Euro invested by the public sector (European Commission or Member States), 3 Euros should be committed by the private sector. The RHC-Platform recommends the European Commission to support the implementation of the RHC-SRA by allocating a yearly budget of 114 million Euro to RHC research and innovation projects.

	Potential Contribution	Key research and innovation areas by 2020
Biomass	By 2020: 124 Mtoe By 2050: 231 Mtoe	• Small scale CHP for domestic, industrial or regional solutions. • Tri-generation. • Advanced fuels (new solid biocommodities, thermally treated biomass fuels, pyrolysis oil) replacing coal and fossil oil in CHP. • High efficient large-scale or industrial steam CHP with increased high temperature heat potential (up to 600°C).
Solar Thermal	By 2020: 13 Mtoe By 2050: 133 Mtoe	• New materials, designs, and manufacturing technologies for solar thermal collectors. • Reducing costs of high solar fraction systems, multi-functional solar façade systems and solar based hybrid systems covering the full heating load. • Optimised heating systems for "Solar-Active-Houses" and highly efficient solar-assisted cooling systems. • Improved low to high temperature solar thermal solutions for industrial processes using optimised large-scale collector arrays.
Geothermal	By 2020: 10.5 Mtoe By 2050: 150 Mtoe	• Integration of design of the shallow geothermal system and building energy system with regard to optimum thermal use and operational strategy. • Optimisation of components such as borehole heat exchangers, well completion materials, compressors, pumps etc., including improved drilling methods. • Innovative exploration, drilling and production methods for deep geothermal resources, including related surface installations, for reducing overall cost and risks caused by geological uncertainties. • Reducing cost and increasing the lifetime of Enhanced Geothermal Systems - EGS (focus on exploration, drilling, hydraulic fracturing, formation treating, reservoir predictive models, and heat production).
Cross-cutting	Energy saving potential by 2020: Industrial heat pumps: 20 Mtoe District Heating: 50.7Mtoe / year District Cooling: 5.5 Mtoe / year	• Efficiency increase for heat pump technology (both electrically-driven and thermally-driven applications). • R&D to make available integrated, flexible, highly efficient and environmental friendly district heating and cooling systems, in particular through a better valorisation of local resources, development of low-temperature networks and the integration of innovative thermal storage. • R&D to increase storage density using phase change materials and thermochemical materials. • Development of advanced algorithms for optimal planning, management and control of hybrid systems.

Figure C: Clusters of key research and innovation areas by technology type

Synoptic table of research priorities by technology type and by application (short- to long-term)

	RESIDENTIAL		NON-RESIDENTIAL	
SOLAR THERMAL	ST.1	New surfaces, coatings, materials, construction designs, and manufacturing technologies for solar thermal collectors	ST.6	Multifunctional building components, including façade and roof integrated collectors, for new and existing buildings
	ST.2	Cost effective solar based hybrid systems able to satisfy the entire building heating demand	ST.7	Highly efficient solar assisted cooling systems combining heating and cooling
	ST.3	Optimised heating systems for 'Solar-Active-Houses'	ST.8	*Solar Based hybrid systems for 100% renewable heat solutions*
	ST.4	*Research on the next generation of the Solar Active House – The Smart Solar Building*	ST.9	*Research on new absorption and adsorption chillers*
	ST.5	*Improving the components of solar thermal cooling systems*		
BIOMASS	BIO.1	Improve system design of residential biomass heating systems	BIO.6	Cost effective solutions to reduce dust emissions
	BIO.2	Demonstrate the potential of efficient biomass biolers and stoves to improve air quality and reduce energy consumption	BIO.7	Cogeneration technologies and small scale biomass gasification technologies
	BIO.3	Cost-effective micro-CHP systems	BIO.8	*Development of advanced cost-efficient high quality solid and liquid biomass fuels from agro-biomass, bio-degradable waste, forestry and aquatic biomass*
	BIO.4	*Development of next generation of firewood stoves (and insert appliances and cookers)*		
	BIO.5	*Fuel Flexible residential scale boilers*		
GEOTHERMAL	GEO.1	Optimisation of ground-coupling technology (i.e. technology to exchange heat with the ground in an optimal way)	GEO.4	System concepts and applications for geothermal cooling in warm climates
	GEO.2	Improving the understanding of the shallow geothermal reservoir	GEO.5	Development of ground coupling technologies and installation techniques for high capacities
	GEO.3	*Research on pipe material for borehole heat exchangers (BHE) or horizontal ground loops*	GEO.6	*Integration of design of the shallow geothermal system and building energy system with regard to optimum thermal use and operational strategy*
CROSS-CUTTING	CCT.1	Cost competitive heat pump kit for houses with existing boiler	CCT.9	High capacity heat pump for simultaneous production of cold and hot water for heating/cooling the building
	CCT.2	Optimisation of thermally driven heat pumps and their integration in the boundary system	CCT.10	Integration, automation and control of large scale hybrid systems for non-residential buildings
	CCT.3	Automation, control and long term reliability assessment	CCT.11	*Sorption cooling systems driven by hot water at moderate temperature*
	CCT.4	*Development of a heat pump for near-zero energy buildings (single family house)*		
	CCT.5	*Next generation of highly integrated, compact hyrid systems*		
	CCT.6	Next generation of Sensible Thermal Energy Storages		
	CCT.7	*Improving the efficiency of combined thermal energy transfer and storage*		
	CCT.8	*Increased storage density using phase change materials (PCM) and thermochemical materials (TCM)*		
GENERAL	RHC.1	Developing standards for the overall system design and for hydraulic and electrical interconnections of different building components		
	RHC.2	Elaborating standards, tests, and benchmarks for system efficiency		

		INDUSTRY		DISTRICT HEATING
SOLAR THERMAL	ST.10	Medium temperature collectors developed and demonstrated in industrial applications	ST.12	Optimize large-scale solar collector arrays for uniform flow distribution and low pumping power
	ST.11	*Turn-key solar thermal process heat systems*	ST.13	*Advanced solutions for the integration of large solar thermal systems into smart thermal/electrical grids*
BIOMASS	BIO.9	Development of highly efficient large-scale or industrial CHP with enhanced availability and high temperature heat potential	BIO.11	Cost efficient CHP plants using biomass and biogas
	BIO.10	*Development of high efficient biomass conversion systems for tri-generation (heating, cooling and power)*	BIO.12	*Development of CO_2-negative bioenergy systems*
GEOTHERMAL	GEO.7	Geothermal Heat for industrial processes up to 250 °C	GEO.10	Deep Drilling
	GEO.8	Production pump technology for temperatures >180 °C	GEO.11	Production technologies
	GEO.9	*Unconventional resources and very high temperatures*	GEO.12	Surface systems for heat uses in DHC (incl.CHP)
			GEO.13	*Enhanced Geothermal Systems (EGS)*
			GEO.14	*Resource Assessment for deep geothermal heat use*
CROSS-CUTTING	CCT.12	Enhanced industrial compression heat pumps	CCT.17	Large scale demonstration of Smart Thermal Grids
	CCT.13	Process integration, optimisation and control of industrial heat pumps	CCT.18	Booster Heat Pump for DHC
	CCT.14	*Improvements in Underground Thermal Energy Storage (UTES)*	CCT.19	Develop and roll-out DHC driven white goods and low temperature solution for domestic hot water preparation
	CCT.15	*Improvement of sorption cooling form renewable energy sources*	CCT.20	*Improved, highly efficient substations for both present and future lower temperature networks*
	CCT.16	*New Concepts for industrial heat pumps*	CCT.21	*Optimised integration of renewable enrgy sources in DHC systems and enhancement of thermal energy storage at system level*

NOTE: Research and Innovation priorities resulting in advancements whose impact is mostly expected by 2020 are indicated in regular font. All other priorities indicated in italic font are expected to have a significant impact after 2020.

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1.
Introduction

1 Introduction

Renewable Energy has proven to be a driving force for Europe's economic growth and sustainable long-term prosperity. Renewable energy technologies offer a safe, reliable, clean and increasingly cost-effective solution to all heating and cooling needs, which account for nearly half of the final energy consumption in the European Union.

The vast majority of energy supplied for heating and cooling is however still produced by burning fossil fuels such as oil, gas and coal – with a severe environmental impact arising from the associated greenhouse gas emissions and posing a risk in terms of energy security.

It is against this background that in 2008 the European Commission (EC) supported the establishment the **European Technology Platform on Renewable Heating and Cooling (RHC-Platform)** with the aim to create a common framework within which European industry and research stakeholders can define technological research needs and strategic priorities to increase the use of renewable energy sources (RES) for heating and cooling and to consolidate EU technological leadership (Figure 1).

Building on the strategies for Europe 2020 and for an Innovation Union, the EC's proposal for the next EU framework programme for research and innovation (Horizon 2020)[1] recognises the key role of European Technology Platforms (ETPs) as part of the external advice and societal engagement to implement Horizon 2020 . The RHC-Platform takes a holistic view of research and innovation priorities related to renewable heating and cooling technologies, providing strategic insight into market opportunities and needs, sharing information with over 650 stakeholders from 25 EU Countries and mobilising public and private organisations to work in partnership and deliver on agreed priorities.

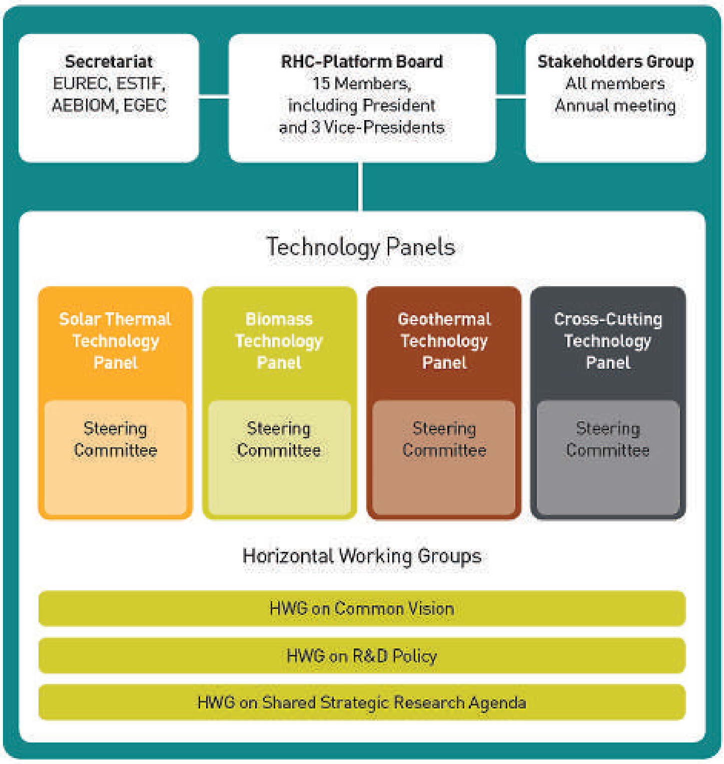


Figure 1: Structure of the RHC-Platform

[1] European Commission (2013).

With the publication of the Common Vision for the Renewable Heating & Cooling sector in Europe in 2011[2], the RHC-Platform proved that the theoretical and technical potential of renewable energy sources can, under the right conditions, exceed Europe's total heating and cooling consumption. However, the report also pointed out that discovering how to make such a potential economically viable remains a challenge.

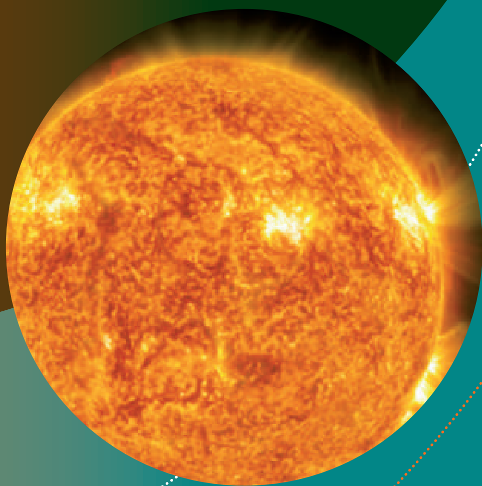
In order to realise the Common Vision, the RHC-Platform has produced the present **Strategic Research and Innovation Agenda for Renewable Heating and Cooling (RHC-SRA)**, a key document which addresses the short, medium and longer term R&D needs in the field of renewable heating and cooling technologies and puts together the strategic research priorities identified for Biomass, Geothermal, Solar Thermal and Cross Cutting Technologies.

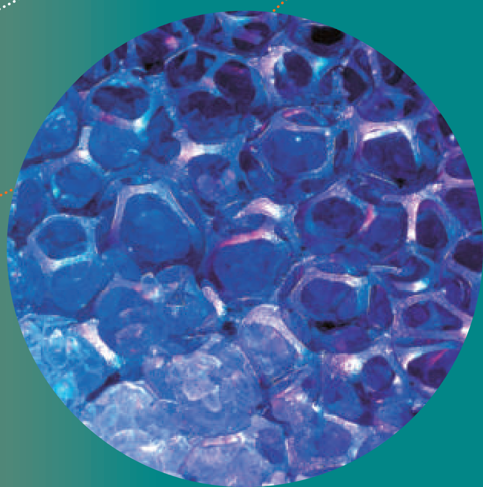
The RHC-SRA sets out the likely directions of technological and organisational changes that will need to be converted into specific research activities over the next years, starting from Horizon 2020 (2014-2020). Furthermore, it aims to facilitate the coordination of other research programmes in and between member states. As market growth to a great extent depends on major technological advances, the implementation of the RHC-SRA, along with appropriate market conditions, will be crucial to realising the shift to a renewable energy system in which European citizens can enjoy affordable and sustainable heating and cooling services.

The RHC-SRA has been prepared by the RHC-Platform's Horizontal Working Group on Shared SRA, it was edited and coordinated by the Secretariat of the RHC-Platform and ultimately approved by the Board of the RHC-Platform. Numerous experts provided useful insight directly to authors or through the open consultation carried out in February and March 2013. This publication was made possible thanks to the support of the European Commission through the Seventh Framework Programme for Research and technological Development (Grant Agreement n. 268205).

[2] RHC-Platform (2011). The Common Vision's key findings are presented in Chapter 2.3 of the present publication.

2.
Renewable Heating & Cooling: Vision, Opportunities and Challenges






2.1 Defining heating and cooling

Heat and cold are forms of thermal energy[3]. We heat and cool to adjust the temperature of indoor air for comfort, to produce domestic hot water (DHW) and in industrial production processes.

Heat and cold present a number of differences with other forms of energy such as electricity in that:

- Heat and cold transmitted over long distances are subject to relevant losses[4].
- Heat and cold must be supplied at least at the temperature level which matches the demand[5].
- Storage of heat and cold is generally easier and less expensive than electricity storage.

The transport problem results in the fact that a heat (or cold) source must be near the site of usage in order to keep an acceptable relation between heat (or cold) losses to heat (or cold) transferred. Maximum transport distances for small capacities are in the range of a few tens of meters, while for larger capacities they can be up to several kilometres, such as in a district heating system. Storing heat in the form of phase-change materials (PCMs) or chemical compounds is the only way to transport it over even longer distances[6]. Without transport, solutions for meeting heat and cold demand will have to focus on individual, decentralised installations from single houses to grids on a municipal and regional level.

While the transformation issue in electricity is that of voltage, in heating and cooling it is a matter of temperature (Info Box 1). In any case, the temperature of heat or cold supply must meet the required temperature of the installation. In the heating sector, transformation of heat to different temperature levels is just a matter of time when an adjustment towards ambient temperature is desired: heat will eventually cool down (or heat up) to the desired temperature, and mixing may be applied to speed up this process when fluids are concerned.

Info Box 1

Transformation of voltage in the electricity sector can be done with high efficiency using electromagnetic-inductive transformers; the principle was already discovered by Faraday and Henry in 1831 and before 1900 numerous types of transformers for many applications were in practical use.

The thermodynamic principles of refrigeration and heat pumping, allowing for a kind of "heat transforming" to adjust temperature levels, date back to the same era as theoretical work by Carnot (1824), a patent issued to Perkins in 1834, and the first practical application of heat pumping by Rittinger (1855).

These principles laid the foundations for the refrigeration cycle in use today. Market uptake however, in particular of heat pumps, took almost a century to materialise.

Nicolas Léonard Sadi Carnot
(1796-1832)

Peter Ritter von Rittinger
(1811-1872)

[3] Following a practice of engineering and energy technology disciplines, in this publication the terms "heat" (or "cold") and "thermal energy" are used interchangeably. However in physics these two concepts are well distinguished. In thermodynamics, heat is always accompanied by a change in entropy and it is defined as energy in exchange between two systems, or a single system and its surroundings. As a process variable, heat is never a property of the system, nor is it contained within the boundary of the system. Thermal energy is a state function and, in contrast to heat, it exists on both sides of a boundary.

[4] The effort to isolate a heat transmission line is much higher than to isolate a electricity cable

[5] This is the primary purpose of heat pump technology, that is to transform low temperature renewable energy from the air, ground or water to heat at higher temperature that can be used for space heating, heating water or cooling.

[6] A truly ancient example of phase change material used for storage and transport of cold is ice, harvested in cold areas and transported over long distances for use in hot regions and seasons, already in the Roman Empire. Ice harvesting, transport and storage reached industrial scale in the 19th and early 20th century.

Heat users also quite often have a specific demand profile comprising issues of temperature, capacity, and timing. A simple, constant heat source will not be able to cover this demand, so at the end, for most applications, additional and more flexible technology will be required to make renewable heat or cold sources useful. These technologies for storage, adjustment of temperature, matching of capacity, etc. are referred to as "Cross Cutting Technologies". More specifically, "Cross-cutting technology" is the term used by the RHC-Platform to describe any energy technology or infrastructure which can be used either to enhance the thermal energy output of renewable energy sources (RES), to enable a greater fraction of the output by the system to be used, or to allow the exploitation of RES which would be difficult or impossible to use in building-specific applications.

Without further R&D in these cross cutting technologies, and suitable technical solutions for outstanding problems, renewable heating and cooling will not be able to cover a substantial part of the heating and cooling demand described below.

2.2 Demand and market in Europe

The heating and cooling sector plays a crucial role within our primary energy supply. Heat, defined as the consumption of thermal energy for heat production and use in stationary applications, accounted for 47% (corresponding to 544,2 Mtoe) of the final energy consumption in Europe in 2010 (Figure 2)[7]. This proportion is in line with average of industrialised countries.

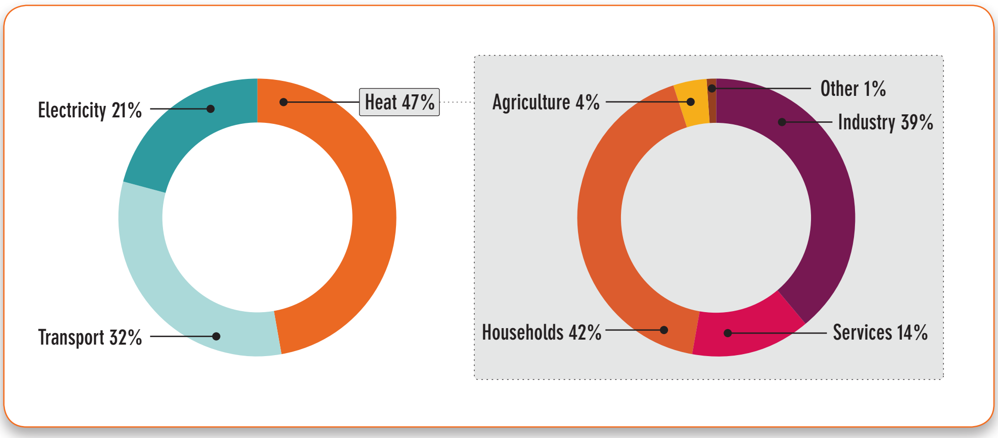


Figure 2 - Final energy use in EU-27 by type of energy (left)[8] and final energy use for heat by individual sector (right) for the year 2010[9]

The dispersed nature of the renewable energy applications for heating makes accurate quantification difficult, which is also the case for cooling. In line with the European Commission's definition of renewable energy sources[10] and consistent with our previous publications[11], **renewable heat** is defined as the conversion to heat of a useful temperature of one or more of these renewable energy sources: the radiation of the sunlight, the chemical energy of biomass or the thermal energy of earth, air or a water body. A "useful temperature" is one that is demanded by a consumer directly or for a secondary conversion process.

Building on the definition of renewable heating, **renewable cooling** is defined as the decrease in temperature of indoor air for thermal comfort, obtained through the conversion / transfer of a renewable energy source[12]. Lowering air temperature below human standards for thermal comfort (e.g. for storing or freezing food) is defined as refrigeration and is not considered in this publication.

Electricity, including power generated from RES, is used extensively in heating and cooling processes (e.g. in water boilers, electrical resistance heating and air conditioning systems), but is beyond the scope of the RHC-Platform[13].

[7] The figure for heat consumption is based on the European Commission publication "EU energy in Figures Statistical Pocketbook 2012". It is derived as follows: Heat Consumption = Final Energy Consumption (1153.3 Mtoe) – Final energy consumption in Electricity (243.9 Mtoe) – Final Energy Consumption in Transport (365.2 Mtoe). It should be noted that it was not possible to avoid double counting the electricity assumed to be used in heating, cooling, and transport. The energy consumption for cooling is particularly difficult to assess as it is mostly included in data for electricity.

[8] Source: Own calculation based on European Commission (2012b)

[9] International Energy Agency (IEA) (2010)

[10] EU (2009)

[11] RHC-Platform (2011)

[12] In a number of applications there is no conversion, only transfer of thermal energy for cooling purposes. According to the prevailing literature (cfr Oko Institute e.V. Contribution of Renewable Cooling to the Renewable Energy Target of the EU, 2012) there are two types of case. Direct cooling systems (also known as free cooling) use substances that already have the required low temperature (e.g. snow, sea water, ground water) without the intervention of additional technologies such as heat pumps or chillers. In the case of indirect cooling the system requires electricity or water input to reduce the temperature (e.g. active cooling through heat pumps; evaporative cooling). Generally, these passive cooling processes could also be considered renewable cooling, however the technology must meet pre-defined efficiency standards (e.g. a minimum Seasonal Performance Factor – SPF for heat pump technology) as stated in the RES Directive (EU 2009).

[13] To avoid that the same energy is statistically counted twice, renewable electricity should always be counted towards the renewable electricity targets – no matter whether this renewable energy is used by a heat pump operating in the cooling mode.

In the EU, the share of heating and cooling from renewable sources has increased from 57.6 Mtoe in 2004 (i.e. approximately 9.6% of total consumption) to nearly 80 Mtoe in 2010 (i.e. 14.4%) (Figure 3). A linear increase in the market share is expected from 2011-2020, and for the period 2020-2030 a further market gain of 10%. This advancement is dependent on RES becoming standard in new energy efficient buildings in all EU countries.

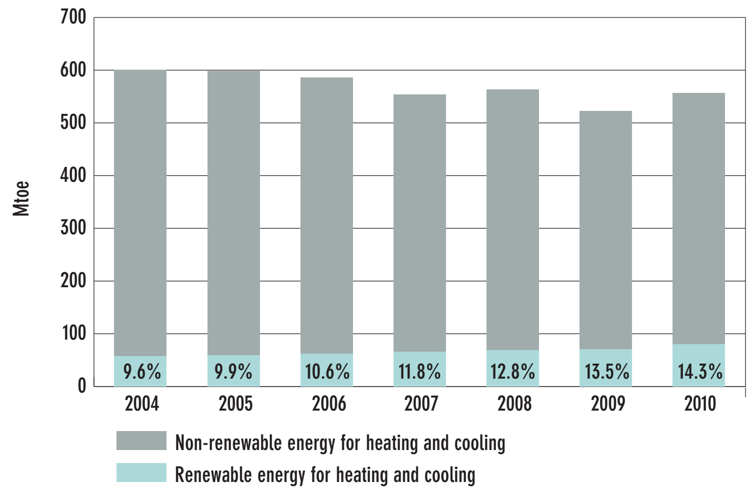


Figure 3 - Heating and cooling supply in the EU-27 (2004-2010)[14]

2.3 From Common Vision to Strategic Research and Innovation Agenda

In May 2011 the RHC-Platform launched its first official publication: the "Common Vision for the Renewable Heating and Cooling Sector in Europe". The study is an assessment of the potential of renewable heating and cooling technologies to contribute to the European and national energy needs and targets, and identifies major technological and non-technological challenges to the uptake of the RHC systems.

Heating and cooling account for a significant proportion of Europe's energy demand. Efficiency gains are required in both residential heating and industrial processes with better use of thermal energy being crucial for meeting the 2020 renewable energy targets and Europe's 2050 target of 80-95% reduction in GHG emissions. The key highlights of the Common Vision are outlined in what follows.

The evolution of energy consumption for heating is expected to follow a different trend to that of cooling. As a consequence of energy efficiency measures and support schemes which are being implemented at EU[15] and national levels, **a significant reduction of heat demand could be realised in the coming decades. The opposite trend is expected for cooling demand**, the growth of which will be driven by increase in average temperatures due to global warming, the current trends in commercial building architecture and intolerance to thermal discomfort[16].

[14] European Commission (EC) (2012a)

[15] The Energy Performance of Buildings Directive – EPBD (EU 2010) is currently the main EU legislative instrument to reduce the energy consumption of buildings. Under this Directive, Member States must establish and apply minimum energy performance requirements for new and existing buildings, ensure the certification of building energy performance and require the regular inspection of boilers and air conditioning systems in buildings. Moreover, the Directive requires Member States to ensure that by 2021 all new buildings are so-called 'nearly zero-energy buildings'.

[16] This trend of growing cooling demand is particularly meaningful in Southern Europe. In countries such as Spain, Italy and Greece the annual number of hours of cooling demand already exceeds the number of hours of heating demand, especially in non-residential buildings.

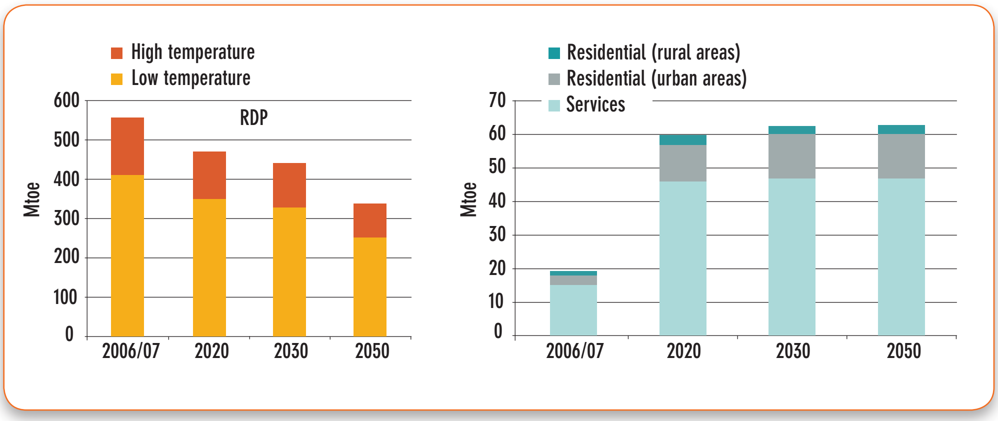


Figure 4 – Projections of heating and cooling demand in the EU. Source: RHC-Platform (2011)

The theoretical and technical potential of renewable energy sources could exceed Europe's total heating and cooling consumption. Nevertheless, discovering how to economically realise such potential remains a challenge. The optimal combination of renewable energy technologies to meet the thermal energy needs of a given user depends on local conditions such as population density, intensity of use, quantity and quality of available energy infrastructure and resource availability. The majority of energy use takes place in urban areas, characterised by higher population density, where district heating and cooling networks can represent a critical infrastructure to ensure large-scale integration of renewable energy sources.

In 2020 over 25% of heat consumed in the European Union could be generated with renewable energy technologies. The large majority of renewable heating and cooling will still be produced from biomass sources, although solar thermal is expected to have the highest average growth rate among the renewable energy technologies for heating and cooling in the decade 2010 – 2020. Increasingly competitive geothermal, aerothermal and hydrothermal heat pumps will gain market shares as efficiencies rise. Enhanced Geothermal Systems (EGS) will be realised in different European regions producing heat at temperatures suitable for both direct use and electricity. Improved thermally driven cooling systems (e.g. from solar or heat pump technologies) will make it possible to cover around 5% of cooling demand from the service and residential sectors by 2020.

By 2030 renewable heating and cooling technologies could supply over half of the heat used in Europe. Improved compact and seasonal thermal energy storage systems will be crucial to meeting the heating and cooling requirements in buildings. In most of Europe, biomass will be used for small-scale heating as well as industrial processes; 2nd and 3rd generation biofuels will also play an important role. Solar thermal will satisfy approx. 15% of the overall European low temperature heat demand and it will be increasingly able to meet the heat demand of medium and higher temperature industrial processes. Geothermal heat pumps and geothermal direct use will be firmly established, especially in agricultural applications and for pre-heating industrial processes requiring heat over 250°C. Aerothermal and hydrothermal heat pumps will be widely used in residential and non-residential buildings. A smart energy exchange network will enable heat at different temperatures from multiple low-carbon energy sources to be shared efficiently between different customers.

By 2050 the combined energy supply of RHC technologies could reach close to 600 Mtoe, representing more than the expected total demand for heating and cooling. Biomass could contribute 231 Mtoe, while geothermal could account for 150 Mtoe and solar thermal for 133 Mtoe (Figure 6). Aerothermal and hydrothermal technologies are expected to provide at least 75 Mtoe of heat. Being cost-competitive with any alternative fossil fuel, RHC will be used in district heating & cooling, small-scale hybrid systems and advanced energy stores. Whether these targets are met or not depends on economic growth, the evolution of heat demand and the relative price of alternative fuels, all of which are hard to predict 40 years into the future. Big technical challenges must be overcome to make renewable energy technologies fully cost competitive.

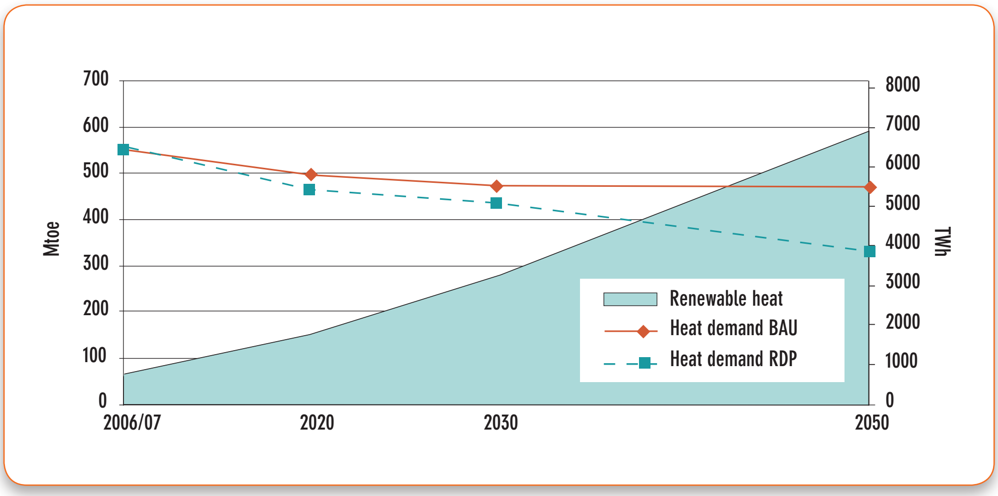


Figure 5 - Heating supply from renewable energy sources in EU. Source: RHC-Platform (2011)

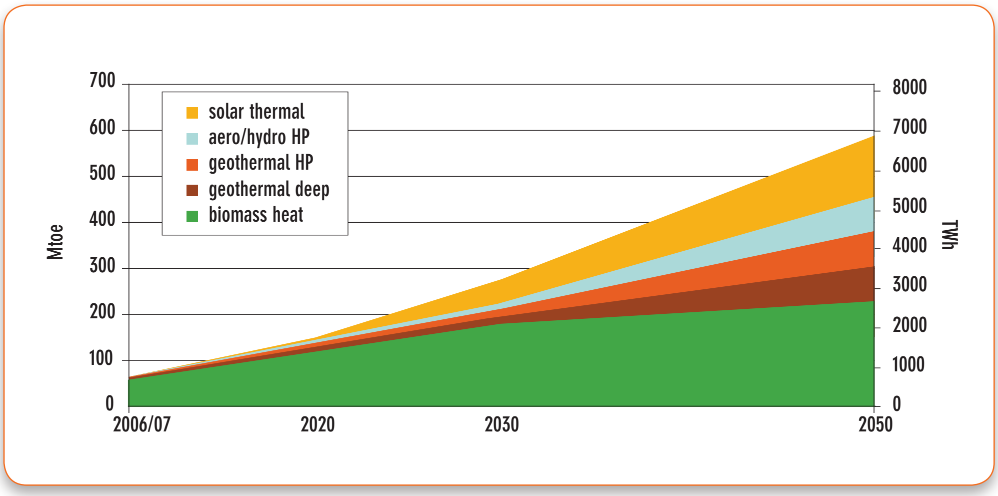


Figure 6 - Heating potential by renewable energy sources in EU. Source: RHC-Platform (2011)

The enormous challenges ahead are not only technological. Tomorrow's energy systems are defined by the policy and legal frameworks we adopt today, which must **provide the right conditions to attract large-scale public and private investments**. Public support will increase as the full potential of social benefits, such as green jobs, is realised. Successful deployment of renewable energy technologies also has to take into account the needs of end-users and of others affected by the technology[17].

In a global market, the main competitive strength of the European RHC industry is the high quality of its technologies. Recognition of EU-wide CEN standards, certification and quality labels must therefore be increased. The information provided should not only include the relative efficiency, but also the annual running cost, greenhouse gas emissions and the expected system lifetime. Market deployment also ought to be supported through policies favouring a stable and reliable framework for investors and at offsetting the high upfront costs associated with RHC.

Unlocking the potential of renewable heating and cooling (RHC) technologies requires a substantial intensification of R&D activities as well as policy measures to overcome non-technological barriers. The comprehensive agenda of priorities presented in this publication gives decision-makers from the public and private sector a concrete tool to put the Common Vision into practice.

[17] For instance, the European Environment Agency (EEA) estimated costs of air pollution from the 10,000 largest polluting facilities in Europe between € 102 and 169 billion in 2009.

2.4 Common Vision and NREAPs: a comparison

Following the assessment of the potential of renewable heating and cooling technologies, it is worth comparing the Common Vision for RHC with the actual plans developed by the 27 EU Member states for this sector. Such an analysis, however, ought to be limited to the year 2020 as reliable projections are available only from the National Renewable Energy Action Plans (NREAPs) submitted to the European Commission in compliance with Article 4 of Directive 2009/28/EC[18]. Relevant data from these plans are reported in Appendix II.

According to the NREAPs, in 2020 RHC will make a total contribution of 111.2 Mtoe in the EU. The main source will still be biomass, despite its relative share decreasing from 97% in 2005 to 81.1% in 2020. The RES share in this sector will grow from 12.5% in 2010 (estimation by Member States, actual share reported by EUROSTAT is 14.4%, see Figure 3) to 21.4% in 2020. To reach the 2020 targets, therefore, RHC should grow at a total annual rate of at least 5.1%[19].

In terms of final energy consumption, taking into consideration advanced energy efficiency scenarios used by the majority of national governments, the final heating and cooling consumption should decrease by 4.1% compared to 2005 levels. However, it will still represent 48% of the EU gross final energy consumption in 2020.

Figure 7 shows the interplay between the RHC vision and the projections by Member States. In terms of forecasting RHC penetration by 2020, the NREAPs (111.2 Mtoe) are less ambitious than the Common Vision for RHC (148 Mtoe). Second, looking at energy consumption, Member States foresee a higher consumption than does the Common Vision. However, it is difficult to assess, for instance, whether and how the NREAPs of 2010 take into account the possible energy savings triggered by the new Directive on energy efficiency[20] adopted in 2012.

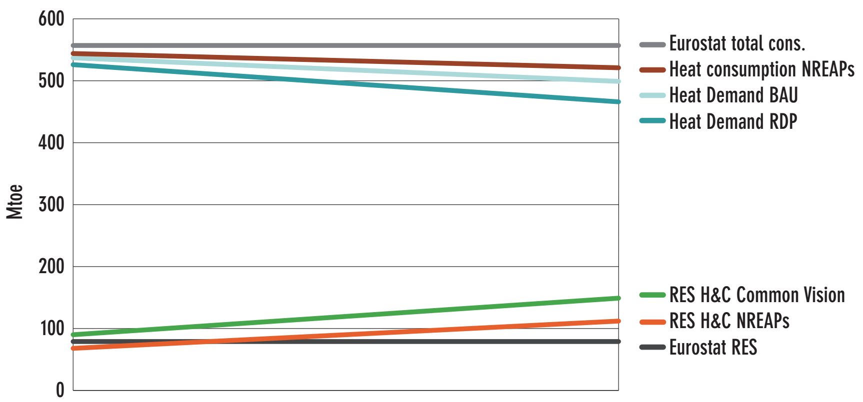


Figure 7: Modelling of heat consumption and supply until 2020: interlink between the Common Vision and the NREAPs

Furthermore, according to EUROSTAT, RHC contributed 79.8 Mtoe already in 2010 (see Fig. 3) i.e. 12 Mtoe higher than the cumulative figures provided in the NREAPs for the same year (67.8 Mtoe). It therefore appears that at least initially the potential of renewable heating and cooling technologies has been underestimated.

In conclusion, the RHC Vision and the NREAPs present similar trends to 2020 and both forecast significant growth rates for renewable heating and cooling technologies. It means that putting the RHC-Platform scenario into practice is challenging but definitely feasible. And this is also valid for the timeframe to 2050. Yet, a slight difference (that is 37.2 Mtoe or 3.6 percentage points) exists between the Vision and the NREAPs in terms of RHC share of the EU energy mix; however, such a gap could easily be bridged in the coming years with e.g. increased awareness and adequate R&D resources allocated to the priorities identified in the following chapters.

[18] These plans, dating back to 2010, were intended to provide detailed roadmaps of how each member state expects to reach its legally binding 2020 target for renewable energy, including sectorial targets and the technology mix they expect to use.

[19] Szabo et al. (2011)

[20] EU (2012)

2.5 SRA Governing Principles

This Strategic Research Agenda is the first of its kind for the renewable heating and cooling sector. It provides stakeholders with a structured and comprehensive view of the strategic research priorities to enable an increasing share of heating and cooling to be supplied by RES. The contribution of renewable heating and cooling to the EU energy targets by 2020 and beyond will be determined by the availability of reliable, efficient and affordable technology. Growing the market for renewable heating and cooling applications, achieving significant breakthroughs through targeted, collaborative research and development activities in RHC technology are all prerequisites for the achievement on time of the European Union's objectives.

This publication provides recommendations to policy makers, funding bodies as well as to industry and research stakeholders on how to prioritise the allocation of resources for research, development and demonstration (R&D&D) of renewable heating and cooling systems. In particular, the SRA can be used as input for the identification of the most appropriate areas to fund under Horizon 2020, the successor programme to the Seventh Framework Programme for Research and Development of the European Union.

The report is built on five "Governing Principles" which form the basic set of fundamental assumptions:

I. Time scale.
It is important to fund R&D work now that will have an impact in different time frames to ensure a continual supply of new ideas to the sector. The report distinguishes between three timelines by when the results from the R&D work covered in the RHC-SRA should be commercially available:
- **By 2020: Short term**[21]
- **By 2030: Medium term**
- **After 2030: Long term**

The convention used in this report is to refer strategic and research priorities to the time horizon in which they are first expected to be used in commercial products, not to the year by which widespread use is expected[22].

II. Inclusiveness
Technologies for renewable heating and cooling include a wide range of energy components, applications and infrastructures. This SRA aims at being as comprehensive as possible, on the assumption that a single energy technology cannot emerge as the ultimate solution to Europe's energy challenges. The report expresses overall research and development objectives and where possible it sets specific targets, however it is beyond the scope of the SRA to pick winners. Moreover, the targets presented in this report should not be interpreted as predictions. It is possible that some technologies will even exceed them. The efficiency gains and cost reductions were defined on the basis of rational expectations and opinions of the SRA's authors. Further editions of the SRA will be produced every five years to reflect the technological progress in the renewable heating and cooling sector.

III. Value chain approach and scale of Technology Readiness Levels
Public and private money is required to perform the short, medium and long term research into all parts of the value chain, as well as non-technological priorities. To realise the potential of the RHC-Platform's Common Vision, activities of fundamental research, development and demonstration are necessary depending on the specific technological maturity of the relevant component or system. This report recommends that the combined spending of the public and private sector should be strategically distributed among topics with commercial relevance in the short, medium and long term, covering the scale of Technology Readiness Levels (TRL) from point 1 to point 9 (Fig. 8).

[21] This time period was chosen because EU targets for renewable energy, energy efficiency and CO_2 reduction already exist for 2020.

[22] It should be noted that several research priorities presented in Chapter 3.3 refer to technological achievements which may have already been tested at pilot scale. District heating and cooling systems are widely diverse across Europe, and it is therefore opportune to refer their priorities to the year by when most infrastructures in Europe have attained the performance targets.

Innovation Cycle	Technology Readiness Levels (TRL) scale	
	Level	Description
Research	1	Intellectually-driven investigation with no foreseeable economic application.
	2	Investigation within established disciplines/technologies.
	3	Research within existing technology boundary with practical applications in mind.
Development	4	Applied research to develop innovative technology applications.
	5	Collaborative development within existing industries to produce new or next generation technology.
	6	Technical development of products following a defined longer-term technology 'roadmap'.
Demonstration	7	Demonstration of 'new generation' products involving substantial modification/innovation.
	8	Process/product innovation designed to modify/improve/ differentiate existing products.
	9	Process innovation designed to reduce cost or extend life of existing product range.
Post R&D&D	10	Investment in maintenance or expansion of existing production.

Figure 8: Scale of Technology Readiness Levels adopted by the RHC-Platform[23]

IV. Temperature levels

The extent to which heat can be exploited depends on the temperature level. In this SRA heat is classified as follows:

- **Up to 95°C: low temperature**
- **Between 95°C and 250°C: medium temperature**
- **Above 250°C: high temperature**

To use renewable heat as efficiently and effectively as possible, the RHC supply technology should match as closely as possible the temperature level required by the thermal energy demand[24].

V. References

This publication is based on the information produced by the experts of the four Technology Panels of the RHC-Platform. In particular, it brings together the following sets of strategic research priorities:

- Strategic Research Priorities for **Biomass** Technology (April 2012)
- Strategic Research Priorities for **Geothermal** Technology (April 2012)
- Strategic Research Priorities for **Solar Thermal** Technology (December 2012)
- Strategic Research Priorities for **Cross-cutting** Technology (April 2012)

These reports are essential complements to the RHC-Platform's SRA[25]. They provide additional explanations and a thorough technological analysis which is useful to fully appreciate the underlying reasons for the selection of the research areas presented in this SRA.

[23] Sève et al (2010).

[24] For this reason it is not efficient from a qualitative point of view to use electricity, which is a "high quality" form of energy, to satisfy a low temperature heat demand (e.g. direct electric heating in a residential building).

[25] These four reports are available on the website www.rhc-platform.org/ publications

3.
RHC applications and priorities for residential buildings

3.1 **Demand characteristics**

According to the estimates of a recent study of the European Commission[26] for the EU 27 Member States, **the annual demand for space heating and for hot water in residential buildings** is respectively around **162 Mtoe** (6,766 PJ) and **37 Mtoe** (1,555 PJ). **Cooling represents about 2 Mtoe** (87 PJ), or **just 1% of the total thermal energy demand**.

Energy demand for heating and cooling in the residential sector is strongly dependent upon climatic conditions and follows a clear seasonal pattern.

- In Northern and Western Europe, cooling is very seldom needed in domestic houses, so only heat load needs to be covered.
- In Central and Eastern Europe, most residential buildings today have only a heating system. However, due to demand for high levels of comfort, an increase in cooling applications in this region can be expected.
- In Southern Europe, demand already exists for cooling in the residential sector. In most cases a (small) heating device is also installed in at least one or a few rooms.
- DHW is essential in all climates; there are specific requirements on temperature level and hygienic aspects. Often there is demand for larger amounts in a short time period (storage).

Capacity demand varies from only a few kW_{th} (for small, well-insulated houses) to some 100 kW_{th} for blocks of flats. Renewable energy can also be provided to residential houses through district heating and cooling (see Chapter 6).

In new residential houses as well as in existing and refurbished buildings, space heating loads become smaller due to better insulation. New single-family houses, semi-detached or terraced houses often have no dedicated room for the heating system, requiring a clean and low-noise system. DHW often represents a significant portion of the thermal energy consumption, exacerbated by the practices currently in use to combat legionella bacteria (e.g. heating up the storage volume once a day).

3.2 **Solar thermal technologies**

Residential solar thermal applications represent the bulk of the solar thermal systems installed in Europe. The large majority are used for domestic hot water (DHW) preparation; however, in Central Europe a growing share of the systems supports space heating as well.

In Southern Europe, because of the high solar radiation and temperate climates, simple thermosiphon systems are commonly used. In this instance, the solar heat transfer fluid circulation is naturally driven, since the water store is installed above the solar collector. Usually systems with 1.4 to 2.1 kW_{th} (2-3 m^2 of collector area), using flat plate collectors and a 150 litre store, are used for a family of four. The achieved solar fraction is 50% to 60%.

In Northern and Central Europe, for practical reasons, only forced (pumped) circulation solar thermal systems are used since the collector is installed on the roof and the hot water store is usually situated in the basement. Typically flat plate collectors of 2.8 to 4.2 kW_{th} (4-6 m^2 collector area) and a 300 litre store are used for a family of four. The solar fraction for DHW achieved is about 60%.

There is a huge potential in the residential use of solar thermal for space heating. The so called combi-systems (combining DHW and space heating) are mainly used today in central Europe, especially in Germany, Austria, Switzerland and France. In Germany and Austria, about 50% of newly installed systems are combi-systems with typically 7 - 14 kW_{th} corresponding to 10 to20 m^2 flat plate collector and a 600 to 1,000 litre hot water store. In a well-insulated building, the solar fraction is 25-40% of the overall building heat demand for DHW and space heating.

[26] Pardo et al. (2012) .

Solar thermal energy has the technical potential to deliver a large share of heat for residential buildings. Nonetheless, economical feasibility, meaning delivering heat at a price competitive with the relevant alternatives, is still limited due to the unfair competition from fossil energy and high upfront investment cost.

Solar thermal has very low running costs (solar radiation is available for free) but require a high upfront investment for the solar collector, additional components (water store, plumbing, pumps, controllers, etc.) and installation costs. Operation and maintenance (O&M) costs are very low (1 to 2% per year), particularly when compared with alternative technologies.

Figure 9 presents an analysis of the costs of several system configurations referred to above[27] compared with costs of useful heat produced using conventional sources (gas or electricity) and common technologies and expressed in EUR/MWh. Costs are determined on the basis of the following assumptions:

- Solar heat costs are determined for typical low and high price systems differentiated by type of application and sometimes radiation. The solar heat price is calculated by adding the overall system costs (investment, installation, financing, operation, maintenance, incl. VAT) minus the costs saved by the solar thermal system, e.g. for the hot water storage.[28] By dividing the costs through the solar thermal energy yield over the lifetime of 15 years for thermosiphon systems and 20 years for all other systems, the solar heat costs are calculated. For solar radiation the reference locations of Würzburg for Central / Northern Europe and Athens for Southern Europe are used.
- In comparison with the solar heat costs, the cost of "useful heat" from electricity and natural gas is shown. The "useful heat" is calculated by multiplying the energy content of electricity and natural gas with the conversion efficiency factor (95 and 85%). According to Eurostat data[29], the average costs of energy supplied to homes in the European Union in the second half of 2011 is in the range between 27.65 and 116.52 EUR/MWh for natural gas and between 87.4 and 297.5 EUR/MWh for electricity[30].

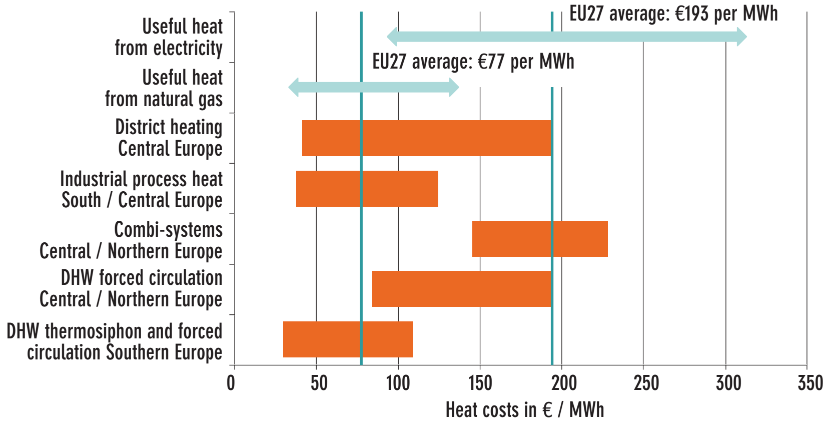


Figure 9 – Comparison of heat costs between different solar thermal applications in different regions and costs of useful heat from electricity and natural gas. (Source: ESTTP based on data from ESTIF and EUROSTAT).

According to Figure 9 solar thermal heat costs vary from about € 30 per MWh for DHW in southern Europe to € 230 per MWh for combi-systems for DHW and space heating in central and northern Europe. In some European countries, especially at southern latitudes, solar thermal heat is already today cheaper than heat from electricity and yet in most countries heat is generated by natural gas or heating oil (similar priced as natural gas)[31].

[27] Costs of solar cooling are not included in Figure 9 since they are not comparable with heating costs and only demonstration plants and early market projects are installed yet.

[28] 3% discount rate applied.

[29] European Commission (2012b)

[30] Reference gas prices to domestic consumer during the second semester of 2011 range between 7.68 €/GJ in Romania and 32.37 €/GJ in Sweden. Electricity prices, to domestic consumer varies from 87.4 €/MWh in Bulgaria and 297.5 €/MWh in Denmark.

[31] In some countries, mainly in southern Europe, solar thermal energy is also already cheaper than heat from natural gas with average costs of € 77 per MWh. In central and northern Europe, the solar energy heat costs for DHW and combi-systems, which are the main applications today, are with € 80 to € 230 per MWh usually more expensive than heat from fossil fuels.

Solar heat costs for district heating systems vary a lot from about € 40 to € 190 per MWh, depending on the existing district heating infrastructure, e.g. due to the high share of district heating in Denmark the costs to connect solar thermal systems is low. The solar fraction has an impact on system's cost, which will be relatively lower if no additional hot water storage is needed for the solar system at small solar fractions and higher in solar thermal district heating systems with significant solar fraction and a very large central hot water storage of several thousand cubic meter water content.

Solar industrial process heat costs depend to a great extent on the type of application and especially on the temperature level needed. Up to now, several solar thermal process heat systems are realised in Europe with heat costs between € 38 and € 120 per MWh.

It is important to realise, that the solar thermal heat costs are guaranteed fixed costs during the entire lifetime of the system. However, the useful heat from electricity or natural gas is calculated based on prices from 2011. Since a further increase of fossil energy prices is expected during the coming decades, solar thermal systems are likely to become even more competitive than what appears when comparing long-term average solar heat costs with todays fossil heat prices.

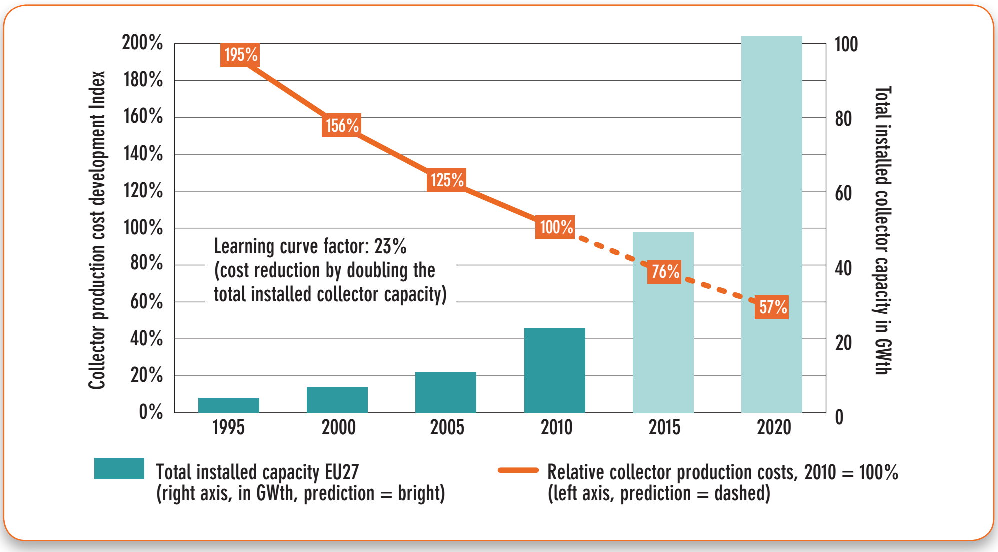


Figure 10 – Collector production costs and market evolution from 1995 until 2020[32].

The potential for solar heat cost improvement can be analysed with the support of Figure 10, which presents an analysis of the learning curve for collector manufacturing in Europe. The learning curve indicates that a reduction of collector production costs of 23% is achieved with every doubling of the solar thermal market in Europe. Since 1995, production costs have more than halved. Assuming the solar thermal targets indicated in the National Renewable Energy Action Plans[33] are achieved, the European market can achieve a total size of about 100 GW_{th} by 2020, which represents a four-fold increase on 2012. In such a case, with a learning rate of 23%, a further reduction of collector production costs of over 43% can be achieved.

The solar thermal collector is only one component of the solar thermal system. Other important components are the hot water storage tank, the controller, the pump station, the piping, etc. Since the investment costs of the other components depend on system types (which continuously evolve in size and efficiency) as well as the application (e.g. depending on the temperature level required) there is no cost index available for solar thermal systems yet. Apart from production costs, installation costs must also be taken into account. In some countries where labour costs are high, the installation costs of small DHW systems reach 50% of the investment. Since research and industry increasingly focus on system integration, it is expected that the costs for the overall system inclusive installation will decline in coming years just as the collector production costs have declined over the last 15 years.

[32] Production costs with reference to a high-efficient flat plate collector panel of about 1.54 to 1.75 kW_{th} (2.2 to 2.5 m² gross collector area) manufactured in Europe, based on data from 'Solrico' & Trenkner consulting' and projections up to 2020 by ESTTP. EU solar thermal market historical data based on ESTIF market statistics and evolution up to 2020 based on the National Renewable Energy Action Plans (NREAPs).

[33] Article 4 of Directive 2009/28/EC (EU (2009)) on renewable energy sources requires each Member State to adopt a national renewable energy action plan (NREAP) to be submitted to the European Commission. In each RNEAP, Member States need to define their national targets for renewable energy sources consumed in transport, electricity and heating and cooling in 2020, indicating how it is planned to meet the overall national target indicated in the Directive.

Besides the socio-economic context, the installation costs depend greatly on the availability of qualified labour. In this regard, the requirements laid down in Art. 14[34] of the RES Directive are expected to have a positive impact on the installation costs. In addition, research and development will play an important role in the development of new collectors and a solar thermal system. New designs and materials will also provide for easier and faster installation processes with a positive impact on overall costs.

3.2.1 Research and innovation priorities with impact in the Short Term

Based on the need to reduce the solar thermal heat costs and to increase the attractiveness to use solar thermal energy, in the short term R&D&D priorities for solar heating and cooling systems in residential buildings should focus on the following areas:

A. Solar collector improvements through the development of higher performing collector materials, designs and production processes

B. Solar thermal system improvements through the development of compact solar based heating systems for hot water and (possibly) cooling for Southern countries and for hot water and space heating (combi-systems) for other countries, combining the solar thermal system and the conventional back-up heating system. These hybrid systems may combine a solar system with a heat-pump, a gas or heating oil condensing boiler or a pellets boiler. This type of system changes the way from an "add-on" system to an integral solar hybrid system with high solar fractions. Due to the compactness of the system, the installation effort will be significantly reduced and a significant improvement of the cost performance ratio is expected, with an increase of the thermal performance of 30% and reduction of the cost by 50%.

C. System technology improvements to increase the solar fraction to at least 50 % for systems installed during the retrofit of existing buildings, and up to 100 % for the installation in new buildings or in 'Solar Active Houses' respectively. Specific system concepts must be developed for different building typologies and regional climatic conditions.

The overall goals by 2020 are to increase the already high system performance by 10% and to reduce the system costs by 50%. These targets can be achieved by focusing R&D on the following topics:

ST.1	**New surfaces, coatings, materials, construction designs, and manufacturing technologies for solar thermal collectors**
Objective	The objective of collector development is the reduction of costs, increase of efficiency and enhancement of reliability. This will be achieved by transparent cover materials with anti-reflection coatings for high optical transmission; switchable coatings that reduce the stagnation temperatures; highly reflective, light materials for reflectors; new absorber materials with low-emission coatings and optimised heat transfer; temperature-resistant and switchable super insulating materials and alternative medium and high temperature materials like polymers or rubbers for collector parts. Efficiency can be increased and costs can be reduced by further development of photovoltaic-thermal (PVT) hybrid-collectors, air collectors and low temperature process heat collectors. Also evacuated flat plate and tube collectors with high efficiency can reduce costs in some applications. Finally, a continued improvement in the collector construction design and manufacturing processes, focusing on mass production of tailored systems and systematic recycling of materials, will lead to further cost reduction of solar thermal collectors.
State-of- the-art	Today, flat plate collector modules with about 2.5 m² area are most commonly used. With spectral selective absorber coatings, they achieve absorbance values of 95% limit infrared emittance to 10%. Sometimes even cover glass with antireflection-coating is used. They are used as all-purpose collector modules, since they are produced in relatively high numbers. However, the further reduction of costs requires a change in materials from expensive to cheaper metals, e.g. aluminium not only for the absorber sheet but also for the piping, or polymers in combination with construction design and coatings and surfaces, which protects the collector against overheating or aggressive environment, and increases reliability.
Target	50% cost decrease by 2020 for solar collectors inclusive mounting rack and installation
Type of activity	40% Research / 50% Development / 10% Demonstration

[34] Article 14 of the RES Directive (2009/28/EC) requires EU Member States to provide, by 31st December 2012, certification or equivalent qualification schemes for installers of building-integrated biomass stoves and boilers, shallow geothermal energy systems, heat pumps, photovoltaic and solar thermal systems so that they can be mutually recognisable.

ST.2	Cost effective solar based hybrid systems able to satisfy the entire building heating demand
Objective	The objective is to develop solar-based hybrid systems, which provide a full heat supply for small and multifamily residential buildings by combining the solar thermal components with a backup heater in one compact unit including a smart controller. This solution will be particularly suited for the retrofitting of existing systems. This will enable cost reduction of "plug and function" systems for material and installation labour time significantly, since the complexity of the system is limited to the prefabricated inner part of the hybrid unit. The performance will be increased and trouble-free operation of the hybrid heating unit will be achieved. These systems will cover at least 30% of the overall heat demand in residential buildings. Innovative system concepts and storage tanks will be developed, which will allow optimal combination of the heat sources. Improved hydraulic designs and components will reduce losses and new controllers will manage the heat flows in an optimal way.
State-of-the-art	Often installers combine a solar thermal system with a backup heater with often suboptimal system design and hydraulics, a big effort in designing and building the system with a lot of hydraulic connections, and the risk of failures. Often the controllers of both heat sources are not coupled with the risk that they have contradictory control strategies.
Targets	A 50% lower price for the ready installed full heat supply hybrid units as compared to the total investment of a solar thermal system plus a backup heater, which will be replaced by the hybrid unit. The system performance will be enhanced by 30% by increasing the solar yield and reducing system losses.
Type of activity	25% Research / 50% Development / 25% Demonstration

ST.3	Optimised heating systems for 'Solar-Active-Houses'
Objective	In 'Solar-Active-Houses' at least 50% of the heat demand for domestic hot water and space heating will be covered by solar thermal energy. This requires a large collector area and a large storage volume. To develop 'Solar-Active-Houses' to a building standard for residential buildings, costs will be reduced and the system performance increased. New concepts for the integration of the collector area and storage volume into the building as well as for innovative system designs will be developed. To manage and control the building's entire energy system, innovative controllers must be developed, including weather and load forecast as well as improved performance monitoring functions. System design and commissioning tools will be available to allow architects and planners to design optimised 'Solar-Active-Houses'.
State-of-the-art	In central Europe there are about 1300 'Solar-Active-Houses' with typically 60% to 70%, sometimes up to 100% solar fraction. The increase of energy efficiency in buildings, together with the use of passive solar technology is reducing the heat demand in buildings, making it easier to increase the solar fraction. Nevertheless, further improvements are required.
Target	Achieve cost-effective, standardised technical solutions for 'Solar-Active-Houses' fulfilling the requirement of at least 50% of solar fraction.
Type of activity	25% Research / 50% Development / 25% Demonstration

3.2.2 Research priorities with impact in the Medium and Long Term

According to the Common Vision for Renewable Heating and Cooling, the contribution of solar thermal to the European heating and cooling demand could account for 15% of the overall low temperature heating and cooling demand by 2030 and it could reach 133 Mtoe by 2050. In order to reach these targets a strong reduction of the energy demand through energy efficiency measures, solar architecture and solar oriented urban and industrial planning will be necessary. Furthermore the right mix of research, development and demonstration activities, consistent market deployment measures and adequate political framework conditions have to be implemented.

The Medium and Long Term priorities for residential solar thermal applications are:

- **Research on the next generation of Solar Active House –Smart Solar Building (ST.4)**. A holistic research approach is needed to provide a cost-competitive 100% solar heating and cooling solution for residential buildings according to the European "Nearly Zero Energy Standard". For single family houses compact solar thermal systems will consist of a collector capacity of approximately 20 kW_{th} (30 m^2 collector area) and a 5-7 m^3 heat store to cover the entire heating and cooling demand. Besides the necessary R&D work for materials and components, the testing and broad demonstration of single units, clusters and urban districts of 100% Solar Active Houses equipped with latest system technology will play a major role.

- **Improving the components of solar thermal cooling systems (ST.5)**. Solar cooling applications shall be able to reach overall yearly electrical COP > 10 by using new control concepts and optimized heat rejection units. Activities should also include the development of standardized, plug-and-play solar cooling kits and, if relevant, high density of hot and cold storage.

	Research and Innovation Priorities	Predominant type of activity	Impact
ST.1	New surfaces, coatings, materials, construction designs, and manufacturing technologies for solar thermal collectors	Development	By 2020
ST.2	Cost effective solar based hybrid systems able to satisfy the entire building heating demand	Development	By 2020
ST.3	Optimised heating systems for 'Solar-Active-Houses'	Development	By 2020
ST.4	Research on the next generation of Solar Active House – The Smart Solar Building	Research	By 2030
ST.5	Improving the components of solar thermal cooling systems.	Research	By 2030

Table 1: research and innovation priorities for solar thermal applications to residential buildings

3.3 **Biomass technologies**

55 million wood stoves, cookers and fireplaces are used in Europe and 1.85 million units are sold annually, which makes them the most widely used RHC technology by far. The annual sales correspond to a total direct turnover of 2.6 billion Euro or 13,000 full-time jobs (excluding fuel production and supply). Whilst the contribution of direct room heaters and cookers to particulate matter (PM) in ambient air is substantial, their potential to be a major primary heating and secondary domestic hot water supply source in the building of the future is large. Biomass heating technology is economically viable already.

Biomass boilers using firewood, wood pellet and – mostly for rural areas – wood chip are highly mature technologies for the boiler exchange and refurbishment market in the existing building stock. The total stock of small scale biomass boilers is about 8 million appliances (most of which are firewood boilers). The annual sales are about 300,000 units. Testing efficiencies and emission performance under certification testing conditions seem to offer only little potential for further improvement (see Figure 11) unless flue gas condensation technology is introduced with expected testing efficiencies >100% (as efficiency definition is based on net calorific value in EN 303-5). The general challenge is to improve the system performance of these technologies for heating and DHW supply under real life conditions. Moreover, a strong focus on system design and building integration is required in order to address changing heat demand in the building sector. On the integration side, combination with solar thermal technology (in all market segments) and with all RHC technologies and building infrastructure (above all in the new building market) will be substantial for the further success of biomass based heating solutions.

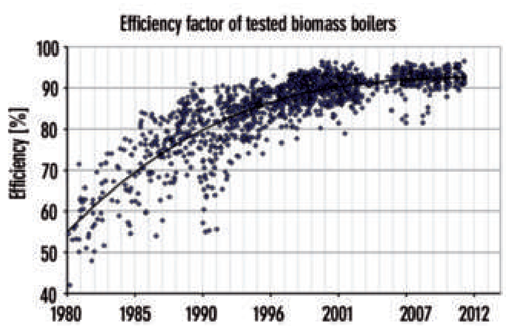


Figure 11: Full load type testing results of biomass boilers according to EN 303-5 over time

	Average capacity of currently sold appliances [kW]	Price [€]	Installation costs [€]	Reparation and maintenance [€/operation life[35]]
Firewood boiler (natural draught)	26	3,700	1,300	1,110
Firewood boiler (forced draught)	26	9,000	1,300	2,700
Pellets boiler	19	9,600	1,300	2,880
Wood chips boiler	47	17,800	1,800	5,340
Firewood stove	8	912	200	288
Firewood cookers	n.a.	1,440	n.a.	n.a.
Pellets stove	8	4,200	200	864

Table 2: Boiler, stove and cooker investment costs for state-of-the-art technologies (Source: Bioenergy2020+(2010); Biermayr et al. (2012))

State-of-the-art fuels for residential biomass applications are almost solely based on wood. Size reduction, drying and densification (in case of pellets and briquettes) are the common pre-treatment and upgrading steps. First attempts to include also the large potential of non-wood resources into the residential fuel supply are undertaken with the establishment of a standard for non-wood biomass pellets (EN 14961-6).

Micro-scale CHP is a highly energy-efficient solution for flexible bio-electricity supply, achieving combined electricity and heat efficiencies of over 85%. Intelligent control concepts and smart system design allow that even under heat driven operation electricity is mostly generated when actually needed in households. Household peak consumption in the evenings can be reduced and electricity losses in transportation are widely avoided. Direct combustion based micro-scale cogeneration systems are available on the European market. These systems exist for liquid biofuels (diesel engines) and for biogas (gas Otto engines and micro gas turbines). A breakthrough in indirectly fired micro scale cogeneration could lead to a tremendous increase in installed capacity. Biomass-based residential-scale thermal cooling technologies are not available yet.

Technology	Fuel	Pel kW_{el}	Price $€/W_{el}$	Status
Internal combustion engine (IC)	natural gas	1	6	110,000 installed
	natural gas, biodiesel, oil	5 – 5.5	4	> 22,000 installed
Thermoelectrics	Firewood & pellets	< 1		R&D, incl. material research
Stirling	natural gas, biogas	1	15	commercially available
	pellets	1	22 – 25	pilot
	pellets	2 – 3	10	R&D
	wood chips, biomass, biogas	35 – 140		-
Steam or organic rankine cycles	natural gas, pellet	0.2 - 2	›10	re-engineering, pilot
	any heat source	~3 – 15	~0.8 – 2.5	pilot, demonstration, field testing
	(concentrated solar), natural gas, oil, biomass	1 – 100		demonstration in automotive and solar applications
	any type of fuel	50 – 100	2.5 – 3	R&D
Gasification + IC	wood chips	30	5	-
	solid fuels	> 30 125	5-7	pilot; demonstration commercially available
	wood, chips, pellets, bio-waste	50 – 500		-
	wood chips	<250	5	demonstration
Externally fired micro-gas turbine (EF-MGT)	wood chips, pellets	25		
Fuel cells	natural gas	2	40-60	commercially available

Table 3: State of the art of micro- and small scale CHP technologies (modified from Haavisto (2010)

[35] A 20-year lifetime is assumed in these calculations.

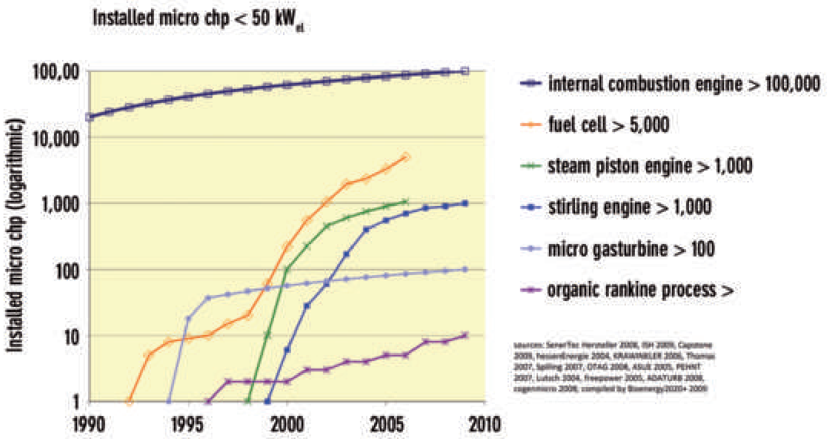


Figure 12: Micro-CHP installations in Europe from 1990-2008 (Various sources, compiled by Bioenergy2020+)

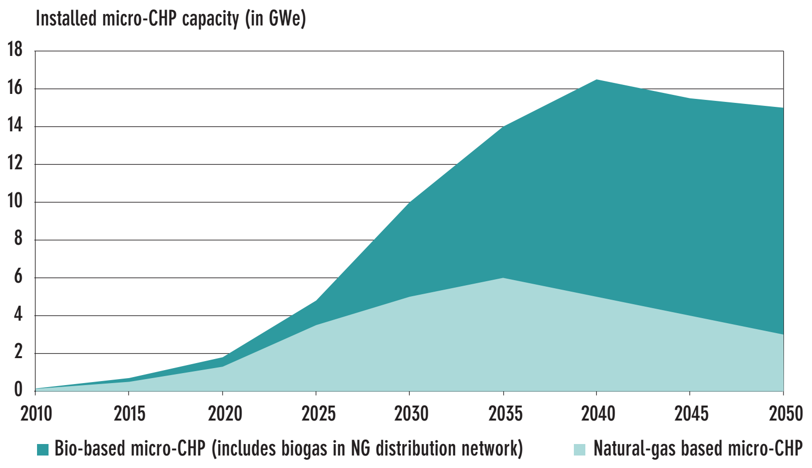


Figure 13 : Market potential of micro CHPs in Europe. Source: COGEN Europe (2010)

3.3.1 Research and innovation priorities with impact in the Short Term

The biggest priorities for residential biomass technologies are:

- To develop small scale combustion systems, which substantially reduce emissions under real life performance
- To develop small scale combustion systems with increased efficiency under real life performance
- To improve cost-effectiveness, i.e. to reduce investment costs, of advanced biomass heating systems in order to allow a further diffusion of this technology throughout Europe
- To develop small scale combustion systems suited to handling novel standardised biomass fuels (non wood solid biomass, liquid, and gaseous)
- To develop and demonstrate micro-scale cogeneration technologies

These priorities also require the development of advanced testing procedures (preferably mandated by standards) and technology development and demonstration. Generally, system design and system integration aspects need to be considered in the technology development processes. Overall system efficiency should be increased by at least 10% to 85% by 2020. Accompanying policy measures must ensure that only the best performing products with a maximum of efficiency and a minimum of harmful environmental impacts may be marketed throughout the EU.

The priorities for short term research are:

BIO.1	Improve system design of residential biomass heating systems
Objective	The objective is to close the gap between steady-state testing and real life performance of residential biomass heating systems without additional costs for customers. This is to increase system efficiency to >85% and to reduce real life emissions (CO, OGC and dust) by 50%. To do so, advanced cyclic testing procedures are required, guiding component and technology development towards advanced system thinking and providing a novel point of reference for component and technology design. Component and technology development focuses on primary and secondary measures to reduce emissions, secondary measures and new heat storage concepts to increase efficiency. Improved system design and intelligent control concepts (e.g. to reduce the number of start and stop cycles) are crucial to support both objectives. The development of optimum system design must consider trade-offs between complexity and costs. State-of-the-art biomass heating systems must be available at significantly reduced investment cost in 2020.
State-of-the-art	Today, the average efficiency of wood boilers under test conditions is well above 90%, however barely 75% is reached in real life operation (when efficiency is assessed in cold weather as well as milder weather). Emissions of manually stoked boilers are 100 mg CO/MJ, 5 mg OGC/MJ and 15 mg dust/MJ, and emissions for automatically stoked boilers are 50 mg CO/MJ, 3 mg OGC/MJ and 10 mg dust/MJ. Real life auxiliary electric energy demand is about 3% for automatic systems. The investment cost of a typical modern pellet-based heating system of 20 kW is about € 20,000 including all equipment usually installed in the cellar and the costs for indoor pellets storage and automatic pellets feeding. Investment costs for a wood chip boiler heating system of the same size are about 20% higher because of higher storage and fuel feeding system costs. Investment costs for firewood boiler plus heat store will cost about half that of the pellet-based heating system. Development trends have gone mostly towards high-tech / high price products in recent years.
Targets	Real life system efficiency of residential biomass heating systems should reach a system efficiency of 85% in 2020. Emissions should reach today's steady-state testing values. Cost-competitive hybrid concepts (biomass / solar, biomass / ventilation) must be demonstrated. Auxiliary electrical energy demand for automatic heating systems (not taking into account hybrid solutions) should be reduced by 1/3 and system investment costs shall be reduced by 20% (not taking into account hybrid solutions). Investment cost of biomass boilers will be reduced by 1/3 in 2020 compared to today.
Type of activity	10% Research / 30% Development / 60% Demonstration

BIO.2	Demonstrate the potential of efficient biomass boilers and stoves to improve air quality and reduce energy consumption
Objective	The main objective is to demonstrate through technology and ambient air quality monitoring that the substitution and retrofitting of the existing stock of small scale biomass combustion appliances and residential heating systems can substantially improve quality of ambient air and contribute to an increase of energy efficiency. Demonstration areas shall cover rural, small urban, and potentially also selected districts of large urban areas, each of which in different geographic (and climatic) regions in Europe, and shall take into account the state-of-technology and economic boundary conditions of the considered geographic regions, i.e. to consider the appropriate technologies for each demonstration area. Derived data shall serve for modelling purposes to support forecasting and decision support for policy makers. In order to obtain a sufficient exchange or retrofit rate, it will be essential to involve local authorities, local professionals (chimney sweeps, installers), and technology providers (chimney manufacturers, stove and boiler manufacturers), and to develop smart concepts for attracting the individual home owners to join exchange and retrofit campaigns.
State-of-the-art	Small scale biomass combustion systems have reached a high performance level regarding emission and efficiency. Until today, however, this improvement could only be demonstrated under test-stand conditions. Based on the results of several scientific studies investigating sources of particulate matter emissions, many local and national authorities are aiming at measures for substantial and sustainable PM emission reduction. A broad exchange and retrofitting of old biomass combustion technology, which has been identified as major primary emitter of PM in Europe, could lead to the expected results. Due to the high costs related to such measures many authorities are demanding a proof (demonstration) of the effectiveness of such measures.
Targets	• Over 50% exchange (and/or retrofit) rate of small scale biomass combustion appliances older than 15 years in chosen demonstration area • Over 50% reduction of PM in ambient air coming from biomass combustion • Over 25% increase in efficiency / reduction in fuel consumption
Type of activity	20% Research / 10% Development / 70% Demonstration

BIO.3	Cost-effective micro-CHP systems
Objective	There will be two distinct fields of application for micro-CHP systems: First, the use as an advanced heating system, which produces electricity in the power range from 0.1 to 5 kW_{el} and operates 1,500 to 2,000 hours per year (e.g. for single family houses or flats). Second, the use as a local heating plant (e.g. micro-grid) which produces electricity in the range 5 - 50 kW_{el} and for more than 4,000 hours per year. The objective of both types of applications are to: • Develop and prove integrated concepts (combustion system / heat transfer component / cogeneration technology) • Develop components • Improve component performance (heat exchangers) and component efficiencies (Stirling, thermoelectric materials) • Improve system efficiencies • Optimise control systems (e.g. communication with electrical grid) • Demonstrate long-term performance to assess reliability and techno-economics of micro CHPs in field operation • Reduce cost As an accompanying measure, the development of a testing procedure, preferably implemented into a European standard, for micro-CHPs is required to facilitate market uptake and to provide a point of reference for technology developers as well as for customers. Technologies which may be considered are thermoelectrics[36], Stirling engine, steam cycles, ORC and externally fired hot gas turbines for solid biomass based cogeneration. Biogas and syngas applications may also include micro gas turbine and fuel cell technology. The latter applications require above all substantial research into gas cleaning.
State-of-the-art	Micro-CHP means the simultaneous generation of thermal and electrical energy with a maximum capacity of less than 50 kW_{el} as defined in Directive 2004/8/EC[37]. Micro-CHP appliances based on internal combustion (IC) engines are commercially available technologies operated with biodiesel or biogas. The latter is also used with micro gas turbines. Investment costs of state-of-the-art IC systems are 4-6 €/kW_{el}. Externally fired micro-CHP technologies are not commercially available. Different technological concepts are under development. So are small and micro scale gasification technologies. These are dealt with elsewhere.
Targets	The electric system efficiencies based on solid state technologies (i.e. thermoelectrics) should reach 2% by 2020, and for systems based on thermodynamic cycles the electric system efficiency should reach 7%. As to the different applications, investment costs may vary as well from ~10 €/W for solid state cogeneration to ~3.5 €/W for thermodynamic cycle based technologies.
Type of activity	10% Research / 45% Development / 45% Demonstration Activities relevant to Materials Science (thermoelectrics)

3.3.2 Research and innovation priorities with impact in the Medium to Long Term

After 2020, the development of low-cost multi-sensor fuel recognition and automatic adaptation of operation will be required in order to allow fuel flexible boilers for a wider, but defined range of fuel qualities.

The priorities for medium and long term research are:

BIO.4	Development of next generation of firewood stoves (and inset appliances and cookers)
Objective	Future room heating appliances must make a substantial step toward reduction of harmful emissions, such as organic gaseous carbon (OGC) and dust. While results of existing certification testing procedures generally indicate good to excellent performance, real life performance reveals substantial potential for improvement and will guide technological development towards the expected impacts. Increased investment costs must be counter-balanced by savings in fuel cost. The objectives consequently are: • To develop advanced testing criteria that better reflect real life performance • To develop and demonstrate reliable combustion concepts and design for firewood stoves, cookers and inset appliances • To develop and demonstrate reliable and cost effective secondary measures for emission control • To minimise the risk of malfunctioning due to user errors • To develop and demonstrate advanced heat storage and slow heat release concepts (materials and system design)
State-of-the-art	Referring to firewood stoves only, today's testing efficiency is 81% with a real life efficiency of about 72%. Under testing conditions these emit 703 mg CO/MJ, 46 mg OGC/MJ and 28 mg dust/MJ, while the real life emissions are 4,463 mg CO/MJ, 664 mg OGC/MJ and 148 mg dust/MJ. Investment costs range from about € 1,000 for a state-of-the-art firewood stove of 6-10 kW to several thousand €. Design elements and advanced fuel storage concepts are the major cost items.

[36] This term refers to solid state cogeneration with thermoelectric materials used as heat exchangers.

[37] EU (2004).

BIO.4	Development of next generation of firewood stoves (and inset appliances and cookers)
Targets	• Development of advanced testing standards better reflecting real performance of room heating appliances • Reduction of real life dust and OGC emissions by >50% by 2020 • The testing efficiency of firewood stoves should be increased to 86% in 2020 and the real life efficiency to >75% • Today's state-of-the-art technology must be available at 50% reduced prices in 2020 • 2020s state-of-the-art technology must be available at today's state-of-the-art prices
Type of activity	20% Research / 50% Development / 30% Demonstration

BIO.5	Fuel flexible residential scale boilers
Objective	Using more difficult fuels (agricultural sources, short rotation forestry, and industrial by-products) requires characterisation and classification concepts for fuels (implemented in product standards, such as those laid down in the EN 14961-6 for non-wood biomass pellets) and corresponding combustion technology. The major challenges are to develop burner and grate concepts to manage ash rich fuels with challenging ash melting characteristics (effective grate cleaning concepts, fuel bed temperature control…) and the development of sensors to identify fuel qualities (heating value, moisture content), and controls that adapt operating parameters accordingly. The lowest emission performance can be ensured through the development and integration of suitable primary and secondary measures for emission control.
State-of-the-art	Today's boilers can combust only one type of fuel (wood chips, wood pellets) or permit manual switching between the two fuel types. Investment costs are equivalent to wood chip boiler systems (~ € 25,000 for 20 kW boiler).
Targets	• Boilers for a wider range of fuel qualities with the need to manually adjust control options • Automatic adaptation to fuel moisture content • Effective management of fuels with up to 5% ash content
Type of activity	50% Research / 30% Development / 20% Demonstration

	Research and Innovation Priorities	Predominant type of activity	Impact
BIO.1	Improve system design of residential biomass heating systems	Demonstration	By 2020
BIO.2	Demonstrate the potential of efficient biomass boilers and stoves to improve air quality and reduce energy consumption	Demonstration	By 2020
BIO.3	Cost-effective micro-CHP systems	Development/ Demonstration	By 2020
BIO.4	Development of next generation of firewood stoves (and inset appliances and cookers)	Development	By 2030
BIO.5	Fuel flexible residential scale boilers	Research	By 2030

Table 4: research and innovation priorities for Bioenergy applications to residential buildings

3.4 Geothermal technologies

In the residential sector, the main geothermal technology to cover heating and cooling demand is the shallow geothermal heat pump system (the ground-source heat pump). The technology is suitable for small, individual houses as well as larger multi-family houses or groups of houses. Capacities range from under 10 kW_{th} to over 500 KW_{th}. The depths of geothermal heat exchange ranges from a few meters to more than 200 m, depending upon technology used, geological situation, demand profile, and other design considerations.

Geothermal heat pumps can deliver all thermal energy required for:
- space heating
- space cooling
- domestic hot water (DHW)

For space cooling, in certain regions with moderate climate, direct cooling from the ground via cooling ceilings etc. is possible, allowing for space cooling with minimum energy input. In warmer regions with higher cooling demand, the heat pump can be used in cooling mode.

For well-insulated houses with a forced ventilation system, geothermal energy can contribute to pre-heating or pre-cooling ventilation air while it passes through intake pipes buried in the ground.

The number of geothermal heat pumps with a capacity below 50 kW crossed the threshold of 1 million units in 2010[38]. The highest numbers can be found in Sweden, Germany and France. The market penetration (installations per capita) is highest in Sweden, Finland and Austria. Geothermal heat pumps are already used in Southern Europe, however, further R&D and practical experience is crucial to fully exploit the advantages of geothermal heat pumps in warmer climates in supplying heat and cold from one single installation.

The performance of geothermal heat pump systems improved substantially since their introduction in Europe in the 1970s. The first plants were installed in Sweden, Germany, and Switzerland, used for heating only. In these regions the typical efficiency, expressed as Seasonal Performance Factor, increased from below 3 in the 1980s to well above 4 today, and with continued R&D, average values in the order of 5 seem feasible for 2020[39].

Also for some shallow geothermal components the improvements can be quantified. The most popular ground-coupling technology is the borehole heat exchanger (BHE); a good efficiency of a BHE results in a small temperature loss between the ground and the fluid inside the BHE. This temperature loss is controlled by the borehole thermal resistance which could be reduced by more than 40 % over the next ten years. The impact of this value to a defined shallow geothermal system is given by the Hellström-efficiency[40], which increased from below 60 % to about 70 % in state-of-the-art installations over the past 10 years (Figure 14). There is still room for improvement, so provided the technology progress is continued, efficiencies of about 80% in 2020 seem achievable.

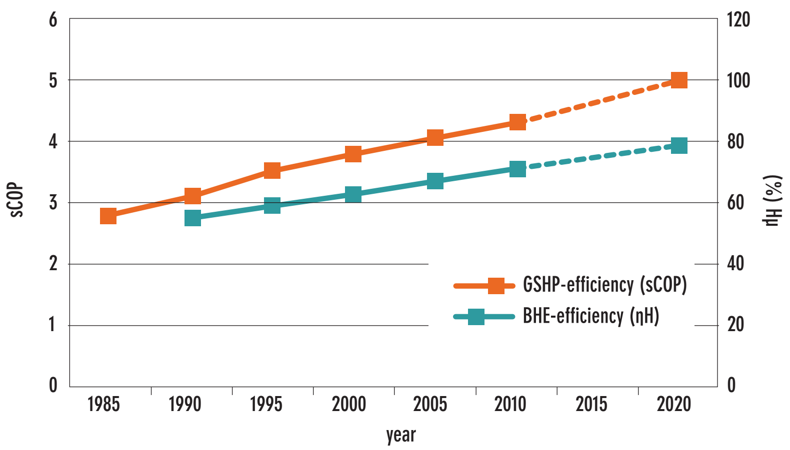


Figure 14: Increase in efficiency of geothermal heat pumps, shown through the seasonal Coefficient of Performance (sCOP) of state-of-the-art systems[41], and efficiency increase of heat transfer in state-of-the-art borehole heat exchangers, expressed as Hellström-Efficiency ηH

The cost, a paramount factor to drive market penetration of shallow geothermal systems, shows a steady reduction in the last decades. A study of the Swiss Heat Pump Association (Fördergemeinschaft Wärmepumpen Schweiz, FWS) calculated the cost for a BHE-system (drilling, heat exchanger, and heat pump) for a small house, and found a reduction of 27.5% over 12 years, from 1992 to 2004. In fact, the situation concerning the first cost is a bit more complicated. While the specific cost for BHE and connections decreased, an increase can be seen for the required BHE length. A heat pump with higher sCOP consumes less electricity at the same heating output, and thus the geothermal energy input need to be increased by increasing BHE length[42]. Thus the better heat pump efficiency actually counteracts partly the reduced specific BHE cost (Figure 15); of course, the reduced electricity input will be a benefit for operation cost. In combination, both factors result in a slight decrease of the cost for the system (Figure 16). When the specific heat costs are calculated, including the first cost as annual capital cost, a stronger decrease can be seen. Better efficiency results in a decrease in energy input for operating the geothermal heat pump system that is much more pronounced than the slight reduction in first cost. In recent years, the lifecycle cost of a fuel oil boiler has surpassed the price of an average shallow geothermal system.

[38] EUROBSERVER (2011)

[39] See Figure 16. The maximum theoretical efficiency for a heat pump process can be expressed by the Carnot-efficiency; at the typical temperature levels for geothermal heat pumps, this would be at values of 7 to 9. So currently a Carnot-efficiency of about 50 % is achieved, with the tendency to >60 % in 2020.

[40] The Hellström-efficiency is defined as the actual heat extraction for certain boundary conditions (geology, building) compared to the theoretical optimum with zero borehole thermal resistance (first suggested by Mands et al., 2008)

[41] Compiled from various sources, e.g. Sanner (1992), Miara et al. (2011).

[42] The net output of useful heat is the sum of the electrical input and geothermal heat input, and thus a lower electricity consumption implies that proportionally more heat has to be extracted from the ground, requiring an increased length of BHE or higher yield of groundwater wells.

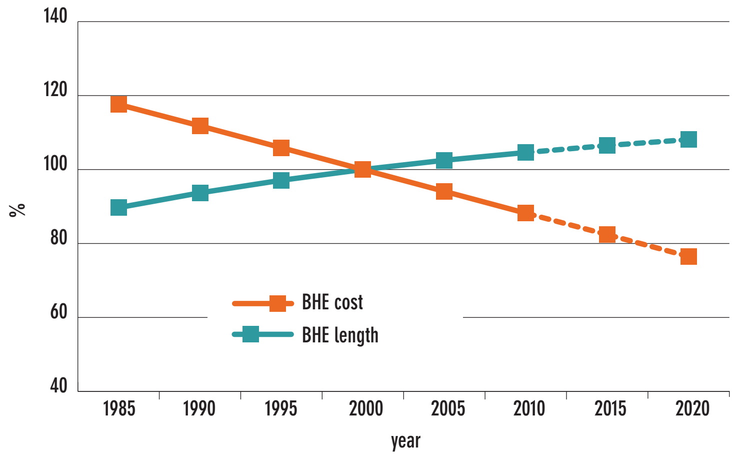


Figure 15: Development of specific cost for BHE (i.e. a unit of BHE length) and of required BHE length in Central Europe

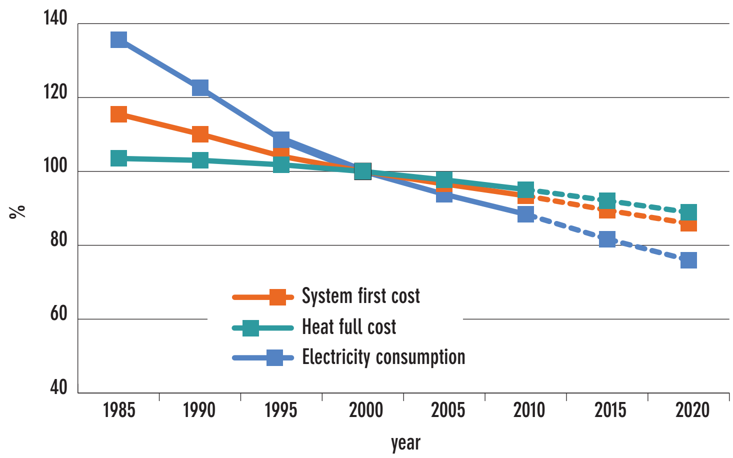


Figure 16: Development of system first cost, heat full cost, and electricity consumption of geothermal heat pump systems in the residential sector in Central Europe[43]

3.4.1 **Research and innovation priorities with impact in the Short Term**

Shallow geothermal systems consist mainly of the devices for exchanging heat with the underground and the components to make this heat available for use in the building, like the heat pump and conventional heating and HVAC (Heating, Ventilation & Air-Conditioning) equipment. The heat pump as such is covered in the Cross Cutting research priorities (see Section 3.5). Any progress in HVAC components (better efficiency, lower cost, adaptation to temperatures delivered by geothermal systems) will also benefit the overall geothermal system. Specific R&D for geothermal heating and cooling in the residential sector thus mainly concerns ground-coupling technologies.

[43] Compiled from various sources, in particular EGEC (2012).

The priorities for short term research are:

GEO.1	Optimisation of ground-coupling technology (i.e. technology to exchange heat with the ground in an optimal way)
Objective	For geothermal systems with borehole heat exchangers or groundwater wells, the drilling of the necessary boreholes is a major cost factor. Hence systems can be made much more economic by improved and innovative drilling methods, allowing for cost reduction. A lot can be expected also from further reducing manual work in drilling and installation, by automation and robotics. R&D in drilling technology is required to further reduce the impact on the surroundings (e.g. sensitive clays, groundwater), to provide techniques to control borehole deviation, etc. In particular in the residential sector, other types of geothermal heat exchangers like horizontal loops, compact screw-shaped heat exchangers, simple energy piles, etc. are in use as an alternative to drilling of boreholes. Also here, the reduction of cost, through optimized and mechanised installation methods, is an issue and needs further R&D-work. The efficiency of heat exchange with the geological strata can be increased by R&D for optimisation of components such as borehole heat exchangers (design, pipe material, and grouting material), well completion materials, compressors, and pumps.
State-of-the-art	For ground coupling, the cost varies between different technologies and different geological settings. A borehole heat exchanger today costs between 30 and 60 €/m, with the lower prices prevalent in Scandinavia and higher prices e.g. in Austria and Germany. Assuming a typical single family house, this results in some 350-700 € per kW installed capacity of the ground heat exchanger only (i.e. excluding the heat pump). The efficiency of ground coupling can be measured by a parameter called borehole thermal resistance; values for current up-to-date technology can be as low as about 0.07-0.08 K/(W•m). To compare these values and their impact on the whole system, the Hellström-efficiency is used; currently values in the order of 75 % can be achieved.
Targets	Reduction of average installation cost by at least 25 % in 2020, and 50 % in a longer term. Increase of heat exchange efficiency to 2020 by 25 % (expressed by reduced borehole thermal resistance or Hellström-efficiency), allowing for either higher efficiency or reduced cost.
Type of activity	100% Development

GEO.2	Improving the understanding of the shallow geothermal reservoir
Objective	To improve the understanding of the shallow geothermal reservoir as an entity and as a process will require the identification and characterisation of the important parameters (thermal, hydrogeological, environmental as well as engineering). To investigate the scientific facts related to environmental impact of shallow geothermal systems to allow regulatory authorities to better develop and amend regulations.
State-of-the-art	Heat transport in the underground, both conductive and advective, has been studied in shallow geothermal R&D-projects since the 1980s. Suitable design methods and operation strategies are available today, but still not all of the processes are fully understood, and there remains the potential to optimise. In particular in the field of groundwater quality for open-loop systems insufficient progress has been made. In respect to environmental impact, long-term consequences in particular need more investigation.
Targets	Increase of efficiency by at least 25 % through better overall system design and operation. Avoidance of negative effects to ground and groundwater.
Type of activity	25% Research / 75% Development

3.4.2 Research and innovation priorities with impact in the Medium and Long Term

In shallow geothermal technology, the majority of R&D-needs are in the short-term range. However, research in new and enhanced materials is likely to have an impact after 2020.

Research on pipe material for borehole heat exchangers (BHE) or horizontal ground loops (GEO.3). Today, plastics like polyethylene are used for these pipes. These materials fulfil well the requirements for cost, handling, longevity, resistance to corrosion, etc.; their main disadvantage is the low thermal conductivity. Material with higher thermal conductivity today means metals, which come with all the disadvantages of high cost, corrosion, handling requirements. And most metals have much higher thermal conductivity than actually is desired, with the geological strata being limited to some 2-4 W/m/K. In consequence, development should aim at a plastic material, cheap and easy to handle (transport in coils, welding possible), resistant to corrosion, and showing thermal conductivity of about 4 W/m/K (as compared to <0.5 W/m/K for the polyethylene of today).

	Research and Innovation Priorities	Predominant type of activity	Impact
GEO.1	Optimisation of ground-coupling technology (i.e. technology to exchange heat with the ground in an optimal way)	Development	By 2020
GEO.2	Improving the understanding of the shallow geothermal reservoir	Development	By 2020
GEO.3	Research on pipe material for borehole heat exchangers (BHE) or horizontal ground loops	Research	By 2030

Table 5: research and innovation priorities for geothermal applications to residential buildings

3.5 **Cross-Cutting Technologies**

Electrically driven heat pumps transform low temperatures renewable energy from the air, ground or water to heat at higher temperature that can be used for space heating, heating water or cooling. Energy from these sources is - with certain exceptions due to local conditions (geology, soil and climate) - available everywhere in Europe at all times. In addition, heat pumps are able to use low-temperature waste heat (e.g. from industrial processes, sewage water or exhaust air of buildings) as an energy source and create high-temperature heat from it. By saving energy compared to conventional heat generation systems, heat pumps increase the share of renewable energy in total final energy consumption.

Properly designed and installed heat pump systems are highly efficient and can fully meet the heat demands of many areas of application. On a final energy basis, their output originates from 66% to 80% from renewable energy. Considering their primary energy consumption, their efficiency depends on the efficiency with which the auxiliary fuel needed to run them (most often electricity) was generated.

As shown in Figure 17, air source units today can achieve efficiencies of around 140 % in terms of primary energy. Electrically driven heat pumps are today's predominant solution for space heating and cooling in residential as well as non-residential buildings. In terms of technology development, manufacturers continue the relentless drive for improved overall system performance, achieved in general through optimised components and more attention to the delivery of completely integrated solutions (Figure 18). This underlines the importance of the heat pump's interplay with the heat distribution system, and a need to focus on more intelligent and integrated controls. The emergence of hybrid systems (heat pumps deployed in conjunction with other renewable or conventional heating solutions) highlights the acceptance of the technology as part of an integrated energy efficient solution in both the retrofit and new-build sectors. Heat pump based hybrid systems can meet the requirements of nearly 100% of the heating market.

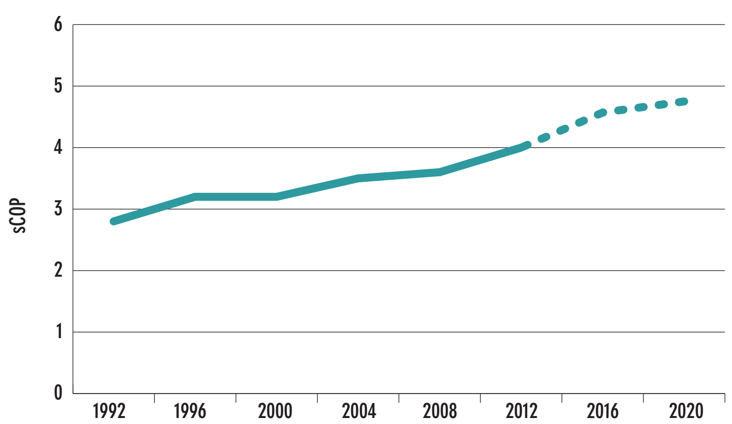


Figure 17: Trend and potential efficiency evolution of sCOP for electrically driven air to water heat pumps in heating mode. Performance described by the seasonal Coefficien Of Performance (sCOP). (Source: EHPA)

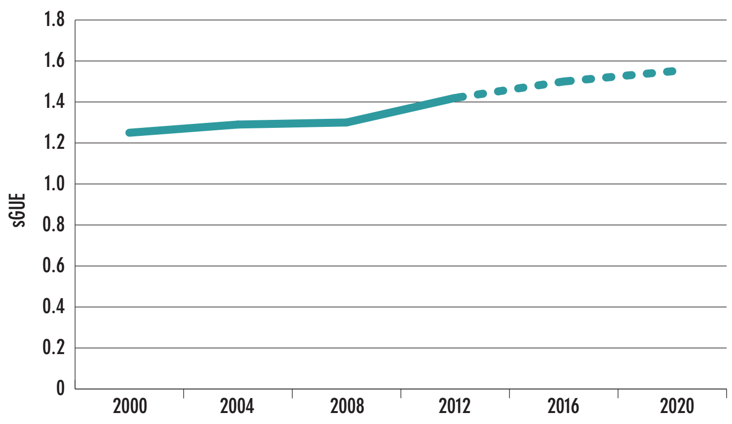


Figure 18: Trend and potential efficiency evolution of thermally driven sorption heat pumps in heating mode. Performance described by the seasonal Gas Utilisation Efficiency (sGUE), equivalent to primary energy ratio). (Source: EHPA)

Manufacturers tend to optimise the design of components and equipment only for the applications with the largest market, which for much of the history of heat pumps has been air-conditioning. Now a lack of development of specific components for other kinds of heat pump that supply heat is becoming a technological bottleneck for the industry. Research is primarily required on improved components (see below). The integration of several components with efficiency improvements is expected to lead to products with superior performance at affordable cost.

Heat pumps	Space heating & hot water	Cooling
Installed cost	-10% to -15%	-3% to -8%
Coefficient of performance	15% to 25% improvement	10% to 20% improvement
Delivered energy cost	-10% to -15%	-5% to -10%

Figure 19: potential improvements by 2020 in terms of costs and performance, expressed relative to 2010. (Source: estimation based on OECD/IEA 2011)[44]

Thermally driven heat pumps use the same thermodynamic cycle as electrically driven compression heat pumps, however the compressor is replaced by a thermal sorption cycle[45]. Therefore thermal energy is needed to drive the cycle and electricity is needed only for auxiliary components like pumps to circulate the working fluid. Thermally driven machines are mainly used for cooling purposes in combination with waste heat or heat produced by renewable sources. However, they can also work as heat pumps with high efficiency.

Within the residential sector, thermally driven heat pumps are applied mainly in two ways. For **heating purposes**, in the last years the main technology available on the market were gas fired absorption heat pumps. By exploiting thermal energy of outside air as a low temperature heat source, a relevant increase of efficiency is possible in comparison to traditional gas boilers (sCOP up to 1.6). In terms of capacity (kW), the systems currently available on the market are only suitable for multifamily houses; the development of smaller applications is a pressing R&D priority. Applications integrating natural gas boilers with adsorption cycles in a single system have recently appeared on the market.

For **cooling purposes**, adsorption and absorption chillers can be combined with existing heating systems. Most applied combinations are the exploitation of district heating for cooling purposes and the combination with building-integrated renewable energy technologies such as solar thermal collectors (solar cooling systems). The first application is described more in details in Chapter 6. The second application – solar cooling - is still a niche market but underwent a strong development in the last years regarding efficiency and cost.

[44] OECD / IEA (2011)

[45] For in-depth analysis of the state-of-the-art and research priorities for thermally driven heat pumps, consult RHC-Platform (2012d).

In Figure 20 the cost reduction of hybrid systems combining solar thermal and sorption chillers is shown. The figure is an example of the available cost reduction potential if hybrid systems are planned and partly pre-integrated as one system.

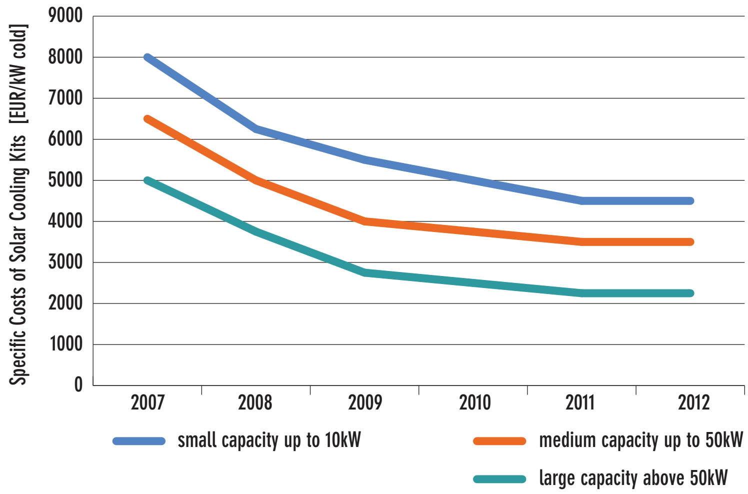


Figure 20: Cost reduction of installed hybrid systems combining solar thermal and sorption chillers (also known as solar cooling systems). Source: Green Chiller ©, 2012.

Hybrid systems are defined as systems which provide heating, cooling and/or domestic hot water through the combination of two or more energy sources in a single system, potentially overcoming the limitations of individual technologies. Hybrid systems are used in small-scale applications like heating and cooling systems for single family houses as well as in large-scale applications suitable for district heating and cooling or industrial processes. The overall system efficiency depends strongly on the way the different sources are combined.

Until recently, the most common hybrid application was the combination of a fossil fuel burner (mainly gas or oil) and solar thermal collector or heat pump. Such hybrid systems represent an interesting and convenient option to reduce fossil fuel consumption until the transition towards the next generation of hybrid renewable energy systems will be completed.

Small-scale systems using a combination of two renewable energy sources have gained market share in recent years. The main examples of hybrid renewable energy systems, coupled to a district thermal grid or functioning on individual basis, are:

- Biomass boilers and solar thermal
- Electrically driven heat pumps and solar thermal
- Thermally driven heat pumps in combination with solar thermal
- Thermally driven heat pumps in combination with district heating

Info Box 2

Today most hybrid systems for heating and DHW are customised combinations of single components assembled by the installer, like the example in Figure 21. This system is typically applied in the existing building stock. A pellet boiler meets 100% of heating demand and serves as back-up for DHW supply, which is mostly provided by a solar thermal installation. The interface between the solar thermal component and the pellets boiler is the DHW boiler. There exist a manifold of variations, amongst others the integration of solar thermal into the heating circuit. The optimised combinations of solar thermal and heat pump technologies are also analysed in IEA Task 44 (www.task44.iea-shc.org).

Figure 21: small-scale hybrid system composed of biomass boiler, solar thermal collector and sensible thermal energy storage (credits: Walter Haslinger, Bioenergy2020)

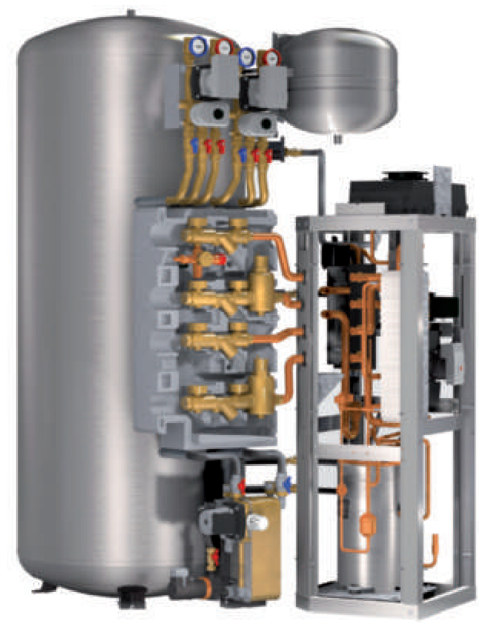


Figure 22: Example of an integrated and prefabricated hybrid system combining solar thermal collectors and an air source heat pump for delivery of heating and domestic hot water to single family houses. Source: Kioto Clear Energy (2013). KIOTO Sonnenheizung – Clear Energy (2013)

Thermal energy storage can hugely increase the technical potential of renewable energy sources and improve the efficiency of other heating and cooling processes. Storage of heat and cold allows it to be utilised when there is demand for it, rather than at the same time that it is generated. A wide range of technologies exist at laboratory-scale, some of them on the cusp of becoming commercially viable. The future of TES applications depends on the achievement of two crucial strategic objectives: reducing costs and improving the ability to efficiently shift energy demand over days, weeks or seasons.

Sensible storage is the most common method of heat and cold storage. A very good storage medium for sensible heat is water, be it in tanks, pits, aquifers (groundwater), caverns, abandoned mines, or other. Also solid matter can be used, like soil or rock in borehole stores. Figure 23 shows some of these options.

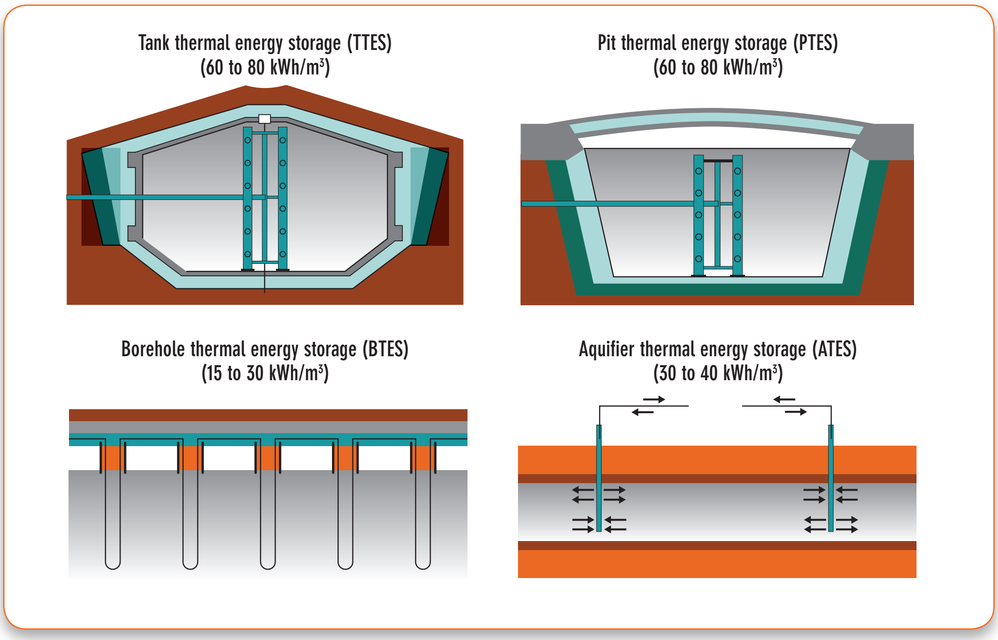


Figure 23: The most frequently used options for storage of large amounts of sensible heat, in liquid (water) or solid (soil, rock) matter. Adapted from: Solites and Danish Energy Agency (2010)

Underground Thermal Energy Storage (UTES) for low temperature applications (at less than 40 °C) has been demonstrated and is now available in some European markets, particularly in the Netherlands and Sweden. These types of systems, using groundwater-bearing layers, are typically referred to as Aquifer Thermal Energy Storage (ATES), using wells into the groundwater, and Borehole Thermal Energy Storage (BTES), using borehole heat exchangers in the ground. Demonstration projects of ATES and BTES[46] for temperatures in the range of 40-90 °C also exist. Research and development into storing heat at temperatures above 90 °C was done in the 1980s, but discontinued. A breakthrough would be needed for that temperature range.

The cost and performance of the underground part of ATES systems did not change much in the past, and are not likely to improve substantially; well drilling and groundwater behaviour cannot be influenced much and thus are limiting factors. The main improvement comes from more accurate and innovative design (including water treatment were necessary) and from efficiency gains in some components like submersible pumps. ATES already is the most cost-effective solution for large sensible heat storage. For BTES, there are more options – all improvements in efficiency and reduction in cost achieved with Borehole Heat Exchangers (BHE) in the shallow geothermal sector are direct, immediate improvements to BTES. Figure 24 shows the historic and expected evolution of BHE costs.

[46] Some types of underground systems are also known as CTES (thermal energy storage in artificial caverns).

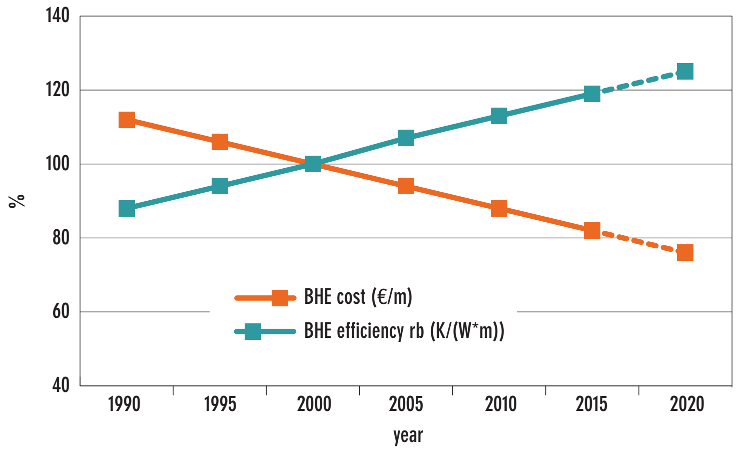


Figure 24: Development of specific cost for BHE in Central Europe and reduction of borehole thermal resistance (i.e. efficiency increase of heat transfer) in state-of-the-art BHE; these improve directly BTES efficiency and economy.

In **latent heat storage**, the material stores heat while changing phase. The phase change "solid-to-liquid" is the most used, but also solid-to-solid change is of interest. The main characteristic of this technology is that during the phase change the materials remain, theoretically, at constant temperature (real systems show a temperature stabilisation around the melting temperature). Materials used in latent heat storage are known as phase change (PCM). The best known and most used PCM is water, but also salt solutions (for low temperature applications), paraffins, salt hydrates, fatty acids, sugar alcohols (between 0 ºC and 130 ºC), and inorganic materials and salts (for temperatures above 150 ºC) are used. Above 250 ºC salts are the most interesting materials (nitrates, chlorides, phosphates, sulphates, etc.).

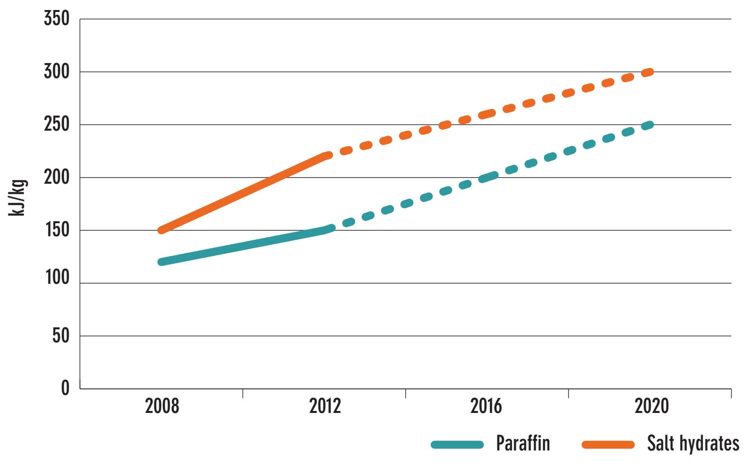


Figure 25: potential efficiency evolution of phase change materials (in kJ/kg)

When the products of a reaction can be stored separately and the heat stored during the reaction can be released when the reverse reactions takes place, this reaction can be used for **Thermochemical TES**. The energy stored in reversible chemical reactions can achieve densities 3-12 times greater than sensible stores and perhaps up to 20 times greater, while being able to deliver thermal energy at different discharging temperatures, dependent on the properties of a specific thermochemical reaction.

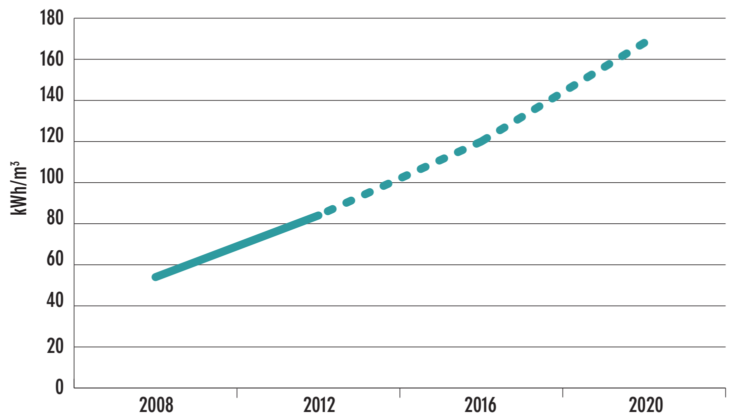


Figure 26: potential storage density evolution of thermochemical materials for seasonal storage of renewable heat (in kWh/m³)

Technology	Capacity kWh/t	Power kW	Efficiency (%)	Storage time	Cost (EUR/kWh)	Reduction of installation cost by 2020
Hot water tank	20-80	1-10,000	50-90	day-year	0.08 – 0.10	-20%
Chilled water tank	10-20	1-2,000	70-90	hour-week	0.08 – 0.10	-20%
ATES low temp.	5-10	500-10,000	50-90	day-year	Varies	-15%
BTES low temp.	5-30	100-5,000	50-90	day-year	Varies	-15%
PCM-general	50-150	1-1,000	75-90	hour-week	10 - 50	-30%
Ice storage tank	100	100-1,000	80-90	hour-week	5 - 15	-20%
Thermochemical	120-150	1-100	75-100	Day-Year	8 - 40	-35%

Figure 27: Characteristics of various thermal energy storage technologies (range of values) and expected evolution between 2011 and 2020 [Estimation based on OECD/IEA 2011][47]

District Heating and Cooling (DHC) allows different renewable energy sources and end-consumers to be connected together in one system, a solution particularly effective in areas characterised by high density of population. The cross-cutting nature of DHC is such that advancements in DHC technology are likely to be beneficial to both residential and non-residential users. For this reason DHC topics are presented in a separate section (3.3).

3.5.1 Research and innovation priorities for Heat Pump technology and Hybrid Systems with impact in the Short Term

Improvements in the building envelope and technology have increased the available applications for heat pump technology. As of today, European manufactures are often world leaders. With regards to the residential heating sector, it should be kept in mind that traditional fossil fuel based solutions can be characterised by low initial cost of equipment and installation. Thus heat pump based solutions must be optimised towards a competitive total cost of ownership (moderate cost solutions together with considerable savings in year-round energy consumption) to successfully penetrate this market. Research, development and demonstration activities are required to support the market penetration of thermally driven heat pumps, including gas fired sorption units.

Building technology has evolved considerably in recent years resulting in differences in new (very low or even plus-energy) and existing buildings (higher feed-in temperature). Therefore heat pump solutions must cover the full spectrum of demand profiles. R&D must address both segments; European heat pump manufacturers will benefit from joint research enabling them to develop unique solutions which, after maturing in the European markets, can become export products.

[47] OECD / IEA (2011).

Improved insulation, tightness and, in general construction in new houses is going to lead to a very significant reduction of the thermal load in winter and probably to the need for higher ventilation or even some air conditioning in summer since the internal heat loads in the house tend to continuously increase. Ventilation systems will mostly incorporate heat recovery heat exchanger in order to decrease the thermal load due to ventilation.

On the other side, Europe's building stock still consists of a large number of inadequately insulated houses that lose a lot of heat. Ideally, these buildings should be insulated and old radiators should be replaced by low-temperature heat distribution systems to enable a heat pump to generate heating and domestic hot water to be installed. The outcome would be a meaningful saving on energy consumption and emissions.

However, a short term solution is represented by the combination of a heat pump with the existing system, in order to raise the temperature of water before it is further increased by the existing boiler. This application of HPs requires only a small HP, keeping investment and installation costs low. In such an installation, the HP will cover most of the annual heating demand only being supported by the existing boiler at low ambient temperatures (winter) or to cover peaks in demand. Primary energy savings along the year are going to be still high. The heat pump will be the only heat generator at outside air temperatures above 2°C (which is the case in most of Europe). Specific research efforts are needed in order to develop "integration kits" enabling the installer to easily and quickly integrate the new technology into the existing system. Smart controls will have to integrate the additional (fossil) heaters at days below 2°C and for peak demand in hot water production. Thus, high sCOP of the integrated system will be reached while satisfying the necessary comfort.

As hybridisation implies interaction between complementary technologies, research on the control and automation strategies is a top priority for hybrid systems to reach their full potential. Further technological developments are required to expand the range of cost-effective hybrid system applications in buildings.

The following research priorities for heat pump technology and hybrid systems are deemed to bring about significant benefits by 2020:

CCT.1	Cost-competitive heat pump kit for houses with existing boiler
Objective	Development of heat pump kit to be integrated in the heating system of houses with existing non-electrical boiler. The expected solution should present the following characteristics: • High efficiency air to water heat pump producing heating water with a temperature lift of minimum 45K. • The supply temperature should be changeable between 50 and 35 ºC depending on the ambient temperature. • The existing boiler will be kept and will only be employed as a back-up system under extreme ambient conditions when the heat pump is not able to attain 60ºC or to increase the temperature of the sanitary hot water. • Compact design in a form of kit with all the necessary components for an easy integration and installation with the boiler heating system. • The control of the system must allow optimal management and automatic operation of the heat pump unit and boiler • With a capacity in the range 4-8 kW, the system should be able to provide the required heat most of the time.
State-of-the-art	Expensive hybrid systems have been developed in recent years, leading to efficient heating and sanitary water production. The proposed kit will not attain such an efficient operation but will help to save energy and reduce gas consumption at a competitive installation and system cost.
Targets	25% decrease in the cost of the heat pump, including installation. The sCOP of the heat pump operating under the described conditions should reach at least a value of 4.
Type of activity	100% Development

CCT.2	Optimisation of thermally driven heat pumps and their integration in the boundary system
Objective	The objective of this topic is to support the market penetration of thermally driven heat pumps by enhancing the efficiency and the long term stability and by reducing the size, weight and cost. This can be achieved throughout the improvement of materials, production processes, components and hydraulic design.
State-of-the-art	Gas fired absorption heat pumps are successfully implemented mainly in large scale applications, such as multifamily residential and non-residential buildings (several thousand units sold); small scale adsorption units entered the market only recently. Water fired sorption chillers are mainly applied in industry and coupled to cogeneration units. Solar, biomass or district combinations are still niche applications with some hundred systems being implemented. Based on increased application of district networks, distributed cogeneration units and solar thermal fields the application possibilities of this technology are expanding too.
Targets	• Reduction of volume and weight of the thermally driven heat pump by 10%. • Enhancement of thermal sCOP of the unit by 5% and sCOP of the system by 10%. • Reduction of parasitic electricity consumption of the overall system by 20%.
Type of activity	70% Development / 30% Demonstration

CCT.3	Automation, control and long term reliability assessment
Objective	Within the development of new generation hybrid systems, special attention should be paid to the automation and control of systems. The scope of this research is to develop an integrated control platform, including the following functionalities: • Weather forecast, based on local observation and/or services available by Internet. • Heating/Cooling and DHW load forecast, based on the learning of system operation and occupants' behaviour. • New processing algorithms to supervise the complete system (adaptive control, learning process, etc.) while maintaining a high degree of comfort and a low consumption of auxiliary electricity. • Intuitive user interfaces which are able to provide information on the system to the user in an understandable language, and which let users adjust the system simply (set point temperature, etc.) • Monitoring and recording of energy production, cost of primary energy consumed, energy efficiency and amounts of GHG emitted. • With more data on the behaviour of systems operating under particular conditions it should be possible to develop performance guarantees. • Fault detection: intelligent analysis of the system behaviour should be included to detect possible malfunctioning before it occurs and to alert the end-user or service company. • Development of an easy to install system with a plug&play function concept of the controller. All of these technical developments on control, monitoring and automation should improve the quality of the systems. In addition to it, specific design and commissioning will allow a reduction in the total cost of the systems on their life duration and lead to guaranteed levels of production.
State-of-the-art	Today hybrid systems are usually composed of customised combinations of components individually assembled by the installer. In several cases this is not one controller for the overall system, but one for each main energy unit, regulating the on and off switching of the unit. This leads to a certain occurrence of sub-optimal programming, Often the data exchanged by the controllers is limited and this affect the possibility of optimising the system. Monitoring is mostly done only in a very limited way or not at all. Parasitic electricity consumption is usually not measured. Mistake detection and optimisation of the system based on this data is possible only in a limited manner. Weather forecast, load forecast and adaptive control are usually not available.
Targets	We expect that research into these two areas will deliver a **20% cost reduction** and a **20% increase in thermal efficiency** in the short term, thus leading to approximately a 40% decrease of the overall system cost.
Type of activity	20% Research (low cost heat meters, sensors and monitoring concepts), 50% Development / 30% Demonstration

3.5.2 Research and innovation priorities for Heat Pump technology and Hybrid Systems with impact in the Medium and Long Term

CCT.4	Development of a heat pump for near-zero energy buildings (single family house)
Objective	Development of a small capacity reversible heat pump (around 2 kW_{th}), with low cost, easy installation, operation and maintenance, for the new low-energy consumption houses of the EU, with optimal integration with the ventilation heat recovery and domestic hot water production. Additionally, the unit should employ a low Global Warming Potential (GWP) refrigerant.
State-of-the-art	The latest developments in this sector are the exhaust air heat pumps which are efficient devices which extract heat from the exhaust air and produce a small extra amount of heat for the house.
Targets	sCOP> 5. The exhaust air heat pump should be able to keep reasonable performance even at low outdoor temperatures such as -10ºC.
Type of activity	60% Development / 40% Demonstration

CCT.5	Next generation of highly integrated, compact hybrid systems

Objective	Efforts should be put into developing compact / prefabricated hybrid systems with the following characteristics:
	• Improved efficiency through:
	  • well-designed systems (having smart hydraulic layouts, energy storage management, being exergetically optimised);
	  • control systems that optimise the energy consumption and take advantage of the availability of renewable energy (optimised integration of both energy systems giving priority to the utilisation of renewable / more cost efficient source);
	  • embedded equipment for energy monitoring in order to have a clear picture of the energy production, cost of primary energy consumed and amounts of GHG emitted;
	  • immediate failure detection, signalled e.g. by excessive energy consumption and notification to the user and/or service company.
	• Inexpensive and simplified installation to reduce damage.
	• Adapted to the various configuration of heating systems (low/high temperature) and climates.
	
	Activities must include the development of suited testing procedures allowing for comparability of performance data and as a reference for the technology development[48].

State-of-the-art	Today most hybrid systems are customised combinations of single components assembled by the installer. The efficiency of the overall system strongly depends of the installer's skills, technical knowledge and choice of the right components. The sCOP of the whole system is rarely known. The inefficient assembling of the hybrid system produces average energy losses of around 20%, which are hardly detected by the customer. Several manufacturers offer installation guidelines for the combination of the core component with a second thermal energy source. However prefabricated, highly integrated hybrid systems have only recently become available. The state-of-the art is represented by the combination in a single system of biomass / solar thermal technology or heat pump / solar thermal system, including a joint heat storage and control.
Targets	• Development of prefabricated, fully integrated hybrid systems using at least one RES contributing over 50% to the final heating and cooling consumption. These systems should be suitable for both new and existing building; including performance monitoring and a customer information system. • 20% cost savings on system installation in comparison with customised hybrid systems dependent on the installer's design. • sCOP / system efficiency increase of 20% in comparison with hybrid systems based on customised design and assemblage by the installer.
Type of activity	10% Research / 45% Development / 45% Demonstration

3.5.3 Research and innovation priorities for Thermal Energy Storage with impact in the Short Term

All TES technological solutions should be supported in parallel: advanced sensible heat storage, PCM and thermochemical. Both decentralised systems and stores connected to the DHC network hold significant potential and it is therefore important to invest in the development of a broad portfolio of options.

Improving the properties of TES materials is important, in particular concerning their stability and the number of charging and discharging cycles they can withstand. The durability of new systems and their constituent parts must also be accurately quantified in order to estimate their long-term performance.

[48] Cfr. also RHC.1 and RHC.2

The priorities for thermal energy storage with short term impact mostly concern sensible and latent storage:

CCT.6	Next generation of Sensible Thermal Energy Storages
Objective	Availability of high-efficiency sensible thermal energy storage devices with significantly reduced heat losses, efficient charging and discharging characteristics and high flexibility to adapt it to and integrate it in existing buildings with limited space for storages. Costs and thermal conduction of the containment materials will be reduced by replacing metal with polymer casings, with or without fibre reinforcement. Novel and compact heat exchangers using improved concepts, geometries and perhaps new materials like polymers will improve the charging and discharging process by increased heat transfer power and therefore reduce charging and discharging time and disturbances of the temperature stratification. Significant improvements on storage insulation will be achieved by the development of long lasting, low-cost and easy to apply high performance insulation materials like vacuum insulation. This will increase the overall system performance, the available storage volume (at the same gross volume of the storage including insulation) and the comfort for users by reduced room heating in summer. The performance of sensible TES will be further increased by improved charging and discharging as well as stratification devices. The integration of sensible TES into smart heating networks will be enabled by the inclusion of intelligent state of charge determination systems fully integrated in the storage.
State-of-the-art	The vast majority of today's storages are based on sensible thermal energy storage, using water as the storage medium and therefore a lot of different concepts, materials and technologies for insulating and charging and discharging of the storages are available. However, the available technologies are not satisfying regarding performance, flexibility and costs especially since thermal storage will become much more important in the heating and cooling sector by using renewable energies. The current limitations of sensible storage technology have a major impact given that a large number of water stores are deployed in combination with renewable energy technology such as solar thermal.
Targets	• 20% cost reduction of mass produced containment. • High performance insulation materials with 50% higher insulation effect than conventional materials and 70% lower cost than present vacuum insulation.
Type of activity	30% Basic research / 40% Development / 30% Demonstration

3.5.4 Research and innovation priorities for Thermal Energy Storage with impact in the Medium and Long Term

The medium to long term priorities for thermal energy storage R&D can be expressed along three thematic lines:
- reliable and efficient system performance of thermal storage;
- more efficient storage through improved heat transfer and heat transport;
- increased storage density using phase change materials and thermochemical materials.

The first line incorporates the integration and optimization of storage in the heating and cooling system, the second line aims at improving the main components in the storage auxiliary system and the third line is dependent on materials development and improvement.

CCT.7	Improving the efficiency of combined thermal energy transfer and storage
Objective	Further development and improvement of fluids that combine the heat transfer function with thermal energy storage. These will lead to smaller required storage volumes, to an increase in heat transfer efficiency and to a reduction in auxiliary energy for pumping.
State-of-the-art	Low-viscosity, non-corrosive fluids capable of storing large quantities of heat and able to work at low pressure are needed for the next generation of TES systems. For medium temperatures, molten salts could offer the ultimate solution. For low temperatures, additional research is needed on PCM slurries and PCM emulsions as well as demonstration of innovative concepts for cooling in buildings with ice slurries.
Targets	• PCM slurries or emulsion with long lifetime, reducing the pumping energy with 25% with respect to a conventional water based heat transfer fluid system. • A reduction of 20% of the storage volume through the use of PCM heat transfer fluids for room heating.
Type of activity	20% Research / 40% Development / 40% Demonstration

CCT.8	Increased storage density using phase change materials (PCM) and thermochemical materials (TCM)
Objective	To increase the storage density of TES based on PCM or TCM in order to enable the implementation of TES in applications with less available volume and to enable the cost-effective long-term storage of renewable heat. Nevertheless, to be effectively applied in heating and cooling systems, the technology should be improved as follows: • Further increasing the storage density to make it possible to integrate PCMs into buildings and thermal energy systems. For building-integrated applications, encapsulation and stabilisation, particularly of salt hydrate PCMs will be important. • Increasing the rate of heat discharge from PCMs that can be used for DHW production. • Finding solutions for problems such as subcooling (with the use of nucleators), phase separation, and hysteresis, typical when inorganic materials, such as salt hydrates, are used. (The use of inorganic materials avoids the fire risk of organic materials such as paraffin.) • Developing microencapsulated PCM for 300 °C<T<1,000 °C. • Developing new materials and/or mixtures that adjust the melting temperature, that is, that have several phase change temperatures, or that change their phase change temperature if stimulated to do so. • Developing heat exchangers that can also encapsulate the PCM. In order to optimise the performance of TCM, activities should focus on: • Development of testing and characterisation techniques for thermochemical materials, including new techniques to determine the state of charge • Design and optimisation of specific charging and discharging technologies • Large scale domestic stores to assess economic viability, construction and installation issues, and manufacturing efficiencies • New concepts to combine solar collector and thermochemical reactor.
State-of-the-art	Phase-change heat storage can be used widely at a reasonable cost[49]. Its main advantages are higher energy density, simplicity in system design and the delivery of heat at constant temperature. Thermochemical materials have the highest energy storage density and are seen as key materials for achieving loss-free thermal storages, also for long-term compact storage. The first generation of thermochemical materials are now being applied in system concepts.
Targets	• New heat exchangers with PCM included. • Energy output: 10 kW • Energy density: 60 kWh/m^3_{system} • TCM target: 4 times more compact than water at system level • Novel TC solar collector: first prototypes • Control of TCM systems: new sensors developed • Improved solar TCM solution for single-family houses
Type of activity	60% Research / 30% Development / 10% Demonstration

	Research and Innovation Priorities	Predominant type of activity	Impact
CCT.1	Cost competitive heat pump kit for houses with existing boiler	Development	By 2020
CCT.2	Optimisation of thermally driven heat pumps and their integration in the boundary system	Development	By 2020
CCT.3	Automation, control and long term reliability assessment	Development	By 2020
CCT.4	Development of a heat pump for near-zero energy buildings (single family house)	Development	By 2030
CCT.5	Next generation of highly integrated, compact hybrid systems	Development / Demonstration	By 2030
CCT.6	Next generation of Sensible Thermal Energy Storages	Development	By 2020
CCT.7	Improving the efficiency of combined thermal energy transfer and storage	Development	By 2030
CCT.8	Increased storage density using phase change materials (PCM) and thermochemical materials (TCM)	Research	By 2030

Table 6: research and innovation priorities for cross-cutting technology applications to residential buildings[50]

[49] Today salts are used with a cost of 700 €/ton, but paraffins at 6,000 €/ton are considered too expensive.

[50] It is important to note that advancements in TES technology are likely to be beneficial to any type of user and to have positive impact on RHC solutions for residential and non-residential buildings as well as for DHC and industrial processed. The research and innovation priorities presented in this Chapter are therefore fully applicable to the other sections of this publication.

3.6 Research and Innovation priorities with generic impact on RHC applications in the residential sector

Systems for the domestic sector must operate minimising human intervention. If intervention is required, it must be simple and easy. The main user requirements are comfort, reliability and low cost. The ideal building application for the domestic sector therefore must be small (but scalable), automatic, reliable and affordable.

Below are some items of relevance to all types of residential heating and cooling from RES that will help to improve system efficiency and ease of installation. These issues are related to the system level rather than to the single component level. While components often are tested and certified with specific procedures (e.g. the solar key mark for solar thermal collectors), such certification practices and schemes do not exist for overall heating and cooling systems.

The observed performance of installed systems in Europe is often below the expected level, and well below the theoretical performance. This tendency increases for complex systems and for hybrid systems. In order to improve the efficiency and longevity of installed systems, it is a priority to develop new industry standards and testing procedures.

RHC.1	Developing standards for the overall system design and for hydraulic and electrical interconnections of different building components
Objective	The main objective is to elaborate and validate new standards for the design and interconnection of RHC systems. In particular, these activities aim at: • ensuring cost-efficiency and interoperability • enabling low-cost, easy and fail-safe installation (plug and function or plug and flow) The expected outcome is a set of harmonised EU standards for the connection of renewable heating and cooling equipment and systems. This will unlock new market opportunities for manufacturers and system developers.
State-of-the-art	A lot of components in consumer-type RHC (i.e. in the residential sector) are still designed to national standards, company rules, or just individually hand-made. Also, different types of equipment can belong to different clusters of standardisation, preventing easy combination e.g. in hybrid systems. The interchange of components from different countries or manufacturers is thus limited, and designers as well as installers are confronted with challenges in interconnection.
Targets	Reduce the first cost of components and installation. Improve system functionality, reliability and longevity as well as inter-component compatibility.
Type of activity	25% Research / 50% Development / 25% Demonstration

RHC.2	Elaborating standards, tests, and benchmarks for system efficiency
Objective	In the residential sector, the need for standards in design and implementation is greatest. End users here do not have sufficient knowledge to judge design and implementation quality. Standards and standardised procedures need to be developed to ensure renewable heating and cooling systems are satisfactory in all aspects. Ideally, such procedures should be implemented in accordance with technical standards and for the certification of overall systems. Learning from driving cycle tests in the car industry, RHC system should also test by cycle, rather than by steady-state tests. Benchmarks have to be created to give end users and designers a judging system by which they can value its performance. Continuous monitoring campaigns are required to establish such benchmarks, but also to allow for feed-back on the success of R&D activities.
State-of-the-art	Consumers cannot effectively judge the appropriateness of design and the quality of installation. Comparing efficiency between different systems is difficult. There are no simple benchmarks to support such judgement. Existing tests reflect component performance under mostly steady-state conditions but not overall systems performance.
Targets	In collaboration with industry, define one or more reference tests to measure real life performance of RHC systems. Harmonise international test procedures to ensure transparency for comparison of RHC options. Produce a labelling scheme enabling end-users and manufacturers to evaluate and compare system performance, and by that create a pressure towards and market for more efficient systems.
Type of activity	25% Research / 50% Development / 25% Demonstration

4.
RHC applications and priorities for non-residential buildings

4.1 Description of demand characteristics

This sector includes a wide range of public and private non-residential buildings, such as offices, hotels, restaurants, shops, schools, universities, hospitals, data centres, swimming pools and various other services.

A recent study of the European Commission[51] estimated the annual demand in the EU of useful energy for space heating and for hot water at around 56 Mtoe (2,284 PJ) and 17 Mtoe (625 PJ), respectively. The estimated useful cooling demand is around 32 Mtoe (1,350 PJ) which represents only 30% of the total demand. According to the PRIMES model (EC DG ENER, 2010) the heating / cooling mix in the non-residential buildings will significantly change in the next years, ending up to 52% heating and 48% cooling.

In the services sector, the heating and cooling demand is strongly influenced by the type of building and its use. The characteristics differ from that of the residential sector in the following aspects:

- Loads are typically higher than in the residential sector, starting with some 10 kW_{th} for small businesses or offices, to 1 MW_{th} or more for larger projects
- Space cooling / air conditioning is almost a standard in this type of application, creating a definite requirement for providing cooling from renewable sources
- Forced ventilation is the norm in this type of buildings, resulting in a need for heating and cooling of ventilation
- There is in most cases a high internal heat generation, mainly in shops (lighting, refrigeration, etc.[52]), but also in other buildings (large number of persons, ICT-facilities, etc.)
- Heating and cooling loads can vary widely in a short timeframe (conference rooms / theatre / cinema, shopping or office hours, etc.)
- In many cases, DHW heating is not required (or it is negligible); notable exceptions are hotels, hospitals, sports/recreational facilities, where a large and sudden demand for DHW can occur (e.g. showering in the morning or after sports events)

In consequence, the RHC technologies to cover this demand must be rather flexible in size, adaptive to quick changes, and able to supply substantial amounts of cooling to the buildings. The system concepts are more complex, with a combination of several heat- and cold sources and distribution devices. Digital energy control systems of buildings are required for the optimum operation of these installations, both for comfort and for efficiency reasons. On the other hand, professional operation and maintenance in this type of application can be more easily guaranteed here than in the residential sector.

4.2 Solar thermal technologies

In general, the service sector requires larger solar thermal systems, which allow economies of scale but also imply customised planning. The complexity in the design and installation of such systems is higher. Moreover, safety requirements are more demanding, e.g. by dealing with steam in the system. The efficiency of the solar thermal system depends a lot on the demand curve and the temperature requirements, e.g. solar thermal systems are well suited to supply the high volume of hot water consumed during the whole year by hotels, hospitals and homes for elderly people.

Most of the demand for cooling in the service sector is currently supplied by electrical systems. Thermally driven cooling technologies constitute promising alternatives and are set to play a key role in the efficient conversion of energy in the field of building air-conditioning and refrigeration, especially in southern Europe. Today, these technologies are used largely in combination with waste heat, district heat or co-generation units. Thermally driven cooling cycles can be run with solar thermal energy too, thus producing solar air-conditioning and refrigeration. In climates where cooling is not required all year round, these systems can be used for cooling in the summer season and for space heating in the heating season.

[51] Pardo, N. et al (2012)

[52] Some shopping malls do not have any heating demand under normal operating conditions, even in moderate climate.

4.2.1 Research and innovation priorities with impact in the Short Term

R&D priorities for solar heating and cooling systems in non-residential buildings aim at simplifying installation, improving integration, increasing stability, reliability and long-term performance. Enabling a higher share of solar collectors to be integrated into the building envelope is also a priority. The improvement of thermally driven cooling components deserves special attention.

ST.6	Multifunctional building components, including façade and roof integrated collectors, for new and existing buildings
Objective	Solar thermal systems will be integrated into the building envelope by means of multifunctional components. Collectors, storage and other components will become structural elements fulfilling multiple functions in the building, such as heat generation, storage and distribution as well as static function. They will optimise the use of passive and active solar energy in the building, generating heat, regulating the building temperature, distributing and storing heat and cold. Some building components will become itself part of the heating and cooling system, with improved aesthetics and integration of multifunctional components fulfilling the requirements of buildings regarding security and maintenance.
State-of-the-art	Today, solar thermal system components are – as the heating and cooling equipment in general – separated from the building components. Only the concrete core activation for heat and cold distribution is increasingly used. The solar collector is usually installed with a small distance to the roof tiles, however it is sometimes already integrated in the roof or in the façade with multiple functionality, such as insulation and protection against the weather elements. Some pilot installations have been realised using prefabricated integrated solar façades, with a solar collector on the outside, a heat distribution system on the inside and a heat store in between.
Targets	Development of multifunctional solar elements, which will be used as building components, e.g. solar collectors as roof and façade elements and building walls as heat stores with multiple functionalities and high flexibility regarding the architectural integration available in the market by 2020. Availability of prefabricated multifunctional solar façade systems for energy-related refurbishment of existing buildings.
Type of activity	20% Research / 50% Development / 30% Demonstration

ST.7	Highly efficient solar assisted cooling systems combining heating and cooling
Objective	The main research regarding cooling components will focus on developing technical solutions to make the systems more economically attractive and well performing on a long-term basis. For the first criteria, plug and function systems will be developed so as to decrease installation cost. These systems will require hydraulic configurations as simple as possible when at the same time leading to very low primary energy consumption when coupled with back up. Specific building applications will be identified so as to maximise the solar energy usability all year long as well on cooling as heating (space and DHW). Specific developments are expected on the adaptation of solar system to low parasitic consumption through new heat rejection concepts and on system architecture leading to very low cost for operation and maintenance. Finally lots of effort should be devoted to the development of packaged solutions reducing installation hassle and increasing the level of standardisation of solar cooling systems, either they are small, medium and even large capacity.
State-of-the-art	In 2011 about 750 solar cooling systems were installed worldwide, including installations with small capacity (less than 20kW)[53]. Due to the large number of system components, i.e. cooling equipment, solar collectors and heat storage appliances, which are not optimized yet, the investment costs are high and solar thermal cooling systems are not yet cost-competitive with conventional electrically-driven cooling systems.
Targets	Overall efficiency (in equivalent power consumption) of the solar system for heating and cooling of more than 10 (COP) and solar cooling system costs halved by 2020.
Type of activity	30 % Research / 40% Development / 30% Demonstration

4.2.2 Research and innovation priorities with impact in the Medium and Long Term

Solar thermal applications to the service sector have a significant potential in the Medium to Long Term. Research activities should focus on the following priorities:

- Development of cost effective **solar based hybrid systems for 100% renewable heat solutions (ST.8)** leading to solar fractions above 50%. These system concepts are particularly suitable to replace conventional heating systems of swimming pools, carwash facilities and other application characterised by constant daily heat demand through the year with only week-end breaks.
- **Research on new absorption and adsorption chillers (ST.9)**. The performance of solar air conditioning and refrigeration systems can be increased considerably due to higher temperature of heat rejection in new absorption and adsorption chillers, as well as new desiccant and evaporative cooling concepts (solid and liquid desiccant sorption systems).

[53] Mugnier & Jakob (2012).

	Research and Innovation Priorities	Predominant type of activity	Impact
ST.6	Multifunctional building components, including façade and roof integrated collectors, for new and existing buildings	Development	By 2020
ST.7	Highly efficient solar assisted cooling systems combining heating and cooling	Development	By 2020
ST.8	Solar based hybrid systems for 100% renewable heat solutions	Research	By 2030
ST.9	Research on new absorption and adsorption chillers	Research	By 2030

Table 7: research and innovation priorities for solar thermal applications to non-residential buildings

4.3 **Biomass technologies**

There are a variety of biomass boiler technologies available to provide energy for heating and sanitary water to the service sector at very competitive costs. Rated thermal loads for the service sector range from a few tens of kW up to the low MW range. Wood chips, pellets and other locally available biomass residues are applicable as fuels. The boilers are installed either as single boiler solution or in cascades. When implemented in bi- or multivalent installations (these are installations using multiple energy carriers), biomass boilers are usually providing the base load energy supply for economic reasons.

For applications requiring a couple of 100 kW and smaller scaled rated loads, CHPs are potentially interesting and economically feasible technology options if a reasonable number of operating hours is achieved. Also, biomass-based cooling with absorption and adsorption chillers are viable technology options.

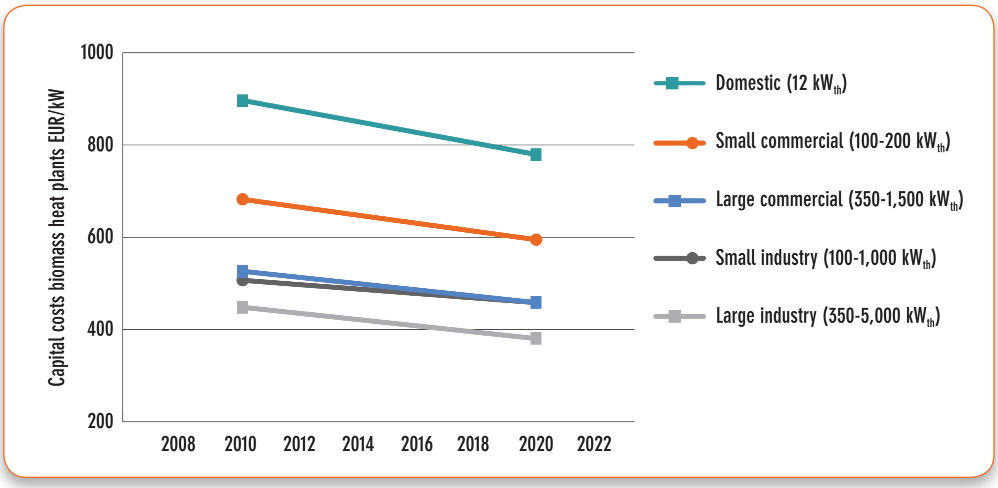


Figure 28: potential evolution of capital costs for biomass heat plants (adapted from IEA 2012b)

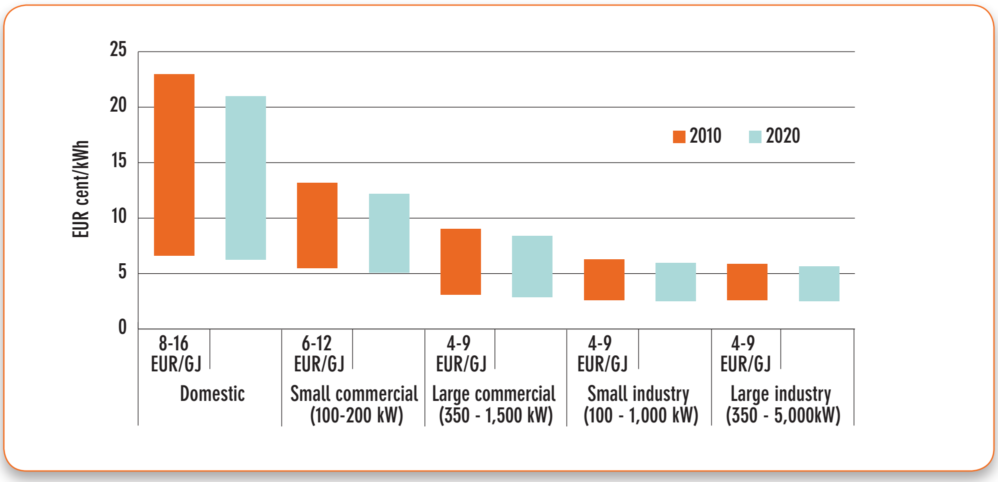


Figure 29: Biomass heat production costs in 2010 and 2020 (adapted from IEA 2012b)

4.3.1 Research and innovation priorities with impact in the Short Term

As biomass technologies covering the heat and sanitary water demand of the service sector become increasingly competitive, more demonstration projects are needed to create confidence and to spur Europe-wide diffusion. The main challenges are in the development and demonstration of cost-efficient and energy-efficient system concepts, which make use of different technologies for RHC in bi- or multivalent (hybrid) systems. Intelligent system design and effective heat storage are key priorities for efficiency improvements. Another core element is the development of integrated, plug & play control technology optimised for the integrated use of other renewable energy technologies and relevant components.

Whilst the above is mostly related to cross-cutting topics, the main challenges related only to biomass technology are the development of cost-effective solutions to reduce dust emissions and the development of small scale CHPs.

BIO.6	Cost effective solutions to reduce dust emissions
Objective	In order to overcome the tightening of air quality requirements, secondary measures to reduce dust emissions will be required in the future. Therefore, reliable and cost-effective PM abatement technologies for applications of roughly 100 to 500 kW_{th} are to be developed and demonstrated. These can either be fabric filters, electrostatic precipitators (ESPs) or scrubbers and/or condensers. Whilst sophisticated combustion systems for high-quality fuels should be able to withstand tighter air quality requirements with primary measures only, combustion of lower grade woody, non woody, RDF and pre-treated fuels will require the use of secondary measures. Their application must be able to show a clear economic trade off between increased investments and fuel cost savings.
State-of-the-art	PM abatement technology is state-of-the-art for biomass plants of 500 kW nominal thermal loads and more. Typical investment costs for existing PM abatement technologies are about 1/3 of the total investment costs of the biomass plant. For the thermal load range of 100 to 500 kW, there are no proven economically viable technologies available so far. Several technologies (bag house filters, fabric filters, ESPs, scrubbers) are under development and/or under demonstration, or just appearing on the market now. No technology has reached successful commercialisation so far.
Targets	Technological goals are to reliably achieve clean gas concentrations complying with the relevant air quality requirements with a successful decoupling of abatement technology and boiler performance, and a maintenance-free operation. In order to become viable technology options, investment costs have to be reduced by roughly 25%. To do so, new production technologies for serial production of PM abatement technology is necessary.
Type of activity	40 % Development / 60% Demonstration

BIO.7	Cogeneration technologies and small scale biomass gasification technologies
Objective	The objective is to develop and demonstrate technologically reliable and economically competitive cogeneration technologies in an electric nominal power range of roughly 10 to 250 kW electric. The technological options to be validated are Stirling engine, steam engine, ORC, and externally fired gas turbines based on biomass combustion, as well as internal combustion engines (IC) or small-scale gas turbines using syngas from biomass gasification. Whilst for the combustion-based concepts it will be crucial to develop heat transfer concepts that avoid deposit formation on and fouling of heat exchangers, syngas quality will be crucial for the success of gasification-based cogeneration concepts. The latter will require the further development of small-scale gasification concepts and the development of cost-effective syngas cleaning technology to overcome tar problems. Applicable fuels range from wood pellets for the smaller scale technologies, up to low grade wood chips or even locally available non-wood or pre-treated biomass fuels derived from waste streams for the technologies on the upper electric output range considered. For the demonstration stage applications allowing for an expected required minimum of 5,000 hours of full load operation and a higher tolerance regarding different fuel qualities must be identified. Heat use for heating purposes or for thermal cooling must be ensured.
State-of-the-art	So far, only IC concepts using biogas and / or biodiesel are commercially available in the concerned scale. Solid biomass-based cogeneration technologies are not commercially available yet. Several concepts, based both on biomass combustion as well as on gasification are under development however no technological breakthroughs have been achieved in recent years.
Targets	Economic viability and cost competitiveness without the need of subsidies by 2020 (assuming reference oil price of 100$ per barrel)
Type of activity	25% Research / 50% Development / 25% Demonstration

4.3.2 Research and innovation priorities with impact in the Medium and Long Term

The development of new types of biomass fuels could have a significant Medium and Long Term impact. Research activities should focus on the following priority:

- Development of advanced **cost-efficient high quality solid and liquid biomass fuels** from agro-biomass, bio-degradable waste, forestry and aquatic biomass (**BIO.8**). Smart and sustainable supply chains should be demonstrated in all climatic regions of Europe, including improvements in biomass fuels storability, drying and logistics.

	Research and Innovation Priorities	Predominant type of activity	Impact
BIO.6	Cost effective solutions to reduce dust emissions	Demonstration	By 2020
BIO.7	Cogeneration technologies and small scale biomass gasification technologies	Development	By 2020
BIO.8	Development of advanced cost-efficient high quality solid and liquid biomass fuels from agro-biomass, bio-degradable waste, forestry and aquatic biomass	Development/ Demonstration	By 2030

Table 8: research and innovation priorities for Bioenergy applications to non-residential buildings

4.4 Geothermal technologies

In the services sector, shallow geothermal energy systems (ground source heat pumps or underground thermal energy storage) is the most relevant technology, ranging in capacity from some 10 kW_{th} for small businesses or offices, to 1 MW_{th} or more for larger projects. The ability to provide both heat and cold is the major asset for shallow geothermal technologies in this sector. Systems will generally be more complex than those for the residential sector, and the geothermal system in most cases will be combined with other technologies, creating hybrid systems.

Also deep geothermal energy (i.e. from boreholes deeper than 400m, or from high enthalpy geothermal resources) might be applicable in cases with higher heat demand. Many thermal spas have for a long time used geothermal heat for heating. Large offices, hospitals, etc. can use deep geothermal heat. The relevant R&D-needs are included in Chapter 6 on district heating.

For the cost, the same basic facts as reported in Chapter 3 apply. However, in the non-residential sector, the economy of plants usually is better, as a significant demand for cooling adds to the running time of the system, and also scale effects reduce specific first cost to less than 70 % of the specific cost of smaller, residential systems. Generally less than 50 % of the cost goes into the underground works on these shallow geothermal installations.

4.4.1 Research and innovation priorities with impact in the Short Term

The main R&D needs and priorities are similar to the issues raised for residential heating-cooling activities. The specific challenges in the services sector arise from the complexity of these systems and their varying demand, and from the size of the required ground coupling installation able to meet the higher capacities without exceeding the given limitations in available ground area.

Typically, buildings in the service sector require both heating and cooling. Nonetheless, certain buildings only express a cooling demand. Thus the underground must be operated not only as a renewable heat source, but also as a storage device for heat and cold.

GEO.4	System concepts and applications for geothermal cooling in warm climates
Objective	Shallow geothermal energy offers advantages for cooling using the ground as a heat sink. However, this by now is mainly limited to Northern and Moderate climates with a pronounced summer/winter temperature swing. In warm climates or in the case of applications mostly used for cooling, additional re-cooling of the ground, hybrid systems, and short-term storage options etc. need to be developed in order to allow for sufficient share of cooling from the ground
State-of-the-art	Cooling in shallow geothermal systems has started in areas with colder climates, where adding this feature is relatively simple on the side of the resource. Numerous good systems show that the concept works well under these conditions. Unfortunately, the highest cooling demand is in warmer climates, where ground temperatures are higher naturally, and design for high shares of cooling is more of a challenge.
Targets	• Allow shallow geothermal cooling for regions and applications not suitable by now, increase regional range of applicability to all Europe. • Increase efficiency of cooling in warm climate by 25%
Type of activity	60% Development / 40% Demonstration

GEO.5	Development of ground coupling technologies and installation techniques for high capacities
Objective	With the larger capacities required, and with the restricted area available on most building plots, improved ground coupling technologies must be developed, e.g. deeper BHE, BHE under buildings, "geoactive structures" (energy piles, parts of the building foundation as heat exchangers), or other technologies. For the work on larger construction sites, time and space restrictions are a major problem. Improved drilling and installation techniques should be developed for work under these conditions, also taking advantage of possible synergies by having several drill rigs working at the same site.
State-of-the-art	Most drilling rigs and installation equipment for BHE, groundwater wells etc. are designed for a limited number of boreholes at one spot. For larger buildings, more rigs and the related number of skilled personnel are required. An understanding for the potential for automatisation of all processes has just started to grow.
Targets	Allow drilling and installation in shorter time than today, and at sites with more limitations in area. Increase the potential for automatisation in the drilling and installation process.
Type of activity	30 % Development / 70% Demonstration

4.4.2 Research and innovation priorities with impact in the Medium and Long Term

GEO.6	Integration of design of the shallow geothermal system and building energy system with regard to optimum thermal use and operational strategy
Objective	Heat transport in the underground is relatively slow, while building energy systems require a prompt response. These characteristics can be matched by integrative design. However, the majority of geothermal heat pump systems today are planned in the classical way of the HVAC industry, by adding different components for heating and cooling to meet the required thermal capacities. For an optimum geothermal system, on the contrary, a holistic approach must be taken, including the geothermal part, the conventional technology, and the whole building and its intended use. In the case of most larger buildings, the geothermal system will be designed to cover as much as possible of the base load for heat and cold, being supplemented by other sources. The goal of design and development should be to ensure maximum contribution from geothermal (and other renewable) sources. Integrative design and construction approaches are required to optimise the common operation of the different system components, and storage and/or heat pumps are required to bridge gaps in capacity or temperature. Improved ICT technologies (central digital building control, building automation systems) are crucial for operating these systems.
State-of-the-art	In most cases geothermal systems today are designed as an add-on to conventional project design in an advanced stage. So the geothermal technology just can try to adapt to the demand as created by the planned project, and no adjustment of other parameters towards optimum overall system concepts is possible. A change in practice and availability the necessary tools and structures for site investigation and design could create a leap forward in system efficiency.
Targets	• Increase system efficiency by 25 % and pursue a target of 100 % RES for the overall heating and cooling system. • Improve system reliability and operation stability.
Type of activity	75% Development / 25% Demonstration

	Research and Innovation Priorities	Predominant type of activity	Impact
GEO.4	System concepts and applications for geothermal cooling in warm climates	Development	By 2020
GEO.5	Development of ground coupling technologies and installation techniques for high capacities	Demonstration	By 2020
GEO.6	Integration of design of the shallow geothermal system and building energy system with regard to optimum thermal use and operational strategy	Development	By 2030

Table 9: research and innovation priorities for geothermal applications to non-residential buildings

4.5 Cross-cutting technologies

In **large non-residential buildings** (public buildings, commercial malls, hospitals, offices, hotels...) it is often advantageous to use central systems in order to increase the size of the equipment, exploit at maximum the available resources by integration with other energy systems and sources and run under optimal conditions. This is a good application for new heat pump solutions since it is a market in which the European manufacturers keep a strong position with their technology for hot/chilled water production, and still hold a great share of the market. In this segment both air, water and ground coupled heat pumps can be a very efficient solution.

Future research on heat pump technology should aim at high efficiency heat pumps/chillers, working with low Global Warming Potential (GWP) refrigerants, preferably natural, with minimum charge and tight containment, and featuring efficient capacity modulation as well as the highest capabilities for combination and integration with other energy systems.

Within large non-residential buildings the energy system used is often a combination of different units and different technologies. The choice of installing a hybrid solution instead that a system using a single energy source usually does not affect the price of the large-scale system as much as it does for the small-scale ones. There is a need for the development of new decision support tools for these large-scale systems. Improvements are sought in the automation, system hydraulics as well as in the parasitic components (e.g. heat rejection units).

The same research and innovation priorities presented for Thermal Energy Storage in residential buildings have an impact also on heating and cooling applications in the service sector.

4.5.1 Research and innovation priorities for Heat Pump technology and Hybrid Systems with impact in the Short Term

CCT.9	High capacity heat pump for simultaneous production of cold and hot water for heating/cooling the building
Objective	Development of a high efficiency, high capacity heat pump solution for heating and cooling of buildings with simultaneous production of hot water for space-heating and chilled water for cooling. Among the solutions to be explored, the system could operate by automatically changing the refrigerant circuit in order to reject/take the necessary heat to/from the air or the neutral temperature loop of the building (air and water versions of the heat pump). Additionally, the heat pump should preferably employ a low GWP refrigerant and offer competitive cost, high reliability, optimised control and easy integration with other systems.
State-of-the-art	A few European manufacturers have recently announced this kind of heat pump. An improvement of reliability and efficiency is required
Targets	Capacity around 100 kW, sCOP around 10 for production of hot water at 40 °C and chilled water at 10 °C. Minimum refrigerant charge.
Type of activity	10% Research / 60% Development / 30% Demonstration

CCT.10	Integration, automation and control of large scale hybrid systems for non-residential buildings

Objective	Efforts should be put into developing large (>100kW) hybrid systems with the following characteristics:
	• Improved efficiency through:
	  • well-designed systems (good hydraulic layout, exergetic optimization,…);
	  • control systems that optimise the energy consumption and take advantage of the availability of renewable energy (optimise solar gain, increase sCOP, increase mean system efficiency,…);
	  • embedded equipment for energy monitoring to have a clear picture of the energy production, cost of primary energy consumed and amounts of GHG emitted;
	  • more rapid failure detection, signalled, for example, by excessive primary energy consumption and notification of the user and or service company
	• Weather forecast, based on local observation and/or services available by internet.
	• Heating/Cooling and DHW load forecast, based on the learning of system operation and occupants' behaviour.
	• New processing algorithms to supervise the complete system (adaptive control, learning process, etc.) while maintaining a high degree of comfort and a low consumption of auxiliary electricity
	• Load shift potential to be used only with storages (buffer storages, building envelope used as thermal storage)
	• Smart grid integration
	• Development of new business models and load shift tariffs

State-of-the-art	A few demo projects exist; system efficiencies are rather low compared to single technologies due to poor performance of control, failure detection, etc.
Targets	Payback time of 5 to 7 years of the additional investment cost for the hybrid system compared to a standalone solution due to the optimum use of RES and the use of flexible energy tariffs.
Type of activity	50% Development / 50% Demonstration

4.5.2 Research and innovation priorities for Heat Pump technology and Hybrid Systems with impact in the Medium and Long Term

CCT.11	Sorption cooling systems driven by hot water at moderate temperature
Objective	The development of new or improved sorption systems for production of chilled water for cooling of buildings driven by low temperature heat sources, as for instance solar. The expected outcome also includes the development of optimised solutions for the heat rejection, fully reliable and automatised operation, and easy integration with other systems.
State-of-the-art	Sorption technology has significantly improved in the past years. However an increase in the efficiency of the whole system, including heat rejection and auxiliaries, and an increase in reliability need to be carried out to improve its application potential in the mentioned sector.
Targets	• Capacity around 100 kW and temperature of the hot source ranging from 60 to 90 °C the system should achieve at least a sCOP value of 0.7. • Payback period of the investment must be less than 8 years, also in comparison with an electrical chiller.
Type of activity	20% Research / 50% Development / 30% Demonstration

	Research and Innovation Priorities	Predominant type of activity	Impact
CCT.9	High capacity heat pump for simultaneous production of cold and hot water for heating/cooling the building	Development	By 2020
CCT.10	Integration, automation and control of large scale hybrid systems for non-residential buildings	Development / Demonstration	By 2020
CCT.11	Sorption cooling systems driven by hot water at moderate temperature	Development	By 2030

Table 10: research and innovation priorities for cross-cutting technology applications to non-residential buildings

5.
RHC applications to industrial processes

5.1 **Description of demand characteristics**

Heat consumption for industrial processes represents a significant share of the total annual heat demand in the EU[54]. The IEA estimates that in Europe in 2010 heat demand for industrial processes was 165 Mtoe[55]. The vast majority of this energy is produced by the combustion of fossil fuels, with a huge impact in terms of greenhouse gas emissions.

Industrial heat demand varies by temperature levels, sectors, countries, and energy supply, since many different industrial processes appear and the energy supply can differ from country to country due to local conditions. Three different temperature levels are used here for describing the quality of the demand for heat to be used in various industries:

- Low temperature level is defined as up to 95°C, corresponding to the typical heat demands for space heating. According to the study Ecoheatcool (2006), around 30% of total industrial heat demand is required at temperatures below 100°C Low temperature heat is needed for industrial processes like washing, rinsing, and food preparation. Some heat is also used for space heating and on-site hot water preparation.
- Temperatures between 95ºC and 250ºC are defined "medium". This heat is normally supplied through steam. The purpose is often to evaporate or to dry. The Ecoheatcool study shows that 27% industrial heat demand is for temperatures between 100°C and 400°C, which includes the classifications "medium-" and "high-temperature" heat.
- Temperatures over 250ºC are "high" and needed for the manufacture of metals, ceramics, and glass etc. Temperatures above 400°C can be created by using hot flue gases, electric induction, or other combustion processes.

Figure 30 provides a view of the distribution of industrial heat demand by temperature levels in Europe, as estimated by the IEA[56]. The graph also shows the expected trend of heat demand until 2050, assuming efficiency gains could be realised in each of these realms[57].

Figure 31 illustrates the breakdown of heat consumption by industry and by temperature levels as identified by the Ecoheatcool. Different renewable energy technologies can provide heat at Low and Medium temperature levels, as summarised in Figure 32. In the short term, few renewable energy technologies, such as biogas, can provide heat at temperatures above 250 ºC at costs competitive with fossil fuel alternatives. In future, high temperature solar thermal collectors and deep geothermal technology may effectively supply these needs. Strategic research priorities for high temperature renewable heat supply are therefore presented in the following Sections of this Chapter.

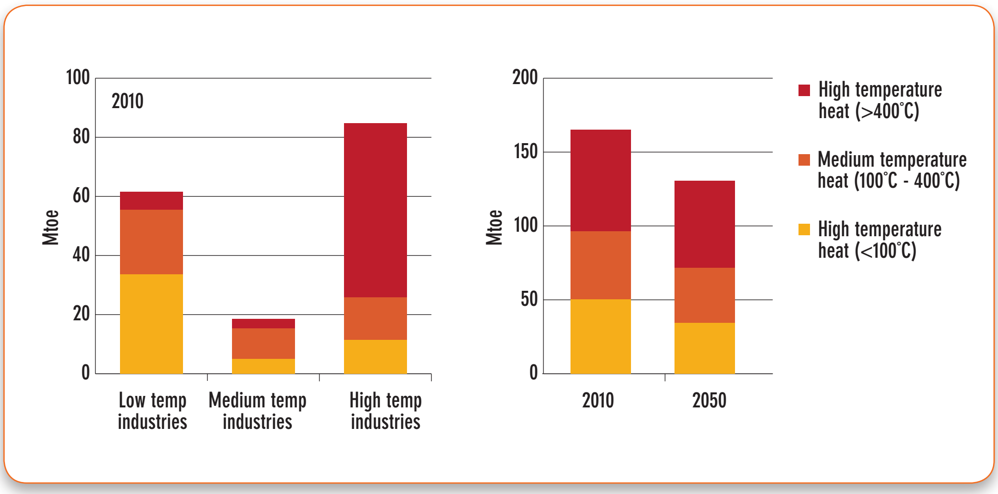


Figure 30: Industrial heat demand by temperature level in the EU in 2010 (left) and industrial heat demand in the EU in 2010 and expected demand in 2050 (right). Source: OECD / IEA (2012).

[54] According to W. Weiss et al (2009), the needs of industrial heat users make up to 44% of the heat market.

[55] OECD / IEA (2012).

[56] See footnote 55.

[57] Note that the temperature levels used by the IEA and shown in figures 30-31 are different from those used in this publication.

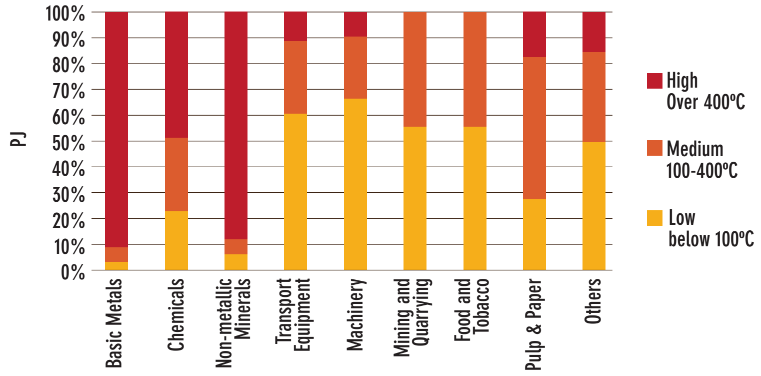


Figure 31: Industrial heat demand by temperature level and industrial sector[58]

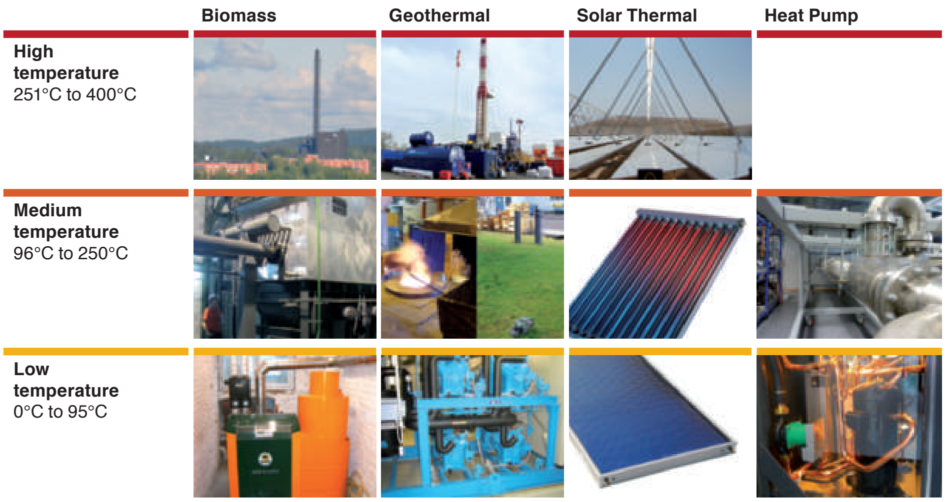


Figure 32: renewable energy supply technologies which meet the requirements of heat demand for industrial processes at different temperature levels.

5.2 Solar thermal technologies

The use of solar thermal energy in the industrial sector is currently insignificant compared to other applications. Only about 200 solar thermal plants are installed worldwide at industrial sites, with a total installed capacity of 42 MW_{th} (60,000 m^2), even though this application has a huge technical and commercial potential. The industrial heat demand, including process heat, space heating, and hot water accounts for 75% of industry's final energy consumption.

Much of the heat demand below 100°C could theoretically be met with solar thermal systems using current technologies, if suitable integration of the solar thermal system can be identified. With technological development, more and more high temperature applications between 250°C and 400°C will also become commercially feasible.

In several specific industry sectors, such as food, wine and beverages, transport equipment, machinery, textiles, pulp and paper, the share of heat demand at low and medium temperatures is around 60% (POSHIP 2001). Solar thermal could contribute here.

Due to their size and because they must be adapted to each specific application, large-scale systems for industrial process heat are custom-designed. Small-scale systems can be pre-fabricated to a greater extent.

[58] Ecoheatcool (2006).

5.2.1 Research and innovation priorities with impact in the Short Term

ST.10	Medium temperature collectors developed and demonstrated in industrial applications
Objective	Using solar thermal collectors in medium and high temperature (100°C–400°C) systems imposes constraints on collectors. Applied research should result in the development of new, high temperature-resistant materials, as well as new collector designs. the following aspects are particularly important : • Adapting and improving collector technology (flat-plate and evacuated tube) which is currently used in low-temperature applications (e.g. either through better insulation or noble gas atmospheres); or, • Developing specific concentrating collectors using light-weight, stable, highly performing and dirt-proof or self-cleaning reflectors which are resistant to degradation due to mechanical cleaning and weathering. Moreover, cost-effective fixing systems are needed for specific installation and maintenance requirements of large-scale applications.
State-of-the-art	Pilot solar systems used for industrial process heat are available in Europe. Many systems for industrial heat are configured to work at higher temperatures than the process would require. Today, arrays of flat plate collectors constitute the majority of the installed capacity due to cost, reliability and modularity reasons. However the use is limited to low temperature processes.
Targets	50% cost reduction on installed collector with increased reliability (lower O&M costs).
Type of activity	10% Research / 50% Development / 40% Demonstration

5.2.2 Research and innovation priorities with impact in the Medium and Long Term

Turn-key **solar thermal process heat systems (ST.11)**. R&D is needed to analyse and optimise medium and high temperature industrial processes to allow new applications of solar thermal technology. Innovative schemes should be investigated for the integration of steam generated by medium-temperature collectors in the production process and distribution network.

	Research and Innovation Priorities	Predominant type of activity	Impact
ST.10	Optimize large-scale solar collector arrays for uniform flow distribution and low pumping power	Development	By 2020
ST.11	Turn-key solar thermal process heat systems	Research	By 2030

Table 11: research and innovation priorities for solar thermal applications to industrial processes

5.3 Biomass technology

Bioenergy co-generation (CHP) as well as tri-generation (heat-power-cold) are interesting concepts to supply direct renewable heat to most industrial processes. Unit costs of bioenergy plants are inversely related with system's size (Figure 33), so larger systems which typically supply their energy to singular industrial heat consumers are generally more cost-efficient than small ones.

Biomass plays a specific role among RES as storable energy source. Bioenergy therefore presents a real advantage when considering its integration in the overall renewable energy system. Besides the production of heating and cooling, CHP (combined heat and power) and tri-generation or CHP-C (combined heat, power and cooling) technologies are able to supply intermittent electricity, balancing both daily and seasonal changes in solar and wind electricity production.

	Conversion Technology				
	Units	FBC	IGCC	D. comb	Ind. comb
Efficiency	%	30	38	31	31
Total Capital Required	mil. €	39	54	2	27
Electricity Prod. Cost*	€/MWh	49	51	33	52
Payback Period	years	8	9	1	7

Figure 33: investment costs related to different large-scale conversion technologies[59].

[59] Biomass input = 80 MW_{th}, same boundary conditions for all conversion technologies. FBC: fluidized bed combustion, IGCC: integrated gasification combined cycle, D.comb: Direct Co-Combustion with Coal, Ind.comb: Indirect Co-Combustion with Coal. Source: Lehrstuhl für Energiesysteme.

5.3.1 Research and innovation priorities with impact in the Short Term

R&D activities on biomass technology for industrial heating and cooling should focus on improving efficiency of large-scale plants and decreasing their carbon footprint. Taking into account the increasing emissions standards and the limited availability of high quality wood resources in Europe, significant R&D efforts are required to develop high-efficient load-flexible multi-fuel systems. Fuel supply will become a crucial issue and R&D activities should therefore always consider the chain integration.

Tri-generation with biomass presents various advantages which make it an interesting solution in different energy systems. Biomass is storable renewable energy and can be used for regulating electricity production. Moreover, biomass can be used for heating, cooling and electricity production with system efficiency of up to 85%.

BIO.9	**Development of highly efficient large-scale or industrial CHP with enhanced availability and high temperature heat potential**
Objective	The aim of this priority is to increase the steam data, i.e. pressure and temperature (advanced steam data), from 540°C to 600°C for 100% biomass-fired plants. Biomass and/or biomass co-firing power plants should increasingly utilise waste heat for industrial heat utilisation. Alternative technology options, e.g. biomass gasification and indirect co-firing, should be investigated. Process adaptations of fuel pretreatment are required, e.g. torrefaction to reduce alkaline content of biomass and improve grindability[60]. Corrosion, fouling and agglomeration (in Fluidised Beds (FBs)) from alkali metal chlorides and heavy metals (Pb, Zn, etc) in biomass-fired plants and co-firing units should be reduced by: • R&D of new materials (austenitic alloys, Ferritic alloys, FeCrAl alloys, Ceramics) suitable for combustion of problematic biomass types, tackling problems such as creeping, cracking, Thermal Mechanical Fatigue (TMF) , corrosion, erosion, fouling; • Development and testing of new additives that result in the formation of less corrosive substances: (i) sulphur containing additives: ammonium sulphate, elemental sulphur, sulfur granules, (ii) phosphorous containing additives: dicalcium phosphate, monocalium phosphate and (iii) AlSi containing additives: kaolin, dolomite, bentonite; • Development and testing of suitable co-firing matrices for problematic biomass fuels, e.g. co-firing high alkali metal-containing biomass with high sulphur fuels; • Demonstration of new types of boiler design that minimize fouling/corrosion in critical areas, e.g. changes of excess oxygen, flue gas temperature and velocities.
State-of-the-art	CHP units fuelled with biomass only currently reach a net electrical efficiency around 30% and this performance is increased to over 43% for co-firing plants. Steam temperature amount to 540°C for clean biomass. Thermal shares of agrobiomass and/or RDF are limited to 20% and in most cases do not exceed 10%. The majority of large-scale plants produce power only, the heat is wasted.
Targets	• Demonstration of a highly efficient (>40 %) steam CHP-plant for clean fuel fractions with enhanced steam parameters (up to 600°C); • Demonstration of a high efficient steam (34%) CHP-plant for broader fuel span with enhanced steam parameters (up to 540°C); • Demonstration of a high efficiency biomass and/or co-firing power plant with an agrobiomass and/or RDF thermal share of 30%; • Total CAPEX and OPEX increase of no more than 5-10% over current state of the art for new technologies; • 1-2 demonstrations of power plants producing only electricity converted to CHP units for provision of industrial heat;
Type of activity	30% Development / 70% Demonstration

5.3.2 Research and innovation priorities with impact in the Medium and Long Term

BIO.10	**Development of high efficient biomass conversion systems for tri-generation (heating, cooling and power)**
Objective	In this R&D priority the main mission is to analyse and identify the role of biomass as a “storable RES” within a 100% renewable energy system, particularly in combination with intermittent RES such as solar and wind. The new tri-generation operating environment requires new, simultaneous functions and capabilities from the biomass CHP-C units: flexible load operation, fuel flexibility as well as operation in integration with energy storages. Specific technologies to increase the intelligence of multi-fuel units must be identified and developed including on-line fuel quality and process monitoring; as well as introducing fertiliser factories in order to fully recycle the ash-bound biomass nutrients back to the fields and forests. The system analysis requires the development of dynamic models that can simulate the daily and seasonal behaviour of urban energy system in different climatic conditions. Depending upon the season, climatic condition and time of day the primary function of such biomass fuelled units may change from electricity, heating, cooling to even bio-oil production (for example with integrated pyrolysis oil production).

[60] Higher Hardgrove Grindability Index (HGI) in order to make biomass ‘coal mill ready’. The HGI was developed as an empirical test to indicate how difficult it would be to grind a specific coal to the particle size necessary for effective combustion in a pulverized coal fired boiler. It can also be used for torrefied biomass.

BIO.10	Development of high efficient biomass conversion systems for tri-generation (heating, cooling and power)
State-of-the-art	At the moment tri-generation has not been demonstrated on a large scale and even in Nordic counties the yearly efficiency of CHP systems does not exceed 65%. At present neither visionary background documents nor integrated energy technology assessments including the whole biomass fuel supply chain exist for biomass based tri-generation in combination with intermittent wind and solar energy supply. The potential and requirements for such systems in various energy and climatic conditions need to be identified.
Targets	• Energy modelling and identification of the requirements of future biomass CHP-C units as part of multi-source renewable energy systems. • Demonstrating tri-generation, with concepts for different climatic conditions, reaching at least 80% average annual efficiency. • Development of innovative concepts for cost efficient fertiliser factories in order to recycle biomass nutrients or recover strategic elements. • Creating test beds for on-line monitoring and measurement techniques. • Identifying business models for two-way tri-generation and poly-generation energy networks.
Type of activity	20% Research / 50% Development / 30% Demonstration

	Research and Innovation Priorities	Predominant type of activity	Impact
BIO.9	Development of highly efficient large-scale or industrial CHP with enhanced availability and high temperature heat potential	Demonstration	By 2020
BIO.10	Development of CO2-negative bioenergy systems	Development	By 2020

Table 12: research and innovation priorities for biomass applications to industrial processes

5.4 Geothermal technology

Low temperature range (<95 °C), including cooling

Geothermal energy can provide heat in the low temperature range as explained in the previous sections of this publication. Because geothermal energy has definite base-load characteristics, and is always available when required, it matches perfectly with stable demand patterns of most industrial processes. The annual full-load hours can be rather high, and thus the return on investment for the geothermal installation favourable. In this form, geothermal heat is already used in agriculture/aquaculture (e.g. greenhouses), drying processes in the food industry, etc. Specific R&D needs are not listed here, as they are equivalent to those in the DHC sector (Chapter 6).

Another geothermal technology useful for industrial applications is underground thermal energy storage (UTES). In particular UTES at 40-90 °C can directly supply heat for low temperature industrial needs such as batch processes or seasonal industries (e.g. sugar refineries), where periods of heat (and/or cold) demand are followed by phases of inactivity.

Geothermal heat can also be used as operating energy for absorption chillers, to supply cooling to industrial processes. R&D priorities for UTES and absorption cooling are included among the cross-cutting technologies presented in this Chapter.

Medium temperature range (95-250 °C)

Geothermal energy can provide heat above 95 °C from deep geothermal resources and from high-enthalpy geothermal resources. High enthalpy resources, some of which show temperatures over 250 °C, are used almost exclusively for electric power production. Use of the heat for industrial purposes is also feasible. R&D will be required to provide for the right matching and adaptation of the geothermal heat source to the specific characteristics of the industrial process concerned.

For the heat source as such, most R&D needs are the same as for deep geothermal in DHC, as long as temperatures below about 120 °C are considered (cf. Chapter 6). As the temperature of the geothermal fluid increases, other problems need to be solved, like degassing of the fluid (pressure control), corrosion, and insufficient pump technology.

5.4.1 Research and innovation priorities with impact in the Short Term

GEO.7	Geothermal Heat for industrial processes up to 250 °C
Objective	Investigations on the best match of geothermal heat sources (hydrothermal or EGS) to the specific characteristics of industrial processes, and development of technology for practical adaptation of geothermal heat to the industrial process. Improve desalination processes (e.g. on islands).
State-of-the-art	Geothermal heat today is only used in some countries for drying processes for a number of commodities, including wood, fish, vegetables, etc. Other uses include heating in agriculture, horticulture and aquaculture.
Targets	Make geothermal heat usable for industrial processes demanding medium-temperature heat; achieve a share of geothermal heat in industry of at least 20 % by 2050.
Type of activity	50% Development / 50% Demonstration

GEO.8	Production pump technology for temperatures >180 °C
Objective	Current LSP (line-shaft pump) and ESP (electric submersible pump) technology can achieve temperatures up to only 180°C. To reach temperatures closer to 250 °C, at the upper end of the medium temperature range, suitable ESP pumps need to be developed. These devices are crucial for economic application of geothermal technologies in this temperature range of industrial heat.
State-of-the-art	Submersible pumps today can work at maximum 180 °C and with a maximum flow rate of about 100 l/s.
Targets	Commercially-available production pumps for high temperatures by 2020, as a prerequisite to meeting the targets of GEO.12
Type of activity	50% Development / 50% Demonstration

5.4.2 Research and innovation priorities with impact in the Medium and Long Term

Geothermal research and development activities whose impact will be mostly in the medium and long term focus mainly on EGS technology, unconventional resources (geopressurised, supercritical, ultra-deep) and on materials science. Also for re-injection of geothermal fluids in certain geological conditions (e.g. some sandstone formations) most probably more time will be needed to develop satisfactory solutions. A specific priority is defined here:

Unconventional resources and very high temperatures (GEO.9). This geothermal research aims at making use of very high temperature resources above 250 °C. Projects like the Icelandic Deep Drilling Programme investigate possibilities for extracting geothermal energy up to 400 °C. Practical results and possible application here can be expected by 2030.

	Research and Innovation Priorities	Predominant type of activity	Impact
GEO.7	Geothermal Heat for industrial processes up to 250 °C	Development / Demonstration	By 2020
GEO.8	Production pump technology for temperatures >180 °C	Development / Demonstration	By 2020
GEO.9	Unconventional resources and very high temperatures	Research	By 2030

Table 13: research and innovation priorities for geothermal applications to industrial processes

5.5 Cross-cutting technologies

Without advancements in cross-cutting technology, decarbonising the industrial heating and cooling demand is likely to be more costly, less efficient and represent poorer value to energy users at all scales. High and medium temperature heat networks serving industrial clusters exploit economies of scale, mitigate investment risk and enable economic deployment of CHP technology.

District Heating and Cooling systems should play an important role in future supply systems to satisfy the industrial heat demand. In this case, the potential for integrating heat inflow and outflow from different industries (also called heat cascading) emerge as key aspect. See Chapter 6 for details.

In industrial applications, research is needed across all heat pump technologies to increase their efficiency and reliability and to harness the potential for heat recovery at different temperatures. Given that heat pumps producing heat at higher temperatures and with a greater difference between the hot and cool side of the heat pump are needed, research priorities should be focused accordingly.

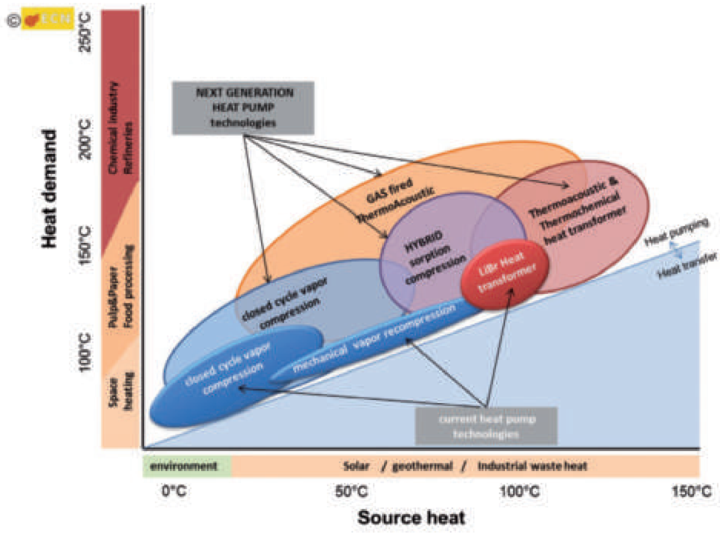


Figure 34: Heat pump technologies and their operating temperatures

Figure 34 plots the driving temperature ("source heat") against the delivered temperature ("heat demand") for various heat pump technologies. Current vapour compression systems deliver heat at a maximum temperature of ~80°C. New vapour compression systems should use low GWP synthetic refrigerants or natural refrigerants (such as butane or water) to reach temperatures of up to 150°C. Components and materials should be developed to achieve temperature lifts of up to 70 K. The use of water as the working medium allows the heat pump to be integrated into industrial heating processes.

Alternative concepts such as heat transformers are interesting when a heat source of more than 90°C is available. Current systems use thermally-driven compression to upgrade waste heat from 100°C to 140°C. Reversible solid sorption reactions, such as the reaction of salts and ammonia are applicable for heat transformation at temperature levels up to 250°C. Similarly, thermoacoustic systems can accept a range of driving temperatures and output heat also in a wide temperature range. A hybrid system can be created by adding mechanical compression as driving input to a heat transformer, allowing for use of low temperature waste heat and still generating temperature lifts of up to 100 K.

5.5.1 Research and innovation priorities with impact in the Short Term

CCT.12	Enhanced industrial compression heat pumps
Objective	Development of advanced compression refrigeration cycles based on novel working fluids for use in medium temperature industrial applications (condensation temperatures up to 150 °C and evaporation temperatures up to 100 °C). Applications of these novel heat pumps include process heat generation as well as waste heat recovery in industrial processes yielding substantial increases in energy efficiency. R&D topics to be addressed in this context comprise: • new working media (low GWP, non-inflammable) or natural refrigerants (water), • improved compressors and lubrication methods for high evaporating temperatures (up to 100°C), • heat exchangers with improved design for direct using of condensing gases (flue gas, exhaust air, drying processes, etc.).
State-of-the-art	Current vapour compression systems deliver heat at a maximum temperature of ~80 °C.
Targets	• Carnot efficiency of at least 0.35 • At least 2 demonstration projects should be realised by 2020. • Condensation temperatures up to 150°C • Temperature lift up to 60 K • Energy saving up to 30% • Cost target heat pump unit: 200 to 300 Euro/kW
Type of activity	20% Research / 60% Development / 20% Demonstration

CCT.13	Process integration, optimisation and control of industrial heat pumps
Objective	Development and demonstration of electrically and thermally driven heat pumps in individual industrial applications as well as in combination with district heating and cooling networks including thermal energy storage. R&D topics to be addressed comprise: • classification of processes (temperature levels, time-based energy demand, etc.), • process integration of industrial heat pumps (control and hydraulic design), • impact of heat pumps on existing process (dynamic behaviour), • selection of components (refrigerant, compressor, heat exchangers etc.) for the process identified,
State-of-the-art	First prototypes of compression heat pumps with evaporation temperatures of up to 40°C and condensation temperatures of up to 80°C are available but still need to be demonstrated. First prototypes of absorption heat pumps using new working pairs without crystallisation effects are available, but not demonstrated yet in real-life operating conditions.
Targets	• 5 lighthouse projects with a capacity of minimum 1 MWth implemented by 2020 • Compression heat pump: minim sCOP of 5, energy savings of at least 30% • Absorption heat pump: minimum sCOP of 1.5; energy savings of at least 50% • Cost target on system level for electrically driven heat pumps (unit plus installation): 400 to 500 Euro/kW
Type of activity	30% Development / 70% Demonstration

CCT.14	Improvements in Underground Thermal Energy Storage (UTES)
Objective	Improvement of system concepts and operational characteristics of UTES systems, investigation of optimum integration of UTES into industrial processes. In addition, the thermal efficiency of storage in different geological conditions should be increased and the thermal behaviour better understood (cf. GEO.6). Of high importance for the reliable operation of UTES is R&D into water treatment technology preventing clogging, and into component selection to prevent scaling and corrosion[61].
State-of-the-art	The first UTES application were in fact used for industrial purposes, providing cold to the textile industry near Shanghai in China in the 1960s. Since then, system concepts have been developed and geological and hydrogeological constraints investigated. UTES today are designed and operated following established routines, however further improvements are still possible and some aspects like hydrochemistry and water treatment await satisfactory solutions.
Targets	• Increased energy efficiency in industrial batch processes by 25 % through heat storage in the underground. • Improve system reliability and plant longevity at elevated temperatures.
Type of activity	40% Development / 60% Demonstration

[61] For more information, cfr. RHC-Platform (2012), Strategic Research Priorities for Geothermal Technology, Chapter 3.2.2.

5.5.2 Research and innovation priorities with impact in the Medium and Long Term

CCT.15	Improvement of sorption cooling from renewable energy sources
Objective	Providing cold from a constant and dependable heat source (like deep geothermal energy, surplus heat from biomass or district heat) could be done by various sorption technologies. The cold might be used in industry, but could also be fed into district cooling systems (Chapter 6). Development is required for conversion technology for heat into cold adapted to the characteristics of the renewable resource, e.g. to improve efficiency of low-temperature absorption chillers and decrease the necessary source temperature to activate the chillers. Reduce medium temperature waste heat by increase of efficiency and solve waste heat disposal (re-cooling) issues.
State-of-the-art	Absorption chillers are available in the capacity range up to 1 MW. In the field of deep geothermal, despite several project ideas, no large absorption cooling yet has been demonstrated. Chillers need to be better matched to the energy source. The market penetration of district cooling is still relatively low, resulting in little experience achieved by now.
Targets	• Develop a new, reliable and clean technology for cold production. • Reduce weight and size of absorption chillers. • Have at least 10 pilot plants in the 1-MW-range operational by 2025, associated to district cooling networks.
Type of activity	60% Development / 40% Demonstration

CCT.16	New concepts for industrial heat pumps
Objective	A broader range of operating temperatures and higher temperature lifts are needed to increase the application potential and the energy saving potential that heat pumps offer. The end users' demands extend beyond the required temperature and cost of the system to topics such as the toxicity & flammability of the working medium and the reliability of the system. No single heat pump technology can cover this entire range of demands, meaning different heat pump technologies should be developed in parallel. The main objective is the exploration of alternative thermodynamic cycles for heat-pumping and heat transforming for different industrial applications, with the goal to increase the operating window of industrial heat pumps so that they can deliver heat at medium pressure steam levels (app. 200°C). Not only will these improvements allow larger energy savings, but they will also unlock the benefits of economies of scale for the European heat pump industry.
State-of-the-art	The efficiency of any heat pump system increases as the temperature difference, or "lift", decreases between heat source and destination. Efficiently providing heat for industry at temperatures higher than 90°C with heat pumps is difficult. Industrial heat pumps (for heating purposes) currently consist of closed cycle vapour compression, open cycle mechanical vapour recompression and Lithium Bromide (LiBr) heat transformers.
Targets	• Delivery temperature up to 200°C • Temperature lift ≥ 70 K • Energy output compared to current technology ≥ 20%
Type of activity	70% Research / 30% Development

	Research and Innovation Priorities	Predominant type of activity	Impact
CCT.12	Enhanced industrial compression heat pumps	Development	By 2020
CCT.13	Process integration, optimisation and control of industrial heat pumps	Demonstration	By 2020
CCT.14	Improvements in Underground Thermal Energy Storage (UTES)	Demonstration	By 2020
CCT.15	Improvement of sorption cooling from renewable energy sources	Development	By 2025
CCT.16	New concepts for industrial heat pumps	Research	By 2030

Table 14: research and innovation priorities for Cross-cutting technology applications to industrial processes

6.
District Heating and Cooling

6 District Heating and Cooling

The fundamental idea behind modern District Heating and Cooling (DHC) is to use local heat, cold and fuel sources that under normal circumstances would be lost or remain unused. District heating, figuratively and literally speaking, provides the pipeline connecting these local thermal sources with heat demand, thereby reducing energy losses and the total volume of primary energy needed in the energy system. It is important to keep in mind that DHC technologies are **suitable for the residential as well as for the non-residential sector, including industries** and therefore advancements in DHC technology are likely to be beneficial to any type of user and to have positive impact on the energy technologies presented in the previous Chapters of this publication.

As energy for DHC is generally generated centrally and on large scale, it can for instance **integrate renewable sources** that are difficult to manage in small boilers. This includes most combustible RES such as wood waste, straw and olive residues, and also waste sources like municipal waste and sewage sludge. Various biomass, geothermal, and solar resources can be effectively integrated into the district heating network by means of different techniques.

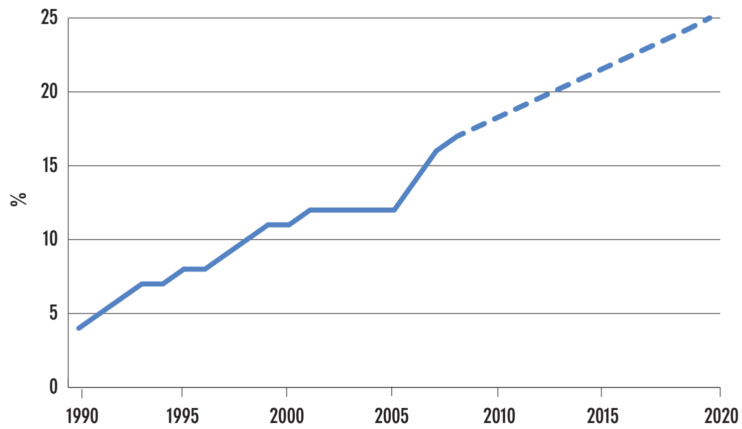


Figure 35: Share of renewable energy in DHC (Source: data provided by Euroheat & Power)

The current district heat supply and distribution networks are appropriate for current levels of heat demand, but with the increase of renewable energy supply and the decrease of final heat demand, DHC must continue to evolve within its context to continue representing a smart, sustainable and inclusive solution. In future the 4th generation of distribution networks will be characterised by the capacity to operate with **lower and/or more flexible temperatures** (Figure 36). This key change will allow both lower distribution heat losses and higher utilisation of available RES such as solar, biomass and geothermal energy.

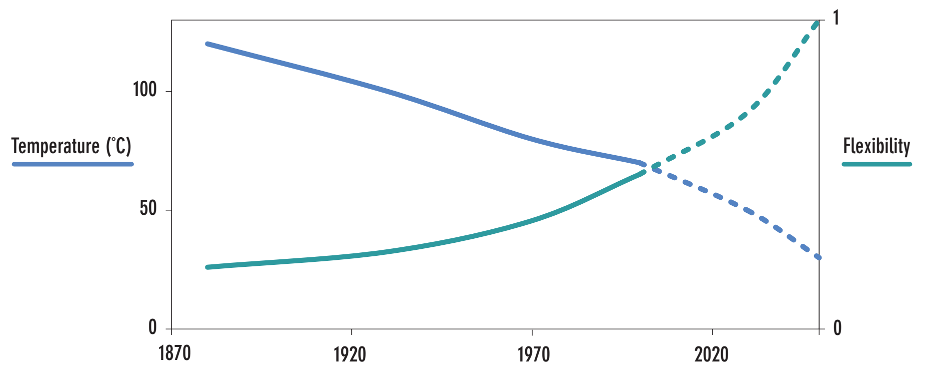


Figure 36: In time, lower and/or more flexible temperatures will be used in the distribution networks (Source: data provided by Euroheat & Power)

The **evolution of the building stock** will have an important impact on the energy systems. More and more buildings will have the capacity to produce and store energy, both electrical (e.g. in connection with e-mobility) and thermal. This will require systemic approaches and organisational innovation, encompassing energy efficiency, low carbon technologies and the smart management of supply and demand. The smart integration of buildings, local energy networks and transport is also at the heart of the European Innovation Partnership on **Smart Cities and Communities** (EIP-SCC)[62]. Several European cities are establishing programmes to foster the interactivity between energy suppliers and energy consumers in order to deliver more efficient services for their inhabitants (Figure 37).

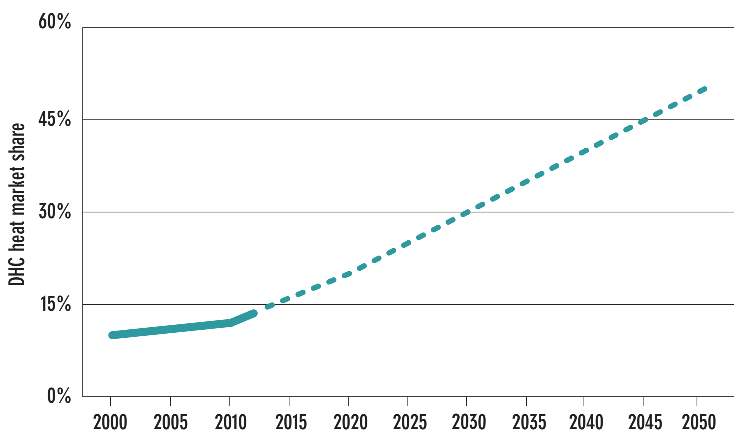


Figure 37: the transition to Smart Cities and the development of DHC are positively related

The **integration among networks** can take place at different levels such as inside the DHC sector itself and between the thermal networks and the other networks (electricity, ICT, water, etc.). The transition to more flexible systems will require the integration of existing systems with new ones. Also, different network scales should be taken into account in addition to traditional centralised structures, such as the installation of distributed micro-networks and connections to energy sources in surrounding regions which will contribute to achieve an overall optimum. Energy storage is a central component of energy efficient systems and it will play a pivotal role in future heating and cooling markets.

[62] European Commission (2012d).

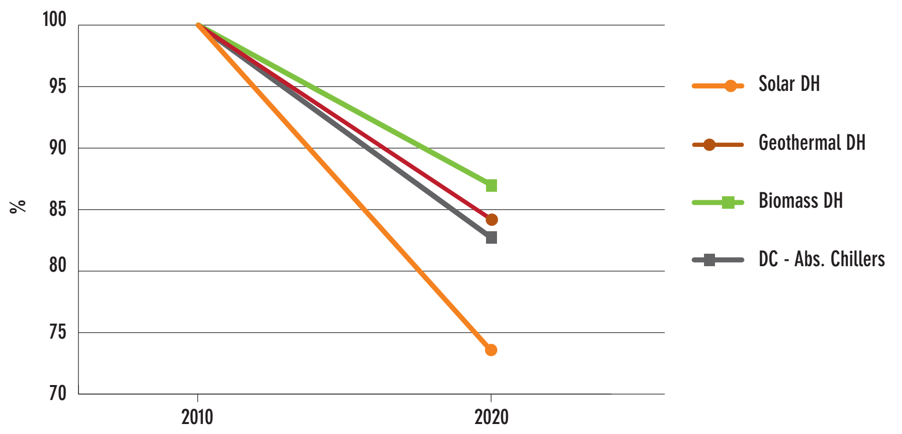


Figure 38: Potential evolution of costs for renewable DHC (Source: Euroheat & Power)

Reaching high penetration of RES in DHC requires drawing on a variety of heat and cold sources. Therefore, advances in any of the related technologies will influence the operation and business models of DHC. As shown in Figure 38, renewable energy distributed through DHC networks could achieve cost reductions in the range of 8% to 26%, depending on the advancements of the supply technologies, namely biomass, geothermal and solar thermal.

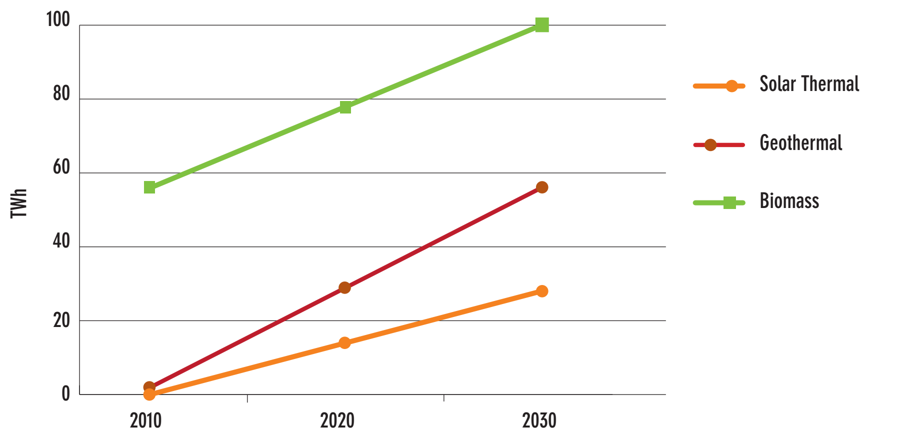


Figure 39: Market potential of renewable DHC in Europe (Source: Euroheat and Power)

DHC has all the ingredients to play a central role in achieving both 2020 and longer term EU objectives. Yet, as an interface with many other energy and non-energy processes and with ever-faster changing customer expectations, further research, demonstration and technological development are needed to enhance DHC's application in a future energy landscape. A significant expansion of network is possible (Figure 39) at competitive marginal costs (Figure 40) to achieve a substantial penetration of RES in urban areas, based on integrated planning of energy generation and access to locally available sources of heat.

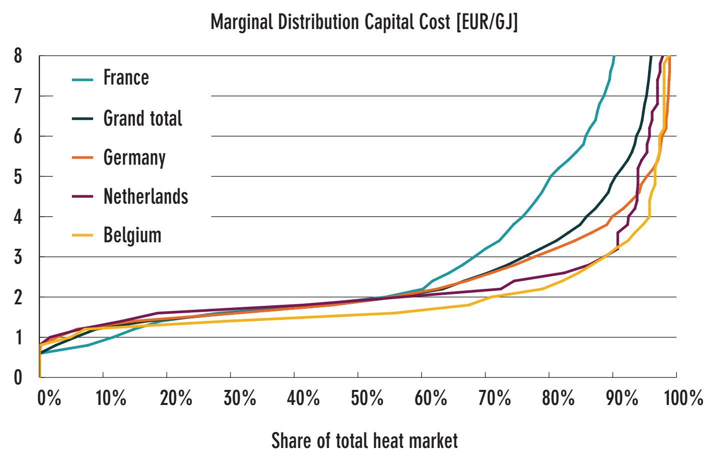


Figure 40: Marginal distribution costs and corresponding urban district heating heat market penetration in four European countries in 2008[63]

6.1 **Priorities for Solar DHC**

In Europe there are around 175 large-scale solar thermal plants for heating and cooling (≥ 500 m²; 350 kW_{th}) in operation with a total installed capacity of approximately 320 MW_{th}. The largest plants are located in Denmark with more than 10 plants exceeding 7 MW_{th} (10,000 m²) of capacity, while the largest as an installed capacity of 23.3 MW_{th} (33,300 m²). These large-scale systems are mainly used for solar district heating which, in most countries, is a small and undeveloped niche market.

Only 1% of the solar collector surface is currently connected to district heating systems, but a couple of central pilot solar heating plants with seasonal storage - mainly built in Scandinavia and Germany - have proved that these types of system can reach high solar fractions (approximately 50%). With the expected growth of district heating systems in densely populated urban areas, solar thermal systems will be able to cover a higher share of the heating demand in urban areas.

ST.12	**Optimize large-scale solar collector arrays for uniform flow distribution and low pumping power**
Objective	Development of large-scale collectors and advanced hydraulic concepts, which are especially designed for huge collector arrays. Basic theoretical computational approaches should be developed and validated by means of adapted methods (CFD, laboratory measurements, and measurements at large real solar collector fields). Particularly, the flow and temperature distribution, as well as the total efficiency and the electricity consumption of pumps and the related friction pressure loss at all hydraulic levels have to be considered. These advanced large-scale collectors, hydraulic concepts, calculation and simulation tools have to provide uniform flow distribution, reduced pumping power and favourable stagnation behaviour. Furthermore also cost effective fixing systems are needed.
State-of-the-art	Due to their size and the need to adapt to each specific application, large-scale systems for solar district heating, industrial process heat, agricultural and water treatment applications are tailor-made. This implies more complex design, such as planning system hydraulics. State-of-the-art collector fields cost around € 285/kWth (€ 200/ m²) when ground mounted and € 360/ kWth (€ 250 / m²) when mounted on flat roofs. Currently, the main challenge is to achieve a theoretically correct design of a large-scale collector field, as well as modelling parallel connections comprising multiple hydraulic levels (collectors, zones, groups).
Targets	Cost reduction of 50% compared to the field cost of state-of-the-art collectors.
Type of activity	50% Research / 30% Development / 20% Demonstration.

[63] Persson & Werner (2011).

6.1.2 Research and innovation priorities with impact in the Medium and Long Term

Advanced solutions for the integration of large solar thermal systems into smart thermal/electrical grids (ST.13). R&D is needed on system technology to develop advanced solar based district heating systems, which are also able to deal with a combination of centralized and decentralized solar thermal systems, heat pumps, biomass CHP plants and waste heat. Smart metering and load management systems are needed to combine solar district heating systems with the electrical grid. Such smart thermal-electrical grids will meet the load balancing needs of combined heat and power production in a free market for heat, cold and electricity.

	Research and Innovation Priorities	Predominant type of activity	Impact
ST.12	Optimize large-scale solar collector arrays for uniform flow distribution and low pumping power	Research	By 2020
ST.13	Advanced solutions for the integration of large solar thermal systems into smart thermal/electrical grids.	Research	By 2030

Table 15: research and innovation priorities for solar thermal applications to DHC

6.2 Priorities for Biomass DHC

Bioenergy in industrial processes and DHC systems is produced through thermo-chemical or biological conversion units with one or two transformation steps. CHP as well as tri-generation (heat-power-cold)[64] are very interesting concepts, both for industry and DHC networks. Due to the rule of decreasing specific investment with increasing network size, such operational and technical efforts can be better handled in larger units which typically supply energy to domestic heat consumers connected to a heating grid or to corporate customers to perform industrial processes.

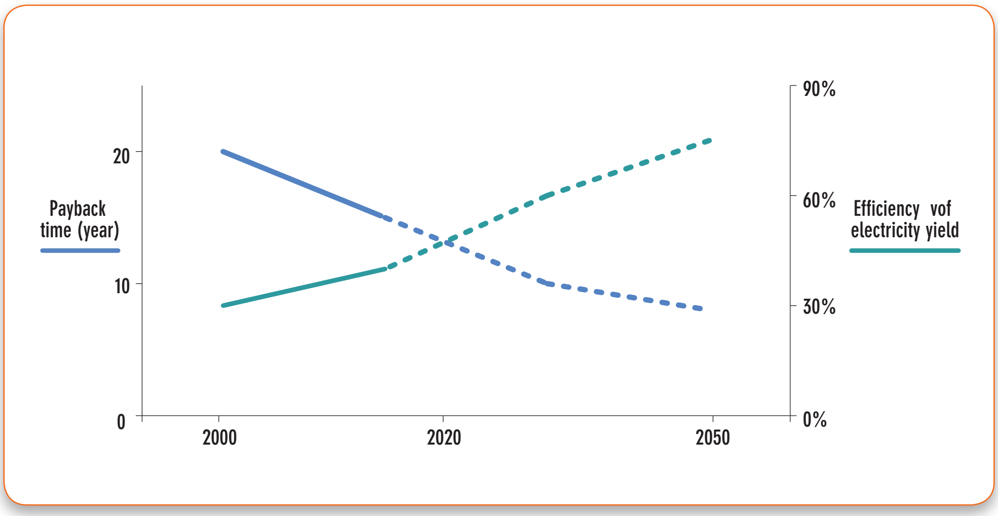


Figure 41: Projected evolution of biomass and biogas CHP plants connected to DHC

Raising the capacity and efficiency of already existing DHC through cost- and energy-efficient solutions is becoming an increasingly important issue. Some hybrid solutions such as the integration of heat pumps for active flue gas condensation are attractive and promising. In its report "Best available technologies for the heat and cooling market in the European Union" (2012), the JRC estimates the investment costs of a woodchip district heating boiler with flue gas condensation at 0.3 - 0.7 M€/MW. The operation costs are estimated to be around 5 % of the investment costs for heat generating capacities between 1 to 50 MW.

[64] Cfr. priorities BIO.9 and BIO.10 in Chapter 5.

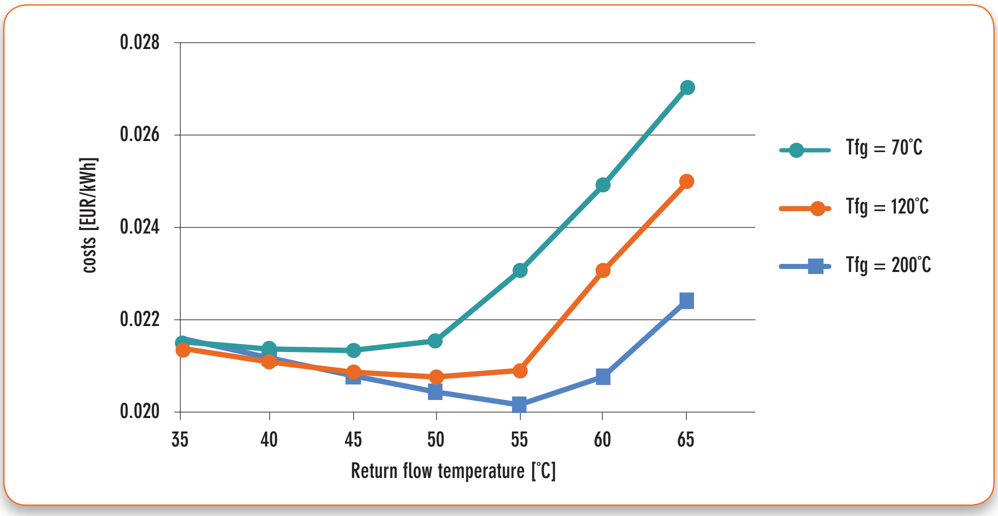


Figure 42: Cost of heat from an active flue gas condensation system in a 10 MW fuel input district heating plant retrofitted with a 170 kW heat pump for different flue gas temperatures [65]

6.2.1 Research and innovation priorities with impact in the Short Term

BIO.11	**Cost efficient CHP plants using biomass and biogas**
Objective	Minimising primary energy use for simultaneous power and heat production. Improving return on investment / competitiveness in comparison with condensing power plants.
State-of-the-art	Investors' decisions are based on financial considerations. In the electricity sector, environmentally-friendly solutions such as cogeneration compete with condensing power plants. Large-scale cogeneration plants require relatively higher investments.
Targets	Improving return on investment, increasing efficiency and optimising power-to-heat ratio of CHP plants through: (i) improved biomass fuel quality, new bio-commodities and cost-efficiency in sustainable biomass fuel production (especially for agro-biomass[66]); (ii) development of alternative technology options (biomass gasification based on gas engines, IGCC or others); (iii) enhancing heat recovery, inter alia, through better management of the summer load and flexible operation schemes; (iv) improving corrosion resistance. Key Performance Indicators: • electricity yield of cogeneration plants above 60% for a total efficiency of 90%; • Payback time for large cogeneration plants below 15 years
Type of activity	30% Research / 40% Development / 30% Demonstration

6.2.2 Research and innovation priorities with impact in the Medium and Long Term

A priority with long term impact is the **development of CO_2-negative bioenergy systems** (**BIO.12**). Bio-CCS (Bioenergy Carbon Capture and Storage) and soil additives from char fractions or carbonized biomass residues will add to carbon negative heating systems. Reduced residential heat demand enhances the potential for carbon negative heating systems with carbon soil deposition. Currently, a lack of incentives in the ETS is holding back the development of Bio-CCS projects. Co-firing and bioethanol production are currently identified as the most promising options for Bio-CCS which faces the challenge of being cost-effectively deployed in small scale units. Research on this topic should include the analysis of bioenergy incentive systems in the EU in view of realizing an economic assessment for Bio-CCS in co-firing and dedicated biomass combustion systems. Bio-CCS with chemical looping is identified as very promising technology for dedicated biomass units.

	Research and Innovation Priorities	**Predominant type of activity**	**Impact**
BIO.11	Cost efficient CHP plants using biomass and biogas	Development	By 2020
BIO.12	Development of CO_2-negative bioenergy systems	Research	After 2030

Table 16: research and innovation priorities for Biomass DHC

[65] Adapted from: Hebenstreit B & Höftberger (2012).

[66] The term agro-biomass generically identifies agricultural residues and herbaceous energy crops.

6.3 Priorities for Geothermal DHC

Deep geothermal energy production is the technology application relevant to this sector, mainly based on direct heat supply by thermal water production and reinjection, but also using other technology like deep borehole heat exchangers (BHE) or heat from geothermal CHP plants. The capacity of such installations start from about 0.5 MW_{th} (in particular deep BHE) and can achieve values in excess of 10 MW_{th}. The heat is fed directly into a district heating system, if production temperature matches the required supply temperature, or it is used as a heat source for large heat pumps (including absorption heat pumps, engine-driven compression heat pumps, etc.). Moreover, cold production is possible through absorption chillers driven by geothermal heat. Further advancements in DHC technologies (including cascading[67] and storage) will make it possible to use geothermal heat more efficiently. Geothermal technologies suitable for DHC networks can also be used for large individual buildings in the services sector (see Chapter 4) or for industrial purposes (see Chapter 5).

6.3.1 Research and innovation priorities with impact in the Short Term

GEO.10	Deep Drilling
Objective	The drilling of boreholes represents a major share of the investment necessary for deep geothermal energy use. Hence reductions in drilling cost can substantially influence the overall economics of a deep geothermal plant. R&D should focus both on novel drilling concepts and on improvements to current drilling technology, as well as for other ways to optimise the economics of drilling operations[68].
State of the art	Today drilling for deep geothermal energy is done using equipment originally intended for the hydrocarbon industry.
Targets	Reduce cost for drilling and underground installations by at least 25 % compared to the situation today.
Type of activity	40% Development / 60% Demonstration

GEO.11	Production technologies
Objective	Improve efficiency, reliability and cost of: • well design and completion, including definition of suitable materials • reservoir stimulation, prevention of formation damage • prevention and control of corrosion and scaling • downhole instrumentation, monitoring and logging • efficient production pump technology, submersible pumps for high temperatures • production management of the reservoir and retrofitting
State of the art	Geothermal well design has reached a good standard, and specifically-designed components like pipes and pumps are available. Production pumps cause high power consumption.
Targets	Reduce operation and maintenance cost by at least 25 %, improve system reliability and energy efficiency of operation, in particular by decreasing energy consumption of production pumps by at least 50%.
Type of activity	30% Development / 70% Demonstration

GEO.12	Surface systems for heat uses in DHC (incl.CHP)
Objective	Geothermal applications for DHC or large buildings require specific technologies to transform the geothermal energy into useful heat to be conveyed through a network or consumed in a building. There is scope for improvement in the technologies that exchange heat between the geothermal source and the heat transfer fluid in the network, both in terms of energy efficiency and resistance to corrosion (e.g. new materials or innovative design). Any further advancement in DHC technologies (including cascading and storage) can improve the efficiency and performance of geothermal district heating.
State of the art	Standard heat exchange and heat/cold distribution systems for conventional heat and cold sources are applied. The characteristics of geothermal heat (steady supply, mostly limited temperature, mineralised waters) determine system's design, however innovative solutions and components are needed.
Targets	Provide optimum heat transfer from the ground source to the distribution system so to increase heat exchange efficiency by 25% and component longevity in the thermal water circuit by 40%.
Type of activity	30% Development / 70% Demonstration

[67] See Figure 43.

[68] More details and possible R&D-paths are given in the sectorial R&D priorities for geothermal technologies: RHC-Platform (2012b).

6.3.2 Research and innovation priorities with impact in the Medium and Long Term

GEO.13	Enhanced Geothermal Systems (EGS)
Objective	EGS technology can provide a major increase in the geothermal resource base, as EGS could be used for a wide variety of applications. Today, only a handful of research facilities and two operational power plants exist. The key challenges for this application are explored in detail in the sectorial document on strategic research priorities for geothermal technology[69]. The main priorities are: • Hard rock drilling technology and well completion • Fracture identification, reservoir stimulation, seismicity • Logging/testing/monitoring, reservoir modelling • Sustainability, rock/water interactions EGS can be considered the major technology for future market increase of deep geothermal energy use.
State of the art	The basic technology for fracking in geothermal sites was already developed in the 1980s. The first EGS (power-only) plant was inaugurated in 2007, with a second one being open the following year. Other projects are under development.
Targets	Make EGS a cost-competitive technology applicable nearly everywhere in Europe.
Type of activity	20% Research / 50% Development / 30% Demonstration

GEO.14	Resource Assessment for deep geothermal heat use
Objective	The primary objective is to improve the quality of feasibility studies, to achieve better system design and adaptation to the geological conditions on site. Knowledge of the geothermal underground reservoir needs to be improved. This is in particular a topic of European interest and with added value of international cooperation, as these reservoirs do not follow national borders. Some trans-national projects supported by the EU have already proven this concept in certain regions. The final target should be the creation of a European geothermal data base of reservoirs suitable for deep geothermal applications in combination with DHC networks. Exploration technologies for subsurface imaging need to be improved, as well as modelling tools for resource assessment and reservoir performance evaluation. An inherent problem of all deep geothermal projects is the geological risk, i.e. the uncertainty of what actually will be found at depth in the reservoir. Here further R&D is required to improve risk assessment, to reduce the exploration risk by better investigations and to develop new solutions for mitigating the exploration risk.
State of the art	Present technology is mainly based on equipment and software developed for the hydrocarbon industry (i.e. geophysical software, logging tools...) and converted for use in the geothermal sector.
Targets	In future, not a single project should be abandoned after the decision to go ahead with drilling.
Type of activity	50% Research / 50% Development

	Research and Innovation Priorities	Predominant type of activity	Impact
GEO.10	Deep Drilling	Development	By 2020
GEO.11	Production technologies	Demonstration	By 2020
GEO.12	Surface systems for heat uses in DHC (incl.CHP)	Demonstration	By 2020
GEO.13	Enhanced Geothermal Systems (EGS)	Development	By 2030
GEO.14	Resource Assessment for deep geothermal heat use	Research / Development	By 2030

Table 17: research and innovation priorities for geothermal DHC

6.4 Research and innovation priorities for DHC technologies

The understanding of different energy demand profiles for various customer groups, e.g. industry, agriculture, residential and service sectors, as well as their interaction is key to support the future expansion of DHC systems using renewable sources. The DHC sector will experience situations where both old and new generations of technologies must be combined: flexibility will be a key feature of future thermal energy networks. Modern DHC systems can still benefit from technological advancements in the generation, distribution and customer sides, allowing the implementation of a holistic approach to thermal energy demand (Figure 43).

[69] RHC-Platform (2012b). Cfr. Chapter 4.6.

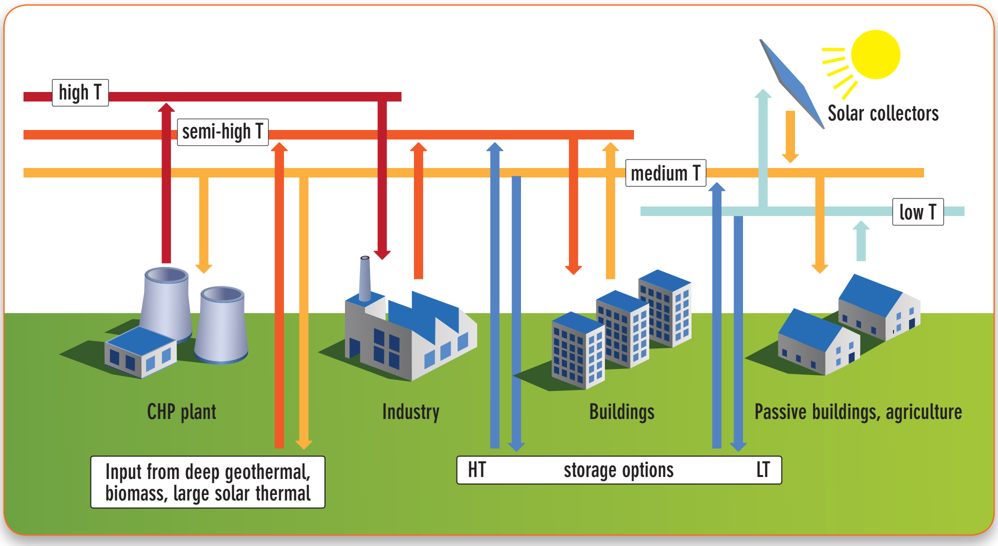


Figure 43: Schematic view of a heat cascading network[70]

6.4.1 Research and innovation priorities with impact in the Short Term

CCT.17	Large scale demonstration of Smart Thermal Grids
Objective	Demonstration of large Smart Thermal Grids which have the following characteristics: • They have to **adapt** fast to changes in energy supply and demand, in a medium-term by adaptation of the temperature level in existing networks and the installation of new distributed micro-networks and in a long-term by adjusting the network development with urban planning. • They should be **intelligently** planned and operated as well as enable the end-user to interact with the heating and cooling system. • They need to be **integrated** in the whole urban energy system from a spatial point of view (related to urban planning parameters and processes) and from an energy system point of view (e.g. with optimised interfaces to other urban networks – electricity, sewage, waste, ICT, etc). • They will help to achieve the highest overall **efficiency** of the energy system, by choosing the optimal combination of technologies and enable a maximum exploitation of available local energy resources by cascade usage. • The implemented solutions will be **effective** in comparison to non-integrated approaches. Solutions will have a significant impact on the overall urban energy system efficiency when the broad diffusion of the technology is given, together with environmental benefits to consumers. • They need to be **attractive** for the citizens and investors by increasing the cost efficiency, creating possibilities for the customers to participate and developing new business models. Advanced district heating systems must be developed that are able to deal with both centralised and decentralised, hybrid sources (e.g. solar thermal, biomass, geothermal, heat pumps, waste heat, waste-to-energy, excess renewable electricity, storage). In addition, smart metering and load management systems are needed for the integration of thermal and electrical grids into a liberalised energy market. Such smart thermal grids have an important potential to meet the load balancing needs of combined heat and power production in a liberalised market for electricity. In terms of components, specific decentralised cooling and air-conditioning units for district heating systems are needed, as well as new cost-optimized forms of long-term heat storages (more on this in Chapter 5). Integration and standardisation of thermal components are required to decrease their price and increase their efficiency. For existing heating grids the integration of heat pumps for active flue gas condensation may be a viable concept, which should be demonstrated. The development and demonstration of bi-directional grids may be an interesting system option for new grids.[71]
State-of-the-art	The deployment of Smart Thermal Grids as described above is almost inexistent in Europe. The most advanced systems usually comply with only part of it. This situation comes from the fact that despite cities are composed of a number of networks – ICT, electricity, heat, cooling, transport, water, etc. – they are developed in parallel, with no real interaction sometimes or even on a competitive basis
Targets	• 25% share of renewable energy in District Heating • At least 10 large scale projects using DHC networks as back-up for excess renewable electricity • At least 5 large Smart Thermal Grid scale projects complying with the strategic implications described above
Type of activity	20% Development / 80 % Demonstration

[70] Adapted from drawing by Ralf-Roman Schmidt (AIT) - The 13th International Symposium on District Heating and Cooling, September 3rd to 4th, 2012, Copenhagen, Denmark.

[71] The concept of Smart Thermal Grids is further developed in RHC-Platform (2012d)

CCT.18	Booster Heat Pump for DHC
Objective	This topic aims mainly at the demonstration of electrically driven industrial heat pumps in district heating and cooling networks. Heat pumps are used to upgrade heat from low temperature sources (e.g. low temperature industrial waste heat below 80 °C or waste water) to temperatures high enough for direct use in a DH network. R&D topics to be addressed comprise: • classification of networks (temperature levels, time-based energy demand, etc.), • integration of industrial heat pumps (control and hydraulic design), • impact of heat pumps on existing networks (dynamic behaviour) • use of the return flow from the DH network as heat source
State-of-the art	First prototypes of compression heat pumps with evaporating temperatures of up to 40°C and condensing temperatures of up to 100°C are available but still need to be demonstrated.
Targets	• 5 lighthouse projects with a capacity of minimum 1 MW_{th} implemented by 2020 • Compression heat pump: sCOP 5 or more for a temperature lift of 35K • Energy cost reduction of min. 30%
Type of activity	20% Research / 30% Development / 50% Demonstration

CCT.19	Develop and roll-out DHC driven white goods[72] and low temperature solution for domestic hot water preparation
Objective	DHC networks can supply a wide variety of household appliances that nowadays produce heat or cold internally with electricity. White goods already exist and are commercially available but they are expensive. The cost of these white goods should be reduced by bringing them from demonstration to mass production. There is a need for demonstration projects to show the feasibility of using in-house appliances which directly use thermal energy from the thermal district energy system. The sector should also develop customised solutions for the hygienic supply of domestic hot water (DHW) using low supply temperatures that are beneficial for the whole energy system. An evaluation of different possibilities of DHW preparation (e.g. additional heating or direct heating without storage) considering the local energy systems framework needs to be made.
State-of-the art	Most often white goods use electricity to produce thermal energy (heat or cooling). Solutions exist which use DHW provided through DHC networks for domestic appliances.[73] If the building is connected to the local thermal district energy network, it is much more efficient and more environmentally friendly to directly use thermal energy delivered by the network. DHW today must be stored and supplied at temperatures over 60°C in order to avoid the development of bacteria (*legionella*). With the development of low temperature systems, the preparation of DHW in DHC networks should be given appropriate attention to avoid the development of legionella.
Targets	• Decrease of the electricity consumption of white goods by 50% in household using DHC, and white goods using DHC becoming cost-competitive with traditional ones. • Develop new plug-and-play solutions which allow the operation of DHC at temperatures below 50°C without risk of bacterial infections.
Type of activity	50% Development / 50% Demonstration

6.4.2 Research and innovation priorities with impact in the Medium and Long Term

CCT.20	Improved, highly efficient substations for both present and future lower temperature networks
Objective	Substations should become smarter, softer, and cheaper. The following priorities are identified: • Improving in the manufacturing process • Costs reduction • Efficiency gains • Capacity to adapt to changes in the energy demand profile. To reach these objectives, R&D must also look at ways to harmonise substations' standards, to reduce materials' cost, to invest in the automation of manufacturing methods and to achieve good performances also at temperatures below 70° C.
State-of-the art	Substations, namely the heat exchangers, are currently designed for temperatures above 70°C. In low temperature DH networks (below 70 °C), the temperature drop across a heat exchanger will be decreased. More efficient heat exchangers will be required to maintain or even reduce the costs for the customer.
Targets	• Reducing heat costs for the costumer by 5% through the use of eco-efficient substations. • Reduce manufacturing cost by 15% compared to current standards.
Type of activity	10% Research / 20% Development / 70% Demonstration

[72] This term defines a range of household appliances which require thermal energy to perform their function. The most notable examples are refrigerators and washing machines.

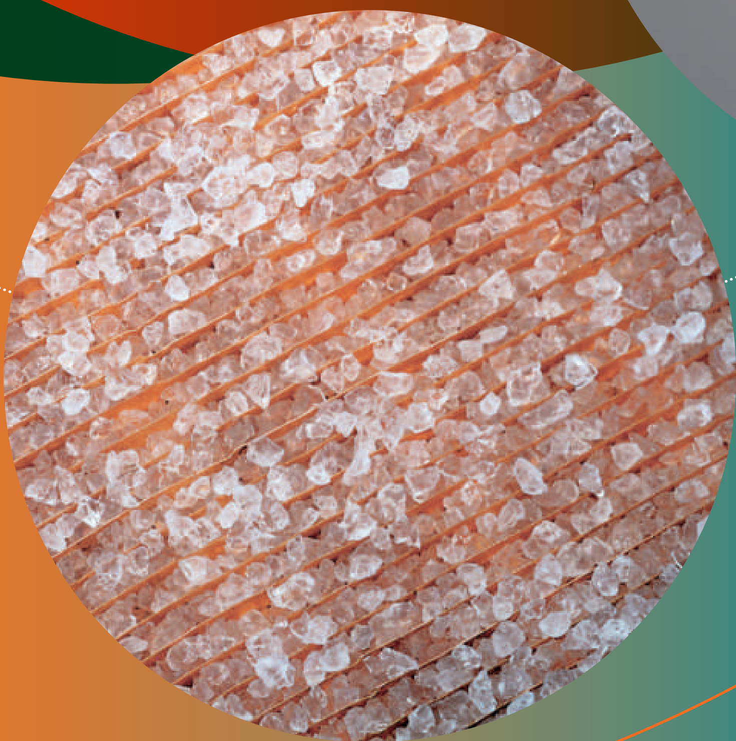
[73] Asko Appliances (2013).

CCT.21	Optimised integration of renewable energy sources in DHC systems and enhancement of thermal energy storage at system level
Objective	Further research activities are needed to allow DHC networks to efficiently integrate all types of RES without jeopardising the quality of the service provided to the consumers. In the same way, it is important to explore new synergies between various customer groups with different thermal needs. The DHC sector must be able to recycle and upgrade all available surplus energy, as well as any surplus industrial heat. Energy storage is a central component for the introduction of more flexible district and heating systems, using variable energy sources with a fluctuating thermal demand. Storage solutions already exist for district heating systems but they mainly suit short term storage. There is a need to develop flexible, efficient, multifunctional and cost-effective thermal storage.
State-of-the art	Currently DHC networks are mainly based upon few individual heat/cold sources, operated proportional to the heat/cold demand of the network. For integration of variable supply from renewable or industrial surplus sources, the system structure and operational strategy must be changed radically. Today's systems for short-term and seasonal storage use tanks with constant volume. In seasonal storage, especially when two tanks are used (cold and hot tank, or charged and discharged tank), twice the volume is required.
Targets	• This activity should result in a 30% reduction of heat costs from industrial surplus heat, and 10% reduction of primary energy use. • Demonstrate in at least 5 projects innovative DHC concepts combining multiple RES and different demand profiles. • Reducing energy consumption by 10% by using and optimising distributed energy storage solutions. • Seasonal cold storage: reach the same efficiency as seasonal heat storage. • For flexible volume tanks: 70% volume occupancy by 2030. • New thermal carrier: 10% more efficient in terms of thermal storage than water.
Type of activity	30% Research / 40% Development / 30% Demonstration

	Research and Innovation Priorities	Predominant type of activity	Impact
CCT.17	Large scale demonstration of Smart Thermal Grids	Demonstration	By 2020
CCT.18	Booster Heat Pump for DHC	Demonstration	By 2020
CCT.19	Develop and roll-out DHC driven white goods and low temperature solution for domestic hot water preparation	Development / Demonstration	By 2020
CCT.20	Improved, highly efficient substations for both present and future lower temperature networks	Development	By 2030
CCT.21	Optimised integration of renewable energy sources in DHC systems and enhancement of thermal energy storage at system level	Demonstration	By 2030

Table 18: research and innovation priorities for DHC technology enabling a higher penetration of RES

7.
Enabling technology



This chapter looks at two key areas to enable the achievement of the full potential of RHC: by developing targeted ICT support tools, and through research in materials science.

7.1 Information and Communication Technology (ICT)

As heating and cooling technologies become more intelligent, the flexibility available to the energy system is increased and the associated costs lowered. **Information and Communication Technology** (ICT) plays an increasing role in reducing the energy intensity of our applications, therefore enabling renewable heating and cooling systems to satisfy a higher share of the energy demand.

By monitoring and directly managing energy consumption, ICT can enable efficiency improvements in all applications which require a thermal energy supply. Some studies suggest that this capacity can be exploited to reduce energy consumption of buildings in the EU by up to 17%.[74] ICT can also address the complexity of measuring energy performance at a system level[75]: Software tools can provide information and data on how to better configure the various elements of a system so as to optimise its overall energy performance in a cost-effective manner. Applications of these ICT tools spread from smaller to more complex, large-scale systems such as urban areas and cities.

ICT developments enabling advancements in controls and performance assessment of RHC systems

Within the next decade, heating and cooling systems will become increasingly integrated. Smarter meters will be at the centre of the integrated solutions, including interaction with other networks (ICT, electricity, water, etc.). Smart meters are expected to facilitate this interaction by collecting data from all the different networks. At the same time, users and installers will demand that the interaction with technology is simplified. This requires large advancements in design monitoring, control, performance analysis, remote maintenance, output control, and certification of heating and cooling systems. Information should be made available in different forms and different levels of detail to multiple communities; operators and utilities require accurate technical data to control their systems, while consumers need to be informed about their energy consumption, the available energy sources and the related costs. Such information should be presented in an easy and intuitive form allowing non specialists to make informed choices. All these improvements will need to be highly reliable without significantly increasing the total cost of the systems

All newly introduced energy subsystems require supervision to understand and assess the performance of the overall system. Biomass unit operation should be optimised through the application of fuel quality monitoring and on-line process monitoring; new on-line sensors and dashboards are required to monitor combustion units and their integration with other components (from energy storage to the heating and cooling distribution network). Different types of combustion process models should be developed and validated based on a common methodology.

There is the need to work on advanced control algorithms and integration into whole HVAC system controls, which are necessary to improve performance. These advanced algorithms can also relate to design performance validation, or to advanced online performance control and maintenance activities. Furthermore, installation cost reductions and control systems' operation are important aspects to be improved.

Accurate and pervasive monitoring is also a key element to perform predictive and optimized maintenance. For solar thermal technology, by analysing the behaviour of systems operating under particular conditions, it is possible to quickly detect possible malfunctioning and to alert the end-user or service company. The performance guarantee of solar thermal systems is expected to improve thanks to technical progress and ICT development.

[74] [GeSI 2008] Bio Intelligence Impacts of Information and Communication Technologies on Energy Efficiency. Smart 2020 Enabling the low-carbon economy in the information age.

[75] For consistency with the wording of the European Commission [EC 2009] - COM(111), in this context a system consists of many energy consuming entities. Examples include data centres, buildings, factories and cities.

Six major areas can be identified where ICT research and innovation may have a direct impact on the performance of the thermal energy system:

- Novel, low-cost and intelligent sensors.
- Development of self-learning and self-adapting control strategies
- Development of control equipment and commissioning tools, ensuring that predicted results are actually obtained by the building system
- Standardized electrical interfaces defined for the interconnection of different sensors and actuators to the control system
- Standardized and low cost communication protocols to transfer monitoring data from sensors to control system and from control system to end-use or service company
- Standardized testing methods and assessment procedures for controller-dependent behaviour of system components

ICT tools for design and simulation

Simulation tools will also play a key role in evaluating, presenting and explaining the advantages of heterogeneous systems, particularly in the case of integration of RES, which bring to the picture parameters that are difficult to control (such as weather conditions). Decision makers need to have a clear understanding of energy systems from several points of view including performance, environmental impact, investment required, efficiency and related savings.

Future simulators need to be able to deal with parameters and information streams that are not commonly found in traditional systems. In addition to mass and energy, they will also need to cope with financial data (revenues, savings, ROI). The availability of such information is critical to making financial decisions and enabling modern business models, such as those related to the Energy Service Companies (ESCOs), to take off - which today they still struggle to do due to the lack of reliable data in support of their business plans.

Among the simulation tools, an important feature is the abilitiy to carry out **detailed thermodynamic system analysis**. Thermally driven cooling requires better simulation tools. Research in connection with systems will focus on the reduction of parasitic energy consumption through the development of highly efficient components (e.g. variable speed pumps, specific heat rejection units, energy-efficient substations) and optimized control strategy. This concerns especially the promising sector of solar thermally driven cooling and heating systems. It requires the development of advanced simulation tools operating at different levels, from molecular up to system scale. Furthermore, performance analysis tools, such as exergy analysis, life cycle analysis and comparison methodologies to assess new concepts, will have to be developed.

Involving the communities

Due to its central role in the development of Smart Cities and Communities initiatives, RHC technology providers should seek to establish stronger links with their current and potential customers. The information provided by ICT systems and tools is of strategic importance to raising acceptance levels and creating awareness, as in the following situations:

- As with any energy plant, the construction of DHC is often perceived as invasive and can be hard to accept for local residents. This would be remediated if citizens had a clearer understanding of the features and advantages of the new systems.
- End users have limited or no awareness of the impact of their behaviour on their energy consumption (particularly for heating and cooling systems). The information provided by monthly (or bi-monthly) bills gives little detail and does not help users identify the major sources of inefficiency.

To give communities the possibility to choose the best energy mix, evaluate new installations and adopt the most energy efficient behaviour, appropriate tools and equipment must be developed. Given their intrinsic functional complexity, additional research is needed on tools that provide a flexible user interface tailored to different stakeholder groups: operators/utilities, user communities, ESCOs, and financial institutions. Each group requires a different "view" (focus, detail level) of the common underlying information (production and consumption information, user profile, social aspects, demographics, economics, business models, etc). Sophisticated data mining and simple but effective visualisation of complex processes is a must for building smart tools and services.

The involvement of end user communities can also be stimulated by implementing social network tools (or extending existing ones) for the dissemination of information about best practices and results obtained by virtuous behaviour. An efficient RHC system is useless if not properly used.

7.2 Materials science

The advanced materials sector is one of the traditional strengths of European industry. Moreover, materials research is at the core of sustainable technologies for and solutions to our thermal energy needs. Research and development of new materials as well as the understanding and use of their properties is crucial to enable scientists and engineers to enhance energy systems and to realize the full potential of renewable heating and cooling technologies.

Materials play a pivotal role in the renewable energy technologies explored in this report. Materials science is ubiquitous and it is extremely difficult - even detrimental - to break it up by specific application. The results of material research generate opportunities for complementarity and synergies between different applications both within and beyond the energy sector. One example is the development of novel thermal insulation materials to store thermal energy, which could also be applied to reduce the losses of district heating and cooling. Both applications have far reaching impact enhancing the potential of RES.

In 2011, the European Commission presented a new working paper dedicated to "Materials Roadmap Enabling Low Carbon Energy Technologies"[76]. Regrettably, materials research for heating and cooling technologies has largely been overlooked in the EC Roadmap. The added value of novel functional and structural materials for heating and cooling is often underestimated in terms of required resources and lead times necessary to ensure differentiating high added value results. In the medium to long term, it is essential that sufficient means are dedicated to materials R&D and demonstration.

The present report by the RHC-Platform addresses a large number of strategic research priorities relevant to materials research. While designed to address the specific needs of each RHC technology, several priorities are common to more than one technology. In addition, a broad range of activities proposed for one application can profitably be shared with other applications either within the energy sector or in other economic sectors (e.g. the work on phase change materials for thermal energy storage is potentially also of great benefit to the construction industry).

Leveraging these complementarities and synergies is of critical importance for the implementation of the RHC-Platform's Strategic Research and Innovation Agenda. Economies of scale and scope can be realised and cross-technology knowledge can be pooled at European level to accelerate the development and integration of innovative materials into low carbon energy technologies. The following table shows the strategic research priorities that are relevant to materials science:

[76] European Commission (2011b).

Type of activity	Relevance to RHC technology	Predominant impact: Short Term	Predominant impact: Medium and Long Term
Research	ST	New surfaces, coatings, materials with increased performance and lower costs (transparent covers with anti-reflective coatings for high optical transmission; switchable coatings to reduce the stagnation temperatures; high reflective and low weight materials for reflectors; new absorber materials with low emission coatings, temperature resistant super insulating materials, alternative high temperature materials like polymers or rubbers for collector parts)	New, highly-porous sorption materials, especially using adsorption chemistry and, possibly, ionic liquids
	TES		New insulation materials / Vacuum insulation
		Intensification of thermal conductivity	New materials' design based on numerical modelling
		New sustainable TES materials	Fluids combining heat transfer and heat storage
	PCM TES	New PCM that are not subject to subcooling	New PCM with higher storage density New materials and/or mixtures that adjust the melting temperature
			New encapsulation and stabilisation methods for PCM, especially for salt hydrates
			Developing microencapsulated PCM at medium (300 °C) and high temperatures (up to 1,000 °C)
	TC TES	Materials for TC heat storage at low temperature	Materials for TC storage of heat at medium and high temperatures
	HP: Working Fluids	Safe refrigerants with almost 0 GWP	Investigation of performance of new working fluids
		High temperature refrigerants for industrial compression heat pumps (temp. up to 150 °C)	High temperature refrigerants for industrial compression heat pumps (temp. above 150 °C)
	HP: Sorption and other issues	Improved materials for magnetic refrigeration	Metal hydrides
		Fundamental understanding of heat and mass transfer at sub-atmospheric and super critical pressure	Salt based chemisorbent development
		New working media for thermally driven heat pumps for elevated temperature levels	Investigation of chemical reactions for the application to sorption processes
		Modified zeolites, SAPO, ALPO	Designer Sorbent working pairs
		Sorbent coating techniques development	
	HP: Heat exchangers	Heat exchanger surface modification Nanostructures	Metal Organic Framework materials
		Improved materials for heat exchangers at temperatures above 150 °C)	Characterisation and development of new working fluids
	BIO	Thermoelectric materials allowing for increased hot side temperatures (> 400°C) and suited joining technologies (insulation, bridging, contacting,…)	Thermoelectric materials allowing for increased hot side temperatures (> 600°C) and suited joining technologies
		Catalysts and active surfaces for enhancing combustion quality	
		CO_2 sorption liquids	
Development	HVAC	Materials for innovative pipe solutions	Liquid-desiccant technology for dehumidification and cooling applications
	ST	High temperature insulation material	Improved multi-functional solar façade elements and systems with additional functionalities and high flexibility regarding the architectural integration
		Further development and integration of materials resistant to high temperatures	Advanced liquid or gaseous fluids for heat and cold transfer
		Improved surfaces, coatings, materials with increased performance and lower costs	
	GEO		Plastic material for BHE with increased thermal conductivity (cf. 4.4)
			Optimum heat transfer fluid for BHE (cf. 4.4)
		Metal alloys or other material for pumps, pipes, etc. in applications above 180 °C, in high-pressure and highly corrosive geothermal environment	
	TES	Materials for storage containment	New PCM in polymers
	HP: Heat Exchangers		Heat exchangers based on advanced materials for application in severe operating conditions (e.g. corrosive media)
	BIO	Cost effective low temperature corrosion resistant heat exchanger materials (for condensing operation modes of small and medium scale boilers)	
		High temperature corrosion resistant heat exchanger materials (to increase steam parameters in large scale CHP plants, or to operate micro CHPs at elevated temperatures) suitable for combustion of problematic biomass types. The materials should solve problems such as creeping, cracking, TMF and corrosion, erosion, fouling	
		Catalysts for reduction of harmful emissions from combustion processes	
		Catalysts for steering syngas composition and for reduction of tar in syngas from gasification processes	
		Development of industrial manufacturing processes of thermoelectric generators (for hot side temperatures >400°C)	Development of industrial manufacturing processes of thermoelectric generators (for hot side temperatures >600°C)
Demonstration	TES		Flexible volume tanks
	DHC	Innovative insulation solutions and materials for thermal energy transport	

Table: 19: Research and innovation priorities for materials science addressing the needs of RHC technology

8.
Research capacities and non- technological issues

The Renewable Heating and Cooling sector's objectives fully match those of the European Commission's Innovation Union and Europe 2020 strategy[77]. These objectives aim at increasing European R&D, as well as stepping up the emphasis on innovation in energy and climate change related technologies. This will improve the competitiveness of both European products and companies not only in our internal market but also on a global scale. As shown in this document, research and innovation are pivotal to the creation of new products/services that generate growth and jobs, thus helping to address social challenges. The RHC sector will bring integrated solutions, of new and clean energy applications that will be used in Smart Cities, in nearly zero-energy buildings, in industry or agriculture. For that purpose, it is important to provide the means, both technical and human, for the EU to develop innovations in the RHC sector, creating a pool of knowledge and competence to foster the competiveness and attractiveness of the R&D work performed in Europe.

8.1 Research infrastructure for RHC

The strategic development of a research infrastructure for renewable heating and cooling is essential to promoting the development of RHC solutions in Europe. This entails exploring synergies between the different technologies comprised in the RHC sector, reinforcing and further developing a competence pool, enhancing cooperation between Member States and public - private R&D activities, managing existing know-how and facilitating a network of research infrastructures.

Strengthening research infrastructure

Taking into account the diverse sectors involved in RHC, one of the main priorities is to forge a stronger collaboration or even integration between existing facilities working on RHC R&D at European and/or national level. After exploring the synergies created by such collaboration, it will be possible to identify the additional needs for multidisciplinary research facilities. While some facilities can originate from existing ones, upgraded to support R&D for other RHC technologies; some new facilities can be set up to complement or replace older ones.

Taking into account that RHC technologies are mostly small scale, with production distributed across Europe, research facilities should ideally also be spread around Europe, attracting and retaining talent away from the main conurbations, thus remaining cost-effective and manageable. The uniqueness of the RHC sector allows for such specificities. The diversity of competences required must be well considered and an equilibrium found between technologies (solar, biomass, geothermal), cross-cutting needs (hybrid systems, thermal storage, large scale systems and district heating) and experimental or testing facilities, for instance. Industrial process heat generation, hybrid systems and thermal storage are some of the areas where current research infrastructure is inadequate.

Cross-sector collaboration and networking activities

Decarbonising the heating and cooling sector is a challenging policy objective due to the large number of individual decision makers and also to the fact that the industry is diverse and fragmented. Well-organised networking activities at European level are essential to stimulate cooperation between research institutes and industry and, in parallel, between different regions (cross-border and cross-sector collaboration). This can result in an effective knowledge transfer among RHC research and innovation performers, which will reinforce European cooperation and facilitate technology development. For instance, a combined approach on both the demand and the supply side is required to integrate RHC technologies into the construction process and logistics chain. This is why public intervention is needed at EU level to foster collaboration and networking between RHC experts and stakeholders of relevant disciplines such as architecture, urban planning, or construction. Moreover, further collaboration with energy intensive industries (such as pulp and paper, glass and metals) should be established to develop new low-carbon solutions for process heat.

[77] European Commission (2012c).

Set up a Joint European Renewable Heating and Cooling programme

In Europe, the strategic development of a research infrastructure for RHC is key for implementing the activities described in this RHC-SRA.

The establishment of a "Joint European Renewable Heating and Cooling Programme" would allow the exploitation and valorisation of the competences existing in different parts of Europe, bringing together a critical mass of research institutes and companies active in renewable energy technology, on storage, refrigeration, process heat etc. While infrastructures for R&D and testing should ideally be set up at European level in the Joint Programme, a small number of Renewable Cooling Development Centres should also be set up at national or regional level in high potential regions such as the Mediterranean basin and Southern Balkans.

The RHC-Platform also recommends the establishment of a virtual or real "European Institute for Thermal Energy Storage" composed of a broad research infrastructure, including testing equipment, which is necessary to meet the huge challenges of this strategically important technology. A wide exchange programme for master and PhD students within research institutes in all Member States should create the basis for a European-wide network of scientists working in this field.

8.2 Education, training and certification

In order to ensure the successful market deployment of RHC technologies, efforts are required to consolidate and harmonise certification, training and education programmes at European level for practitioners, technicians, engineers and scientists. Such programmes should be revised as advances in technology take place, and should be founded on environmental sustainability. Training programmes in Europe need to be increased significantly, not only at university level, but also on professional level. The potential of the labour force has to be deeply studied for the optimization of education, the requalification of employees and vocational training. The market deployment of RHC technologies will create demand for experts and trained engineers for the manufacturing, installing and maintenance of the systems. The increasing imbalance between people retiring and the inflow of young people to the European labour market in general constitutes a future challenge that could hinder the sector's development. Without proper measures, this will cause a shortage of scientific and technical experts. Future needs in the fields of graduate, post-graduate, life-long, and professional training are assessed in the framework of the SET-Plan European Energy Education and Training Initiative recently launched by the European Commission. This initiative covers 10 energy related sectors with the objective to deliver the quantity and quality of human resources required for the achievement of the ambitious European climate and energy targets for 2020. Thereby, suitable integration of RHC in graduate, post-graduate, life-long, and professional training shall be ensured at European level.

Professional training must respond to the needs of the heating and cooling industry. For the geothermal sector, training programmes are not comparable or compatible across Europe and are not adapted to the sector's requirements in terms of content, mainly because of the lack of specific materials and regulations. The adaptation of professional profiles to the requirements of the RHC sector and particularly to those of European legislation (EU 2009) should address:

- Setting up a stable structure to enable the transfer of geothermal technology and know-how from international (scientific) sources.
- Producing a handbook of professional competencies or strategic professional qualifications, including a list of the necessary profiles required by the geothermal sector.
- Updating the existing technical guides and Codes of Best Practices, using as a basis European benchmarks to be adapted to the inherent characteristics of each country.
- Fostering piloting training initiatives geared at drillers and equipment installers based on previous European project models.

For biomass based residential heating and cooling, the influence of poorly trained operators can be reduced through improved operating manuals, operator trainings and public campaigns. Knowledge and skills are frequent barriers for biomass growth particularly in small applications. Certified training courses need to be developed for installers of residential biomass applications to guarantee high quality and good performance of installed systems. Such courses shall be in line with Article 14 of the European Renewable Energy Directive 2009/28/EC (EU 2009) which calls for the establishment of certification schemes or qualification schemes for installers of small-scale biomass boilers and stoves, solar photovoltaic and solar thermal systems, shallow geothermal systems and heat pumps[78].

Development and recognition at the European level of accreditation and certification schemes for not only small-scale renewable energy installation professionals, but for all active staff of a RHC facility, including installation technicians, drillers, project designers, maintenance personnel, trainers and auditors, is a priority. In the building sector, the choice of heating and cooling supply technology is often given secondary priority by planners, builders and home owners. Either at small- or large-scale, the installation of hybrid renewable energy systems may require specialist knowledge and skills that are not yet part of the training of architects, engineers, plumbers as well as energy and urban planners. An important priority is to ensure that building sector professionals are aware of the entire spectrum of heating and cooling solutions to make the best decisions based on life-cycle cost and benefit analyses which take into account future energy prices and CO_2 emissions.

RHC-related content needs to be incorporated into university, Technical and Vocational School (TVS) and postgraduate curricula. Incorporating RHC engineering or technology studies into TVS curricula implies the identification of technical and vocational school diplomas that are most similar to the type of work carried out during project development, installation and maintenance work, as well as the design and implementation of a specialized post-graduate course for higher technical education students that may be interested in pursuing and developing their professional career in the field of renewable heating and cooling. RHC technologies also need to be incorporated into university curricula by imparting lectures in existing Master's and post-doctoral university programs and by the creation of one or several specific undergraduate or Master's degrees. At the moment, there is almost no specific academic training in District Heating and Cooling. It is the responsibility of the sector to ensure that relevant knowledge is passed on to a new generation of engineers, but also to architects, planners, etc. The new generation should be ready to develop smarter cities presenting integrated solutions using renewable energy. The development of specific Master Degrees (Geothermal, DHC...) would be an important step to ensure the long term sustainability of the European energy system.

8.3 Other non-technological issues

The full transformation of the heating market towards renewable technologies needs political support, both to step up the replacement of old heating systems and to increase the uptake of renewable technologies in new and existing buildings. Technological progress, the removal of fossil fuel subsidies and, in a second step, putting a price on CO_2 e.g. through taxation of fossil energy carriers, can help to create a level playing field and make RHC technologies cost competitive with fossil fuels. In the meantime, this process can be facilitated by implementing financial support schemes (direct subsidies, tax reductions, etc.) and building regulations requiring the installation of renewable technologies. In any case, policies must aim at providing a stable and reliable framework in order to increase confidence for investors´ and end-users.

Simplification and harmonisation of the administrative procedures and costs related to renewable energy projects at European level is crucial in order to promote RHC installations in buildings. Energy supply applications should be selected taking into consideration the primary energy factor as well as final energy. Positive and effective communication of the RHC benefits at societal and environmental level, is also important to the sector's growth.

[78] Those schemes may take into account existing schemes and structures as appropriate. There are also a number of training and educational projects at the international level (EU-CERT.HP, QUALICERT, GEOTRAINET, Install + RES), which undoubtedly serve as a reference to this regard.

Standardisation and quality assurance

The market penetration of RHC technologies depends on the capacity of the EU industry to provide innovative solutions, to gain the trust of consumers and to address information barriers. The market for heating and cooling systems is characterised by asymmetric information. Policies are required that ensure that prospective customers are provided with standardised information about the technological solution that best meets the thermal energy needs of the individual building, district or industrial process. This is of special importance for small- and large-scale hybrid systems[79]. The market penetration of efficient hybrid systems could be supported by improving energy performance labels, which should be required for all new heating and cooling systems in the EU by 2020. The information provided should not only include the relative efficiency, but also the annual running cost, greenhouse gas emissions and the expected system lifetime.

Standardisation is needed to ensure quality to the market but should not become an obstacle to the introduction of new products. In parallel with system development, new standards should be developed which are able to characterise not only the thermal performance but also the quality and expected lifetime of a RHC application.

The following priorities are identified:

- Development of accelerated ageing tests for collectors and collector materials.
- Standardised testing methods and assessment procedures for controller-dependent behaviour of system components.
- Elaboration of standards for the hydraulic and electrical interconnections of different building components.
- Standardised electrical interfaces defined for the interconnection of different sensors and actuators to the control system.
- A standard set of tests for hybrid systems should be developed to certify their thermal and electrical efficiency and CO_2 emissions.
- New labelling or certification standards need to be developed to evaluate and compare new thermal energy storage materials and applications as they will become available on the market.
- Standardisation of the information provided to the consumer through improved energy performance labels.

Development of new business models

Renewable energy technologies such as solar thermal and geothermal energy have low running costs but require a high upfront investment. New business models must be developed to overcome the barrier of financing upfront costs. Measures to overcome the "owner-tenant dilemma"[80] are needed for the sector to reach its full potential, in parallel with innovative schemes for outsourcing technical and economic risks, and offering further energy related services such as those offered by ESCOs.

New strategies are needed for technology suppliers and stakeholders of related sectors (such as building owners) aiming at facilitating access to capital, financing of upfront costs, outsourcing technical and economic risks, and including the offer of energy related services. Innovative marketing strategies should be elaborated based on market research to stimulate the refurbishment of the existing building stock and heating systems with modern RHC technology.

In the district heating and cooling sector, today's business models are based on the quantity of heat or cold transported as the expansion of the grid has resulted in the ability to serve more customers. Tomorrow's DHC business will be more complex, offering a broader range of services that should be managed simultaneously, including storage and cooling, and the feed-in of heat or cold from the entities connected to its network.

With the advent of low-energy houses, each customer will consume less heat. Moreover, some consumers will produce their own heat and will store or deliver their surplus to the thermal energy grid or directly to other buildings. All these aspects will lead to a new way of operating the networks, allowing less investment in the production side and a smoother delivery flow, for the benefit of the energy system and its customers. The DHC industry will need to adopt new business models to remain profitable even if less heat is sold.

[79] In fact in hybrid systems the efficiency of a single component is of relative importance and gives only limited information on the performance of the overall system. In order to support the market penetration of innovative and low-emissions of hybrid systems, customers ought to be transparently informed on the efficiency of the entire system and they should have the possibility to compare systems with different components in a direct way. Therefore standardised testing procedures are needed and laboratories should test energy systems following harmonised procedures and cycles.

[80] In many residential and non-residential buildings those who pay the bill are not the decision-makers on infrastructure investments. Owners have to be encouraged to make the necessary investments and to be able to benefit from the measures implemented.

These new models must support the integration of strategic thinking and sustainability objectives in decision making processes (e.g. by incentivising energy savings, delivering capacity and flexibility vs. delivering energy, etc.).

Effective public support policies

Economic and non-economic barriers hampering the uptake of RHC in the building sector can be tackled by effective support policies. For renewable energy technologies that cannot yet compete with conventional fossil fuel alternatives, effective and stable economic incentive schemes are required. Lack of information is another barrier that can be addressed by increasing awareness of the RHC potential under specific climate conditions and for specific applications. A wide experience exists with several types of policy instruments but analysis of the effectiveness of policy measures to encourage RHC deployment is still inadequate. Evaluation studies are needed to assess how support policies can be most effective.

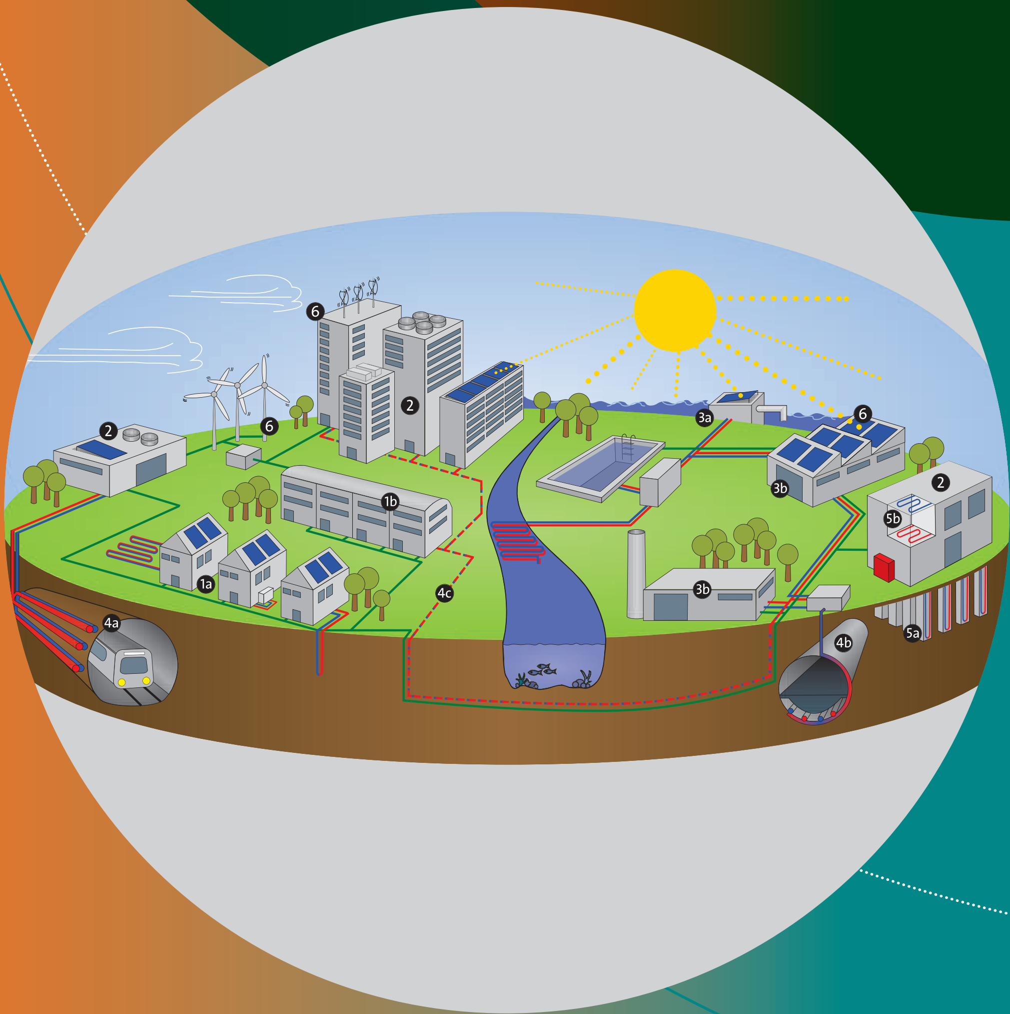
There are good examples of measures to support the development and deployment of smart thermal systems, including DHC, and thereby attain both economic and environmental benefits. Unfortunately, few of the regulatory approaches that theory predicts and practice has shown to be effective in promoting DH networks are currently in force. Research is needed to understand why. The answer may lie in a conflict between the needs of local, regional and national energy systems. In the same way it is of great importance to study how policy frameworks and instruments should be designed to stimulate and support an extension of sustainable thermal systems.

Some markets are already implementing specific "renewable obligations" schemes since several years (e.g. solar thermal obligation) with high success. These mandatory measures have the advantage of being "cost neutral" for the implementing public authority. Moreover, renewable energy solutions are taken into consideration from the very beginning of the planning process, allowing a better integration in terms of technical, architectural and economic impact.

Sustainability and public perception of biomass based heating and cooling

Even though the on-going debate about potential negative environmental, social and economic impacts has mainly targeted biofuels for transport, the same sustainability issues are also relevant for biomass based heating and cooling. It is therefore important to establish suitable sustainability certification schemes to maximise positive impacts such as GHG emission reductions, energy security, employment generation, and rural development and to ensure that biomass based heating and cooling has an overall positive impact compared to the use of fossil fuels. Ensuring sustainability can thereby contribute to a positive perception of the European public and highlight the societal benefits of bioenergy which is essential for successful future market development.

9. Outlook on the Implementation Roadmap



The present chapter aims at providing an overview of the total resources required for the successful implementation of this Strategic Research and Innovation Agenda in Europe. The information provided is based on a quantitative analysis of funding for RHC research, development and demonstration from the public and private sectors in the period 2007-2012 and the expected funding trends to 2020, which rely on a number of assumptions developed by the RHC-Platform[81]. It must be noted that available data is incomplete and the information concerning public investments in R&D for several Member States was not available. As for statistics of heating and cooling consumption, data on resources allocated to RHC R&D are fragmented and research activities are measured according to heterogeneous indicators (also due to the diversity of the underlying RES). A complete overview is virtually impossible due to the scientific and policy interdisciplinarity of RHC systems. The multitude of funding institutions and programmes at Member State (MS) level further complicates data collection.

The RHC-SRA will be implemented with resources from various sources, depending on the nature of the research and innovation priorities and specific needs of the individual technologies. The following sections present the three complementary routes considered to leverage resources required to implement the RHC-SRA:
1. Public funding for R&D at EU level
2. Public funding for R&D at MS level
3. Investments by the private sector

The chapter concludes with an estimate of the budget and investments which will be necessary for implementing the RHC-SRA.

9.1 Public funding for R&D at EU level

The starting point for the characterisation of the EU funding for R&D was a mapping of all projects financially supported by the European Commission in the fields of reference.

A recent study of EURAC research[82] analysed all funds allocated by the EU within the "Work Programme Energy" of the Seventh Framework Programme for Research and Technological Development (FP7) over the period 2007-2012 in terms of EC contribution, overall budget and distribution between the technology paths. This study provides the following information:
- **29** projects directly relevant to RHC received financial support by the EC
- **137.7 mln Euro**: Estimated total budget of RHC R&D projects
- **85.2 mln Euro**: Estimated total EC contribution to RHC R&D projects

Although a complete overview of the FP7 was not available at the time of writing, some key trends are already visible. Figure 44 shows that resources allocated to RHC R&D under FP7 are negligible in comparison with those allocated to nuclear energy or R&D related to other energy technologies.

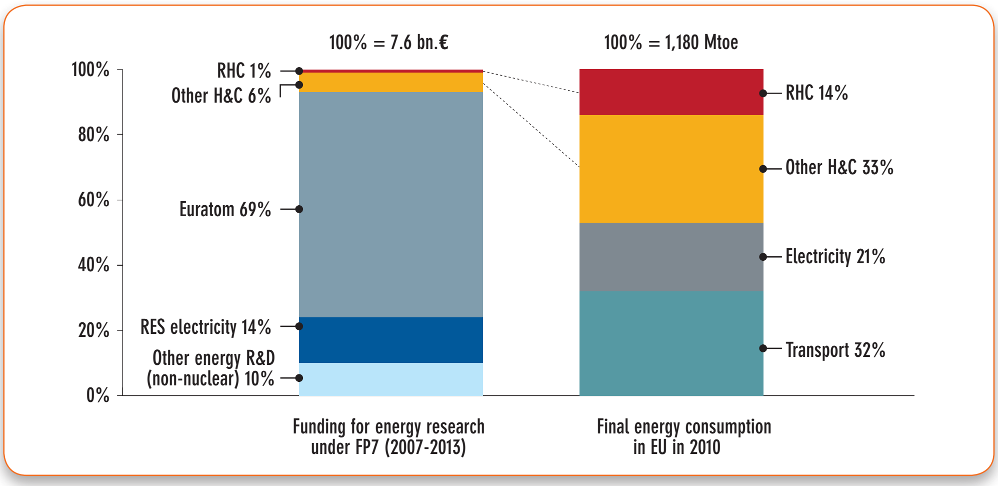


Figure 44: Funding for energy research under FP7 and final energy consumption by sector (Authors' adaptation based on: Pezzutto, S. & Sparber, W. (2013); EU Energy in Figures 2012)

[81] These assumptions do not reflect any formal commitment of EU Institutions or Member States regarding the future level of funding allocated to RHC technologies. The RHC-Platform is the sole responsible for the estimations presented in this publication.

[82] Pezzutto, S. & Sparber, W (2013). It should be noted that some of the projects considered deal with RES for the production of both thermal energy and electrical energy. In these cases, the authors estimated the share of the total budget which is dedicated to RHC R&D.

Reflecting the implementation of new instruments, the number of RHC projects in FP7 has increased compared with FP6 and the average project funding has grown from about 2.9 mln € to about 4.8 mln €. Based on the provisional information the ratio between funding and eligible costs is at 66% in FP7. Although the FP7 call 2013 SMARTCITIES was not taken into account at all with respect to funding allocation, as a whole it is clear that RHC R&D received little attention in FP7.

If the EU does not devote significant and sufficient funding to RHC research and innovation, it risks losing its technology lead in the sector in which most energy is consumed. Early in 2013 the EU multiannual budget 2014 - 2020 will be finalised and "Horizon 2020" – the new EU funding programme for research and innovation – will enter into force on the 1st January 2014. **Now is a crucial time for the EU decision makers to show their commitment towards the European RHC industry by allocating sufficient funding resources to R&D activities**, paving the way for the RHC-Platform's Common Vision to become reality. **The implementation of the RHC-SRA will require a yearly investment of approximately 114 mln Euro of EU resources, totalling 800 mln Euro by 2020**.

9.2 **Public funding for R&D at MS level**

To ensure that renewable energy technology for heating and cooling and the associated industries develop as planned, it is crucial that research resources are mobilised across Europe. This challenge will require investments to be coordinated at European and national level.

EU Member States award relatively little attention to energy research compared with United States or Japan[83]. The public energy R&D spending decreased during the early 1990s with some limited increases in the last decade. Energy R&D spending shows major variations among Member States, but shared priorities exist in some technologies among groups of countries. Synergies should be exploited in these areas, which is of particular importance for capital-intensive RHC R&D activities.

No comprehensive studies have been undertaken to investigate Member State funding of R&D in the RHC sector. On the basis of IEA data, the aggregate direct support for RHC R&D stands at around 55 mln Euro yearly in European countries[84]. Although this data might not take into account the entire and diverse range of RHC technologies, it provides a useful indication of the general trend. **According to an estimation of the RHC-Platform** based on data collected in France, Germany, Italy, Austria and Spain, **from 2007 to 2012 the total public investments in R&D by EU Member States amounted to 350 mln Euro**.

In future, systematic and better reporting of information on RHC R&D spending, programmes and priorities is a pre-requisite for a better coordination of energy R&D programmes among EU Member States. High-quality research infrastructure is built on long-term and adequate R&D budgets. **It is of crucial importance for the implementation of the RHC-SRA that Member States progressively increase national R&D funding for RHC, with the aim of doubling the overall effort by 2020 (corresponding to 800 mln Euro for the period 2014-2020)**.

9.3 **Investments by the private sector**

The heterogeneity in R&D efforts among EU Member States also holds true for the R&D expenditures of the industries in the RHC sector. The scale of technologies involved is so extended and the related value chain so complex that it is not possible to identify all private investments at the different stages of RHC innovation processes.

The approach adopted was therefore to estimate the R&D commitments by industry to 2020 using as basis for this calculation the resources dedicated on annual basis to R&D. According to the estimation of the authors[85], the total turnover of the RHC industries in the EU is 65.2 billion € for 2011. Nearly all private R&D investments are actually performed by the material and equipment manufacturers, therefore the turnover generated by sales of services

[83] Joint Research Centre – Institute for Prospective Technological Studies. "Energy Research Capacities in EU Member States" (2008).

[84] http://www.iea.org/Textbase/stats/rd.asp. Note that 17 out the 27 EU Member States are IEA members and thus included in this database.

[85] Cfr. Table 20. Data provided by AEBIOM, EGEC, ESTIF, EHPA and Euroheat & Power.

(e.g. installation, planning, maintenance) is excluded in the following calculations. The ratio of R&D expenditure to net sales varies significantly, however for most companies this is in the range from 1% to 3%.

Table 20 illustrates the total investments expected of the private sector between 2014 and 2020, calculated as a proportion of the net sales of the component industries.

	Solar Thermal	Biomass	Geothermal	AHP	DHC	TOTAL
Total installed (GWth; Year 2020)	102.5	795	44.9	35.7	n.a.	**942.4**
System price (EUR/kWth; Year 2012)	500	Variable	1,500-7,000	1,000	n.a.	-
Annual system price reduction	8%	3%	2-10%	3%	n.a.	-
Turnover of the entire sector, incl. services (Mln EUR; period 2014-2020)	21,924	200,526	41,808	21,712	264,314	**528,572**
Share of manufacturing industry on sector turnover	40%	40%	40%	40%	3.5%	**40%**
Turnover manufacturing industry (Mln EUR; period 2014-2020)	8,770	80,210	16,651	8,685	9,198	**103,057**
Share of R&D on turnover of manufacturing sector only	3%	2%	2% (5% for EGS)	2.5%	2%	-
R&D investments of manufacturing industry (Mln EUR; period 2014-2020)	263	1,604	381	217	184	**2,432**

Table 20: Total investments expected of the private sector between 2014 and 2020, calculated as a proportion of the net sales of the component industries.

COMPANY	COUNTRY	NET SALES (Mln EUR)	R&D INVESTMENTS (Mln EUR)	R&D INTENSITY RATIO
Bosch Thermotechnology	Germany	450	18.5	4.1%
Dalkia	France	8,300	90	1.1 %
Danfoss DEN	Denmark	322	6	1.9%
Schlumberger	France	29,970	813	2.7%
KWB	Austria	47	4.6	9.8%
Schiedel AG	Austria	200	1	0.5%
Scheuch GmbH	Austria	120	3	2.5%
RIKA	Austria	50	2	4%
VAPO Oy	Finland	706	4.4	0.6%

Table 21: Total R&D investments of selected companies of the RHC sector.

9.4 Overall budget expectations

Since 2007 numerous R&D activities have been carried out at EU and national level which allowed the achievement of significant advancements in RHC technology. Only a minority of research and innovation initiatives have been performed with EU funding from FP7. Nonetheless, the meagre budget that was made available for RHC technology provided a vital impulse to the related industries which achieved cost reductions and crucial performance improvements.

In order to pursue the EU objective of decarbonising the heating and cooling sector, there is a clear need for more resources being invested by the European Union and by the Member States. **The RHC-Platform estimates that 4,032 mln Euro are required for the successful implementation of this Strategic Research and Innovation Agenda in Europe**[86].

Figure 45 illustrates the RHC-Platform's proposal for the resources expected to be committed respectively by the European industry (60%), European Commission (20%) and Member States (20%). **Over the period 2014 - 2020, on average 576 mln Euro should be allocated annually to RHC research and innovation activities**.

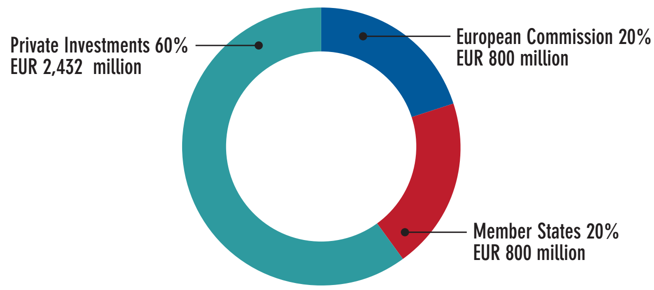


Figure 45: estimation of total resources required to implement the RHC-Platform's SRA between 2014 and 2020, in million Euro and in %.

The EU should put pressure on its Member States to increase their direct national funding for renewable energy research. It should lead by example and, as a first step, increase its RHC research and innovation budget to 114 mln Euro per year. The current economic climate of public spending austerity should not prevent Member States (at aggregate level) to match the EU spending in RHC research and innovation, which also represent an investment in economic growth, job-creation and sustainable development. Finally, as 60% of the required resources should be invested by the private sector, 347 mln Euro is expected to be committed each year by the diverse industrial components of the RHC sector.

[86] 2011 Values.

10.
Concluding remarks

Reliable, affordable and sustainable energy supply is fundamental to the functioning of modern society, to the quality of life of people and to the economic growth of Europe. The use of renewable energy sources for residential, non-residential and industrial heating and cooling applications is the most effective way to achieve emission reductions and to improve energy security.

This **Strategic Research and Innovation Agenda** responds to the need for a **detailed analysis of the priorities for Renewable Heating and Cooling** technology to take centre stage in the EU energy policy and achieve higher levels of market penetration by 2020 and beyond. Specific objectives and measurable targets are identified for each research and innovation priority. The technology-specific targets are mostly expressed in terms of cost reduction and/or efficiency gain; however the implementation of the RHC-SRA in its entirety requires a systemic approach to produce innovative integrated solutions.

Stakeholders of the RHC-Platform are taking active part in the SET-Plan initiative on **Smart Cities and Communities** which promises to effectively support the development of the integrated RHC solutions which are sought by civil society. The success of the Smart Cities Initiative depends on the energy portfolio that will be created, which in turn needs to rely on careful urban planning. The adoption of relevant energy efficiency measures should go hand-in-hand with the demonstration of new renewable heating and cooling projects.

With the RHC-SRA, a comprehensive strategy has been put forward to support the decarbonisation of the heating and cooling sector in the EU and to provide a framework for the European RHC stakeholders to emerge strengthened from the current economic downturn. **Research and innovation** are placed at the heart of the RHC-Platform's agenda as our **industry competitiveness** and **ability to create new jobs** depends on the capacity to further reduce costs and to improve the quality of energy applications and services. **Raising the public-private expenditure** for RHC research to the average annual level close to 0.6 billion Euro is crucial to achieve the full RHC industry potential. To this end, support is required at the EU level through different funding instruments, first and foremost **HORIZON 2020 which should dedicate to RHC R&D the attention and resources the sector deserves**.

Private investors look for the right signals today – from the EU and national governments – to make Europe a competitive and renewable energy economy by 2050. Filling the EU vacuum of climate and energy policies for the period 2020-2030 is essential in order to reduce both regulatory risk and investors' uncertainty. **Ambitious and binding renewable energy targets for 2030** are needed to ensure a stable and positive investment climate across the EU.

Renewable heating and cooling can provide an important contribution to major societal challenges, such as climate change, security of supply and energy efficiency. Today we manage to produce 14% of energy for heating and cooling from RES. But the potential is vaster: RHC technology could satisfy a quarter of EU consumption by 2020. If we are to achieve our ambitions of decarbonisation and market growth, now is the time to work towards **the effective implementation of the RHC-SRA**.

At the time of publishing, the RHC-Platform is working on the production of a Technology Roadmap for Renewable Heating and Cooling. The Implementation Plan will rely on the information provided in the present publication to propose a set of research, development and demonstration projects for the period 2014-2020.

Appendix 1
Renewable heating and cooling in the EU-27 (Mtoe)[87]

Industry	2004	2005	2006	2007	2008	2009	2010
Final energy consumption in industry (all fuels)	335,979	331,227	324,293	325,504	314,988	267,954	291,507
Electricity consumption in industry	96,069	97,138	97,049	98,640	96,943	83,319	88,960
Final consumption of RE in industry (excl.derived heat)	16,561	16,940	17,889	20,117	20,130	19,294	21,655
Other Sectors	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Final energy consumption in households, services, etc. (all fuels)	487,489	493,272	493,361	462,740	483,610	477,614	498,360
Electricity consumption in households, services, etc.	132,859	135,036	140,331	140,427	143,193	144,160	149,130
Final consumption of RE in households, services, etc. (excl. derived heat)	33,667	34,244	34,959	35,561	37,322	38,948	43,492
Total consumption in industry and other sectors (all fuels)	823,468	824,499	817,654	788,243	798,598	745,569	789,866
Electricity consumption in industry and households	228,928	232,175	237,381	239,067	240,136	227,479	238,089
Consumption of heat in the electricity/heat generation sector	572	571	661	629	455	584	637
Transmission and distribution losses for derived heat	5,140	5,198	5,001	4,146	4,199	4,179	4,479
Gross final energy consumption for heating and cooling	600,252	598,094	585,935	553,951	563,116	522,852	556,892
Final consumption of RE in industry and other sectors (excluding derived heat and non-compliant biofuels)	50,235	51,190	52,855	55,685	57,458	58,247	65,152
Production of derived heat from RE (in CHP and Heat plants, solar, geothermal, and combusti-ble renewables)	6,146	6,616	6,898	6,966	7,593	7,918	9,476
Renewable energy from Heat pumps	967	1,225	1,548	2,025	3,447	4,088	4,586
Renewable energy for heat production from compliant biofuels (including derived heat)	275	626	819	877	634	702	652
Renewable energy for heating and cooling	**57,623**	**59,658**	**62,120**	**65,553**	**69,131**	**70,956**	**79,866**

RHC (%)	9.60%	9.97%	10.60%	11.83%	12.28%	13.57%	14.34%

[87] Source: Šturc, M. (2012).

Appendix 2
Analysis of National Renewable Energy Action Plans

Country	Final Energy Consumption in Heating and Cooling* (ktoe)		Share of Renewables (ktoe)	
	2010	2020	2010	2020
Austria	12,007	12,802	3,657	4,179
Belgium	21,804	21,804	766.4	2,588.4
Bulgaria	4,492	4,638	741	1,103
Cyprus	480	527	78	124
Czech Republic	17,805	18,680	1,810.9	2,672.2
Denmark	8,042	7,653	2,480	3,042
Estonia	1,572	1,579	612	607
Finland	14,010	15,300	5,210	7,270
France	67,159	60,000	11,124	19,732
Germany	111,597	93,139	10,031	14,431
Greece	8,644	9,674	1,269	1,908
Hungary	10,347	9,719	949	1,863
Ireland	5,160	4,931	220	591
Italy	58,976	61,185	3,851	10,456
Latvia	2,251	2,612	1,020	1,395
Lithuania	2,417	2,684	666	1,051
Luxembourg	1,235	1,268	25.5	107.8
Malta	44.76	72.73	3.5	4.5
The Netherlands	24,612	24,989	906	2,179
Poland	32,400	34,700	3,980	5,921
Portugal	7,286	8,371	2,240	2,507
Romania	15,788	18,316	2,819	4,038
Slovakia	5,971	5,613	452	820
Slovenia	1,996	2,029	445	625
Spain	33,340	29,849	3,764	5,645
Sweden	14,488	16,964	8,237	10,543
United Kingdom	60,000	51,500	518	6,199
EU-27	**543,923.8**	**520,598.7**	**67,875.3**	**111,601.9**
% of RES in final energy consumption			12.5%	21.4%

**Taking into account additional energy efficiency measures*

Appendix 3
Potential of RHC technology and clusters of key research and innovation areas by 2020

	Potential Contribution	Key research and innovation areas by 2020
Biomass	By 2020: 124 Mtoe By 2050: 231 Mtoe	• Small scale CHP for domestic, industrial or regional solutions. • Tri-generation. • Advanced fuels (new solid biocommodities, thermally treated biomass fuels, pyrolysis oil) replacing coal and fossil oil in CHP. • High efficient large-scale or industrial steam CHP with increased high temperature heat potential (up to 600°C).
Solar Thermal	By 2020: 13 Mtoe By 2050: 133 Mtoe	• New materials, designs, and manufacturing technologies for solar thermal collectors. • Reducing costs of high solar fraction systems, multi-functional solar façade systems and solar based hybrid systems covering the full heating load. • Optimised heating systems for "Solar-Active-Houses" and highly efficient solar-assisted cooling systems. • Improved low to high temperature solar thermal solutions for industrial processes using optimised large-scale collector arrays.
Geothermal	By 2020: 10.5 Mtoe By 2050: 150 Mtoe	• Integration of design of the shallow geothermal system and building energy system with regard to optimum thermal use and operational strategy. • Optimisation of components such as borehole heat exchangers, well completion materials, compressors, pumps etc., including improved drilling methods. • Innovative exploration, drilling and production methods for deep geothermal resources, including related surface installations, for reducing overall cost and risks caused by geological uncertainties. • Reducing cost and increasing the lifetime of Enhanced Geothermal Systems - EGS (focus on exploration, drilling, hydraulic fracturing, formation treating, reservoir predictive models, and heat production).
Cross-cutting	Energy saving potential by 2020: Industrial heat pumps: 20 Mtoe District Heating: 50.7Mtoe / year District Cooling: 5.5 Mtoe / year	• Efficiency increase for heat pump technology (both electrically-driven and thermally-driven applications). • R&D to make available integrated, flexible, highly efficient and environmental friendly district heating and cooling systems, in particular through a better valorisation of local resources, development of low-temperature networks and the integration of innovative thermal storage. • R&D to increase storage density using phase change materials and thermochemical materials. • Development of advanced algorithms for optimal planning, management and control of hybrid systems.

Appendix 4
Synoptic tables of research and innovation priorities by RHC technology type

Strategic research and innovation priorities for Biomass Technology

	Research and Innovation Priorities	Predominant type of activity	Impact
BIO.1	Improve system design of residential biomass heating systems	Demonstration	By 2020
BIO.2	Demonstrate the potential of efficient biomass boilers and stoves to improve air quality and reduce energy consumption	Demonstration	By 2020
BIO.3	Cost-effective micro-CHP systems	Development/ Demonstration	By 2020
BIO.4	*Development of next generation of firewood stoves (and inset appliances and cookers)*	Development	By 2030
BIO.5	*Fuel flexible residential scale boilers*	Research	By 2030
BIO.6	Cost effective solutions to reduce dust emissions	Demonstration	By 2020
BIO.7	Cogeneration technologies and small scale biomass gasification technologies	Development	By 2020
BIO.8	*Development of advanced cost-efficient high quality solid and liquid biomass fuels from agro-biomass, bio-degradable waste, forestry and aquatic biomass*	Development/ Demonstration	By 2030
BIO.9	Development of highly efficient large-scale or industrial CHP with enhanced availability and high temperature heat potential	Demonstration	By 2020
BIO.10	*Development of high efficient biomass conversion systems for tri-generation (heating, cooling and power)*	Development	By 2030
BIO.11	Cost efficient CHP plants using biomass and biogas	Development	By 2020
BIO.12	*Development of CO_2-negative bioenergy systems*	Research	After 2030

Strategic research and innovation priorities for Geothermal Technology

	Research and Innovation Priorities	Predominant type of activity	Impact
GEO.1	Optimisation of ground-coupling technology (i.e. technology to exchange heat with the ground in an optimal way)	Development	By 2020
GEO.2	Improving the understanding of the shallow geothermal reservoir	Development	By 2020
GEO.3	*Research on pipe material for borehole heat exchangers (BHE) or horizontal ground loops*	Research	By 2030
GEO.4	System concepts and applications for geothermal cooling in warm climates	Development	By 2020
GEO.5	Development of ground coupling technologies and installation techniques for high capacities	Demonstration	By 2020
GEO.6	*Integration of design of the shallow geothermal system and building energy system with regard to optimum thermal use and operational strategy*	Development	By 2030
GEO.7	Geothermal Heat for industrial processes up to 250 °C	Development/Demonstration	By 2020
GEO.8	Production pump technology for temperatures >180 °C	Development/Demonstration	By 2020
GEO.9	*Unconventional resources and very high temperatures*	Research	By 2030
GEO.10	Deep Drilling	Development	By 2020
GEO.11	Production technologies	Demonstration	By 2020
GEO.12	Surface systems for heat uses in DHC (incl.CHP)	Demonstration	By 2020
GEO.13	*Enhanced Geothermal Systems (EGS)*	Development	By 2030
GEO.14	*Resource Assessment for deep geothermal heat use*	Research/Development	By 2030

Appendix 4
Synoptic tables of research and innovation priorities by RHC technology type (continued)

Strategic research and innovation priorities for Solar Thermal Technology

	Research and Innovation Priorities	Predominant type of activity	Impact
ST.1	New surfaces, coatings, materials, construction designs, and manufacturing technologies for solar thermal collectors	Development	By 2020
ST.2	Cost effective solar based hybrid systems able to satisfy the entire building heating demand	Development	By 2020
ST.3	Optimised heating systems for 'Solar-Active-Houses'	Development	By 2020
ST.4	*Research on the next generation of the Solar Active House – the Smart Solar Building*	Research	By 2030
ST.5	*Improving the components of solar thermal cooling systems.*	Research	By 2030
ST.6	Multifunctional building components, including façade and rood integrated collectors for new and existing buildings	Development	By 2020
ST.7	Highly efficient solar assisted cooling systems combining heating and cooling	Development	By 2020
ST.8	*Solar Based hybrid systems for 100% renewable heat solutions*	Research	By 2030
ST.9	*Research on new absorption chillers*	Research	By 2030
ST.10	Medium temperature collectors developed and demonstrated in industrial applications	Development	By 2020
ST.11	*Turn-key solar thermal process heat-systems*	Research	By 2030
ST.12	Optimize large-scale solar collector arrays for uniform flow distribution and low pumping power	Research	By 2020
ST.13	*Advanced solutions for the integration of large solar thermal systems into smart thermal/electrical grids*	Research	By 2030

Appendix 4

Synoptic tables of research and innovation priorities by RHC technology type (continued)

Strategic research and innovation priorities for Cross-cutting Technology

	Research and Innovation Priorities	Predominant type of activity	Impact
CCT.1	Cost competitive heat pump kit for houses with existing boiler	Development	By 2020
CCT.2	Optimisation of thermally driven heat pumps and their integration in the boundary system	Development	By 2020
CCT.3	Automation, control and long term reliability assessment	Development	By 2020
CCT.4	*Development of a heat pump for near-zero energy buildings (single family house)*	Development	By 2030
CCT.5	*Next generation of highly integrated, compact hybrid systems*	Development/Demonstration	By 2030
CCT.6	Next generation of Sensible Thermal Energy Storages	Development	By 2020
CCT.7	*Improving the efficiency of combined thermal energy transfer and storage*	Development	By 2030
CCT.8	*Increased storage density using phase change materials (PCM) and thermochemical materials (TCM)*	Research	By 2030
CCT.9	High capacity heat pump for simultaneous production of cold and hot water for heating/cooling the building	Development	By 2020
CCT.10	Integration, automation and control of large scale hybrid systems for non-residential buildings	Development/Demonstration	By 2020
CCT.11	*Sorption cooling systems driven by hot water at moderate temperature*	Development	By 2030
CCT.12	Enhanced industrial compression heat pumps	Development	By 2020
CCT.13	Process integration, optimisation and control of industrial heat pumps	Demonstration	By 2020
CCT.14	Improvements in Underground Thermal Energy Storage (UTES)	Demonstration	By 2020
CCT.15	*Improvement of sorption cooling from renewable energy sources*	Development	By 2025
CCT.16	*New concepts for industrial heat pumps*	Research	By 2030
CCT.17	Large scale demonstration of Smart Thermal Grids	Demonstration	By 2020
CCT.18	Booster Heat Pump for DHC	Demonstration	By 2020
CCT.19	Develop and roll-out DHC driven white goods and low temperature solution for domestic hot water preparation	Development/Demonstration	By 2020
CCT.20	*Improved, highly efficient substations for both present and future lower temperature networks*	Development	By 2030
CCT.21	*Optimised integration of renewable energy sources in DHC systems and enhancement of thermal energy storage at system level*	Demonstration	By 2030

Research and Innovation priorities with generic impact on RHC applications in the residential sector

	Research and Innovation Priorities	Predominant type of activity	Impact
RHC.1	Developing standards for the overall system design and for hydraulic and electrical interconnections of different building components	Development	By 2020
RHC.2	Elaborating standards, tests, and benchmarks for system efficiency	Development	By 2020

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Appendix 6
Abbreviations, Acronyms and Units of Measure

AHP Air-source heat pump	**ALPO** Alumino-Phosphate	**AlSi** aluminium-silocon alloy	**ATES** Aquifer Thermal Energy Storage
BHE Borehole Heat Exchanger	**BIO** Biomass	**BTES** Borehole Thermal Energy Storage	**CAPEX** Capital Expenditure
CCT Cross-Cutting Technology	**CEN** European Committee for Standardization	**CFD** Computational Fluid Dynamics	**CHP** Combined Heat and Power
CHP-C Combined Heat, Power and Cooling (trigeneration)	**CO** Carbon Monoxide	**CO_2** Carbon Dioxide	**COGEN** Cogeneration
COP Coefficient of Performance	**CTES** Thermal Energy Storage in Artificial Caverns	**D.comb** Direct Co-combustion with Coal	**DH** District Heating
DHC District Heating and Cooling	**DHW** Domestic Hot Water	**EC** European Commission	**EF-MGT** Externally Fixed Micro-Gas Turbine
EGEC European Geothermal Energy Council	**EGS** Enhanced Geothermal Systems	**EHPA** European Heat Pump Association	**EIB** European Investment Bank
ESP Electric Submersile Pump	**ESPs** Electrostatic Precipitators	**ESTIF** European Solar Thermal Industry Federation	**ESTTP** European Solar Thermal Technology Platform
EU European Union	**EURAC Research** European Academy of Bozen/Bolzano	**EWG** Environmental Working Group	**FBC** Fluidized Bed Combustion
FBs Fluidized Beds	**FeCrAl** Kanthal (Iron-Chromium-Aluminium)	**FWS** Födergemeinschaft Wärmepumpen Schweiz	**GEO** Geothermal
GHG Greenhouse Gas	**GSHP** Ground Source Heat Pump	**GUE** Gas Utilisation Efficiency	**GWP** Global Warming Potential
H&C Heating and Cooling	**HGI** Higher Hargrove Grindability Index	**HP** Heat Pump	**HT** High Temperature
HVAC Heating, Ventilation & Air Conditioning	**IC** Internal Combustion	**ICT** Information and Communication Technology	**IEA** International Energy Agency
IGCC Integrated Gasification Combined Cycle	**Ind.comb** Indirect Co-combustion with Coal	**LiBr** Lithium Bromide	**LSP** Line-Shaft Pump
LT Low Temperature	**NREAPs** National Renewable Energy Action Plans	**O&M** Operation and Maintenance	**OECD** The Organisation for Economic Co-operation and Development
OGC Organic Gaseous Carbon	**OPEX** Operational Expenditure	**ORC** Organic Rankine Cycle	**Pb** Lead
PCMs Phase Change Materials	**PM** Particulate Matter	**PRIMES** As a partial equilibrium model for the European Union energy markets, PRIMES is used for forecasting, scenario construction and policy impact analysis up to the year 2030	**PTES** Pit Thermal Energy Storage
PVT Photovoltaic Thermal	**R&D** Research and Development	**RDF** Resource Description Framework	**RED** Renewable Energy Directive
RES Renewable Energy Sources	**RHC (RH&C)** Renewable Heating and Cooling	**SAPO** Silico-Aluminophosphate	**sCOP** seasonal Coefficient of Performance
SPF Seasonal Performance Factor	**SRA** Strategic Research and Innovation Agenda	**ST** Solar Thermal	**TC** Thermo-Chemical
TCM Thermo-Chemical Materials	**TES** Thermal Energy Storage	**TMF** Thermal Mechanical Fatigue	**TRL** Technology Readiness Levels
TTES Tank Thermal Energy Storage	**TVS** Technical and Vocational School	**UTES** Underground Thermal Energy Storage	**VAT** Value Added Tax
Zn Zinc	**ηH** Hellström-Efficiency		

Units of Measure

°C degrees Celsius	**€** Euro	**€/m** Euro per meter	**€/ton** Euro per tonne
€/W Euro per Watt	**€/W_{el}** Euro per Watt electrical	**EUR/GJ** Euro per Gigajoule	**EUR/MWh** Euro per Megawatt hour
Euro/kW Euro per Kilowatt	**g** Grammes	**GJ** gigajoule = 10^9 joules	**Gt** gigatonne = 10^9 tonnes
GW_e Gigawatt Electrical	**GW_{th}** Gigawatt of thermal capacity = 10^9 watts	**K** Thousand	**K/(W·m)** Kelvin per Watt and meter
KJ/kg Kilojoules per kilogram	**kW** Kilowatt	**kW_{el}** Kilowatt Electrical Capacity	**kWh** kilowatt-hour = 10^3 x 1 hour
kWh/m³ Kilowatt hours per meter cubed	**kWh/t** Kilowatt hours per tonne	**kW_{th}** Kilowatt Thermal Capacity	**l/s** Litres per second
m Meter	**M€/MW** Millions of Euro per Megawatt	**m²** Square Meter	**mg** Milligram
mg dust/MJ Concentration in milligram of dust per Megajoule	**mg CO/MJ** Concentration in milligram of Carbon Monoxide per Megajoule	**mg OGC/MJ** Milligram Organic Gaseous Carbon per Megajoule	**Mt** megatonne = 10^6 tonnes
Mtoe Million tonnes of Oil Equivalent = 10^6 tonne of oil equivalent	**MWh** Megawatt hour	**MW_{th}** Megawatt Thermal	**OGC/MJ** Organic Gaseous Carbon per Megajoule
PJ Petajoule	**T** Tonne	**TWh** terawatt-hour = 10^{12} watt x 1 hour	**W** watts
W/m/K Watts per meter and Kelvin	**W_{el}** Watt Electrical	**ηH** Hellström-Efficiency	

Appendix 7
Secretariat of the RHC-Platform

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EUREC AGENCY
European Renewable Energy Research Centres Agency

and managed in collaboration with:

AEBIOM
EUROPEAN BIOMASS ASSOCIATION

European Biomass Association

EGEC GEOTHERMAL

European Geothermal Energy Council

ESTIF European Solar Thermal Industry Federation

European Solar Thermal Industry Federation

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European Commission
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