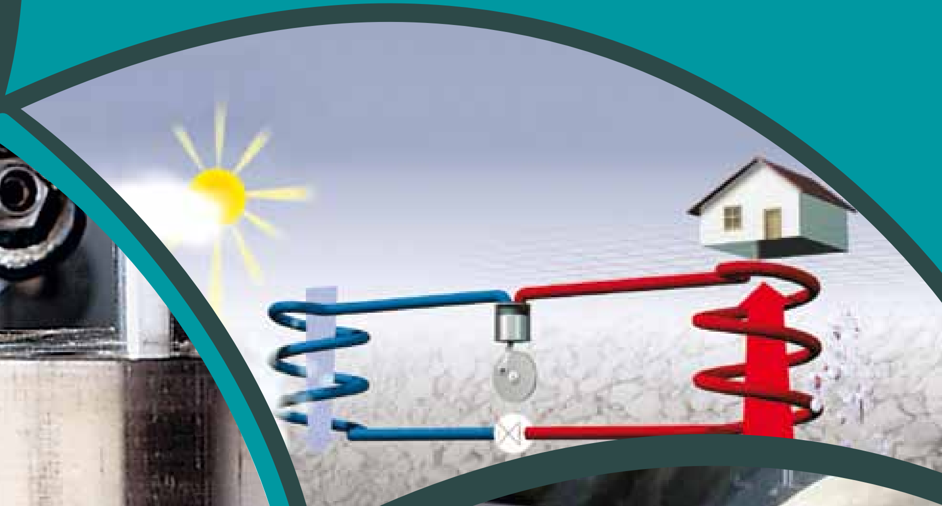
Strategic Research Priorities for Cross-cutting Technology

European Technology Platform on Renewable Heating and Cooling



Renewable Heating & Cooling
European Technology Platform

Strategic Research Priorities for Renewable Heating & Cooling Cross-Cutting Technology

European Technology Platform on Renewable Heating and Cooling

RHC Renewable Heating & Cooling
European Technology Platform

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TABLE OF CONTENTS

1. Introduction to cross-cutting technology

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1. Introduction to cross-cutting technology

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1.1 Definition

Renewable energy sources (RES) for heating and cooling are becoming an increasingly important component of Europe's energy mix. In May 2011 the European Technology Platform on Renewable Heating and Cooling (RHC-Platform) published its "Common Vision"[1], a landmark document which explored the short-, medium- and long-term potential of renewable heating and cooling in the European Union.

The Common Vision demonstrated that the combined potential of biomass, solar thermal, geothermal and aerothermal sources is enough to satisfy the total expected demand for heating and cooling in the EU before 2050[2].

Nevertheless, this objective can only be achieved if Europe makes better use of its resources. Even though RES for heating and cooling generally have very limited environmental impact and may have no greenhouse gases emissions at all[3], efficiency gains are crucial for renewables to fulfill its potential in the next decades. To the RHC-Platform, energy efficiency therefore means achieving synergies among the renewable energy production, distribution and consumption.

"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 a RES, or 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.
Four key energy technologies have been identified that fit the definition above.

- **District Heating and Cooling** increases the overall efficiency of the energy system by recycling heat losses from a variety of energy conversion processes. Heat which otherwise would be unutilised is recovered and used to meet thermal demands in buildings and industries. Renewable sources which otherwise would be difficult to use, such as many forms of biomass and geothermal energy, can also be exploited. By aggregating a large number of small and variable heating and cooling demands, District Heating and District Cooling allow energy flows from multiple RES to be combined while reducing primary energy demand and carbon emissions in the community served.

- **Thermal energy storage** is the solution for a key bottleneck against the widespread and integrated use of RES, since the renewable supply does not always coincide with the demand for heating or cooling. Numerous technologies in sensible, latent or thermochemical form can time-shift renewable energy supply to periods of greatest demand, each of them characterised by different specifications and specific advantages.

- **Heat pumps** transform thermal renewable energy available at low temperatures from natural surroundings to heat at higher temperature. The heat pump cycle can be also used to provide cooling. Heat pumps use aerothermal, hydrothermal and geothermal energy, and can be combined with heat from other RES in hybrid systems (see below). These sources might be renewable in origin or waste energy from industrial processes and exhaust air from buildings. Heat pumps can be highly efficient, although their overall primary energy efficiency depends on the efficiency of electricity production (or other thermal energy source) they use.

[1] Common Vision for the Renewable Heating and Cooling Sector in Europe: 2020 - 2030 - 2050. European Technology Platform on Renewable Heating & Cooling (RHC-Platform), May 2011. Available at http://www.rhc-platform.org/publications/

[2] This forecast is sensitive to future energy savings.

[3] Renewable energy installation may cause limited visual, noise or interference impact, especially at the local level, although generally these can be minimized if the installation is planned and sited sensitively.

- **Hybrid renewable energy systems**, combining two or more energy sources into a single system, can overcome the limitations of individual technologies. This is true for small scale applications such as heating and cooling systems for single family houses as well as for large scale systems suitable for district heating and cooling or industrial processes. The combination of RES available at different times within the system is especially useful if a more constant demand for heat exists, with the overall efficiency of the system depending strongly on the way the different sources are combined.

1.2 Vision and Strategic Research Agenda

This RHC-Platform publication on strategic research priorities for cross-cutting technology is the first of its kind for the renewable heating and cooling sector. It provides stakeholders with a structured and comprehensive view of the potential of cross-cutting technology 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 cross-cutting technology. While some of the systems, components and infrastructure that qualify as cross-cutting technology are already mature, additional efforts on the research, development and demonstration of these enabling technologies is critical for the achievement on time of the European Union's objectives.

Alongside growing the market for renewable heating and cooling technology, achieving significant breakthroughs through targeted, collaborative research and development activities in cross-cutting technology is fundamentally important.

This **Strategic Research Agenda (SRA)** in cross-cutting technology provides recommendations to policy makers on how to allocate the budgets of European and national programmes aimed at supporting research and development and stimulating market pull. In particular, the SRA can be used as input for the identification of the most appropriate areas to fund under the Seventh Framework Programme for Research and Development of the European Union, as well as guidance for the definition of its successor programme Horizon 2020.

Achieving decarbonisation of the heating and cooling sector is a challenging policy goal due to the large number of individual decision-makers and to the fact that the industry is large, diverse and fragmented. The development of this sector can be spurred not only through technological advancement, but also by the regulatory framework which has nurtured the Europe's renewable electricity industry. For this reason, the SRA also sheds light on a number of non-technological priorities which are a prerequisite for the transition to a low-carbon society - a key strategic objective of the European Union.

1.3 Governing Principles

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

I. Time scale

This report categorises the times by when the results of the R&D work covered in the SRA should be commercially deployed in the following way. It is important to fund R&D work now that will have an impact in these different time frames to ensure a continual supply of new ideas to the sector:

[4] This time period was chosen because EU targets for renewable energy, energy efficiency and CO2 reduction already exist for 2020.

[5] It should be noted that several research priorities presented in Chapter 2 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.

- Until 2020: Short term
- Until 2030: Medium term
- Beyond 2030: Long term

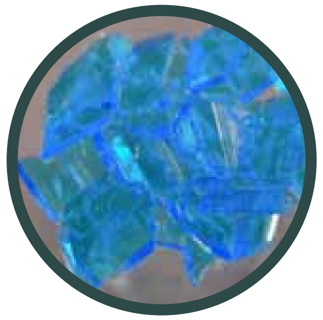
The convention used in this report is to refer strategic and research priorities to the time horizon in which they are first expected to be used in commercial product, not to year by which widespread use is expected.

II. Inclusiveness

Cross-cutting 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 to reflect the technological progress in the renewable heating and cooling sector.

III. Value chain approach

Public money is required to contribute to funding 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 entire value chain.

2. District Heating and Cooling

Photos © A2A

2. District Heating and Cooling

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2.1 Background

To achieve its objective of almost **zero carbon energy supply by 2050**, the EU needs to support the development of integrated, flexible, highly efficient and environmental friendly solutions. The European District Heating and Cooling (DHC) sector fully shares these goals[6].

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, DHC must continue to evolve within its context to continue representing a smart, sustainable and inclusive solution. To enhance DHC's application in a future energy landscape, further research, demonstration and technological development are needed.

In line with the scope and objectives of the Strategic Research Agenda (SRA), this chapter explores the potential of DHC and it identifies short, medium and long term priorities. It takes into account the needs, targets and thematic areas identified through a consultation of European stakeholders[7] and differentiates between **technological** and **non-technological priorities**.

2.1.1 Vision and Potential

In its "Vision", the DHC sector sets out in global terms how it can contribute to the achievement of the EU energy objectives and how European DHC stakeholders see the future development of the sector up to 2050. This document represents the basis for the present SRA chapter on DHC, together with the "Common Vision"[8] developed by the European Technology Platform on Renewable Heating and Cooling.

The DHC sector fully embraces the **Europe 2020** growth strategy developed by the European Commission for the coming years to ensure high competitiveness of the European market. It shares the principles of being sustainable, smart and inclusive that the DHC sector has been working towards for several decades. DHC will play a key role enabling the **green transition** of the heating and cooling sector. **By 2020, in Europe, we predict that 25% of energy distributed through DHC networks will be produced from RES.**

This shall be achieved through **large-scale replication of best practice**: better valorisation of local resources; increasing the use of RES; including surplus energy and energy from urban waste; and by making DHC networks more efficient in relation to the use of new resources. In parallel, to make systems more **flexible**, low-temperature networks should be developed, innovative thermal storage integrated into them and interaction between the DHC network and other energy networks (electricity and gas) optimised. To enable significant expansion, **cost-effectiveness** must be enhanced by moving from custom-made DHC network designs to more uniform designs. Transfer of know-how and optimisation of policies will facilitate market penetration and access to efficient heating and cooling technologies.

[6] As outlined in the document "A vision towards 2020, 2030 and 2050", published by the DHC+ Technology Platform (2009) and available on www.dhcplus.eu.

[7] Priorities and targets presented in this chapter are also based on the findings of a workshop on the "Integration of RES in DHC" organised on the 28 September 2011 by DHC+ Technology Platform and EUREC Agency in the framework of the activities of the RHC-Platform.

[8] See reference in footnote n. 1

Through these developments, in the **medium term** DHC networks will stand as the **backbone** of heating and cooling supply in **smart cities**. The paradigm shift relies on the involvement of communities. In order to give communities the possibility to choose the energy mix they want, they must be provided with the right tools and equipment. The sector needs to understand and anticipate energy demand in both the longer and shortest (from hour to hour) term. A range of sustainable applications and solutions, tailor-made to suit customers' profiles, can replace electricity use for thermal applications. Equipped with modern, reliable and efficient DHC systems, **smart communities** will be empowered **to optimally exploit the energy transition** for the benefit of their citizens.

In the **long term**, DHC will serve as key enabler to complete the decarbonisation of Europe's energy supply. DHC networks, integrated at regional level, will express the full potential of RES for heating and cooling, allowing the development of a holistic approach to thermal comfort needs (heating, cooling and hot water preparation).

2.1.2 State of the Art

The fundamental idea of DHC is to move thermal energy from a place where it is available, unneeded and will be wasted to a place where demand for thermal energy exists. 75% of district heat in Europe comes from Combined Heat and Power (CHP) units, sometimes running on RES. The remaining 25% is based on the production of heat from RES and fossil fuels[9] specifically for the DHC network and its customers.

The **first generation** of district heating systems used steam as heat carrier. These systems were first introduced in USA in the 1880s and later spread to Europe. Almost all district heating systems established before 1930 used this technology, at which time **second generation** systems using pressurised hot water typically over 100 ºC took over.
The current generation **(third generation)** of systems was introduced in the 1970s. Pressurised water at a temperature often below 100ºC is the heat carrier.

The tendency so far has been towards lower distribution temperatures, material-lean components and prefabrication to reduce installation costs. The **forth generation** of DH technology will contain **more flexibility in distribution temperatures, be made of an increasing proportion of standardised components engineered for ease of assembly and maintenance, and more flexible materials**. The result will be a more environment-friendly customer- oriented solution.

District cooling is based on the concept of connecting a network of customers to a cold source via a pipe network. Chilled water is distributed to the customers where it gains heat, thus cooling the building. In this way, district cooling makes use of local resources and can combine different RES, depending on local conditions and tailored to the users' needs.

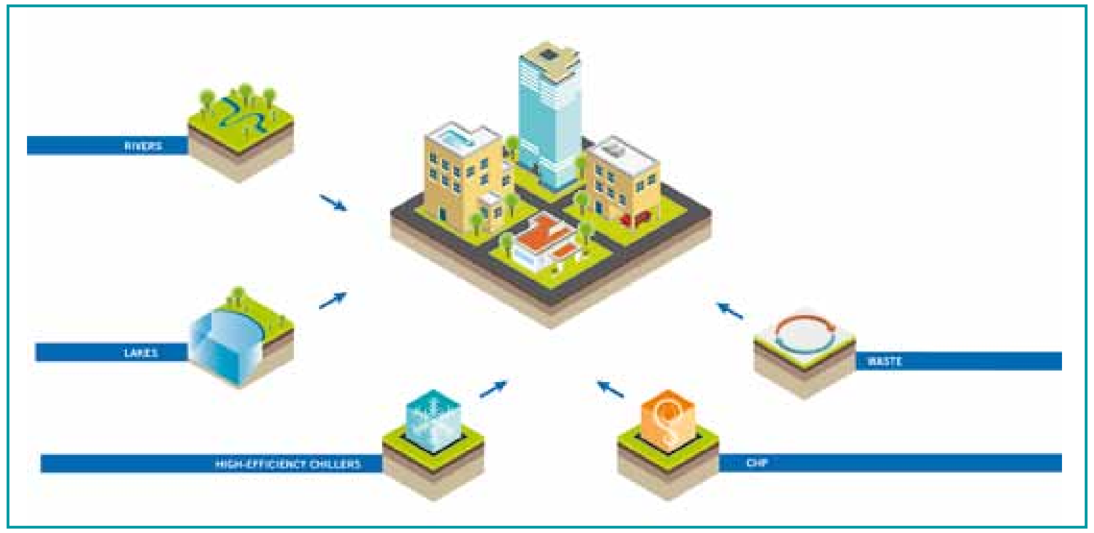

Figure 1 - District cooling can combine different cooling sources

[9] Euroheat & Power (2011): District Heating and Cooling – Country by Country survey.

▶ 2.1.3 Nature and time dimension of research priorities

To understand the past, present and future development of the DHC sector, it is important to understand its cross-cutting nature. By essence, DHC involves a large range of topics, from thermal energy production to its consumption, including customer relations, networks management and integration, etc. The sector must have access to cheap and reliable thermal sources and distribute the resource to consumers, respecting certain qualitative and quantitative aspects, to the benefit of all involved actors. Driven by the ability to provide synergies between local resources and thermal sinks, DHC systems have interfaces with a huge variety of other energy and non-energy sectors.

For these reasons, the DHC industry constantly works in close relation with other stakeholders, like the renewable energy industry (solar, geothermal, biomass, incl. waste), building owners, operators and users, industrial facilities and the service sector, but also with urban planners, local authorities etc.
While **parameter changes in any of the related sectors may pose challenges in terms of technical and operational adaptations in DHC systems**, the huge complexity of the legislative environment as well as ever faster societal changes imply particular challenges for the various business models and their development over time.

Moreover, as DHC development varies largely between EU Member States, studies[10] distinguish between consolidation, expansion, modernization and emerging countries with each of these categories having particular research possibilities and needs. Accordingly, the transition to zero carbon energy solutions poses different challenges in countries where 2nd generation District Heating are still predominant than in countries with advanced 3rd generation systems or only very few existing systems.

As a consequence not only a wide range of technological issues (§2.2), but also of socio-economic issues (§2.3) need to be addressed.

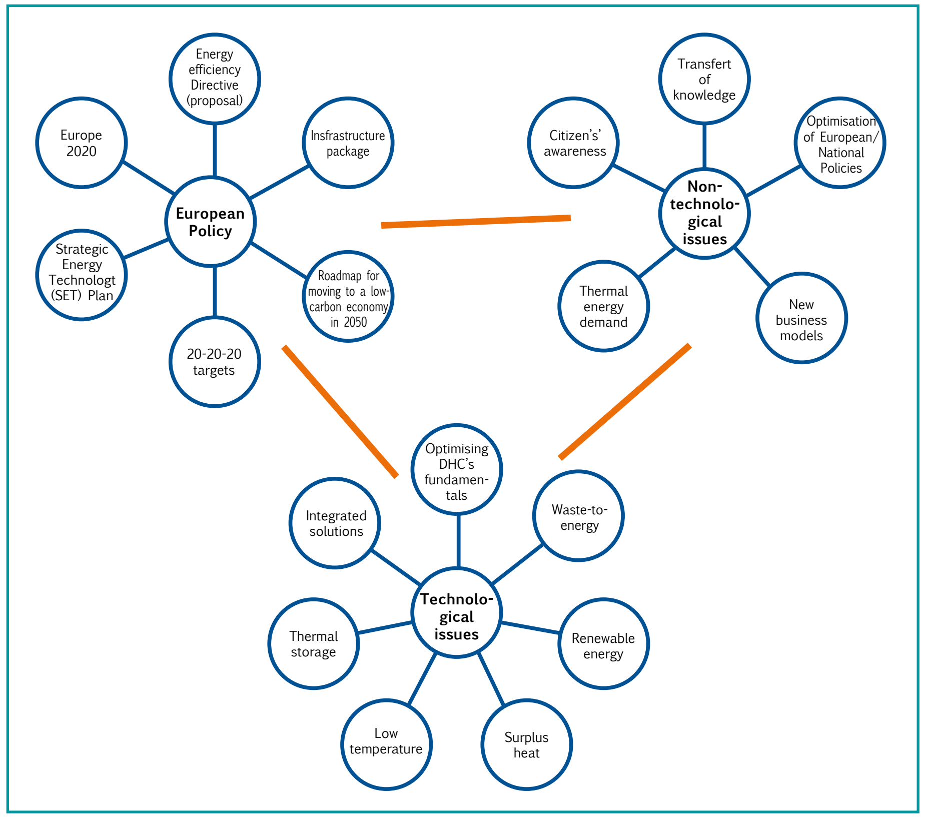

Figure 2 - SRA context and selected research and development topics

10 www.ecoheat4.eu

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The cross-cutting nature of DHC also impacts on the **time dimensions** in research. On the one hand, changes in any of DHC related sectors, be they incremental or disruptive, require a highly adaptive and pro-active approach closely following developments of the context. As investments in DHC systems are, on the other hand, capital-intensive and long-term, it is important to highlight that all topics mentioned in this document need attention as of today.
However, to reflect the anticipated evolution of the energy system as depicted in the Common Vision, the technological research priorities have been categorised according to the common time-scale of this SRA.

For the non-technological strategic priorities, no distinction has been made, as they are of more generic and reiterative character (i.e. any long-term scenario on thermal energy demands would need to be reassessed in regular intervals in order to cross-check against real developments). Similarly, business models need to evolve in line with new technical developments.

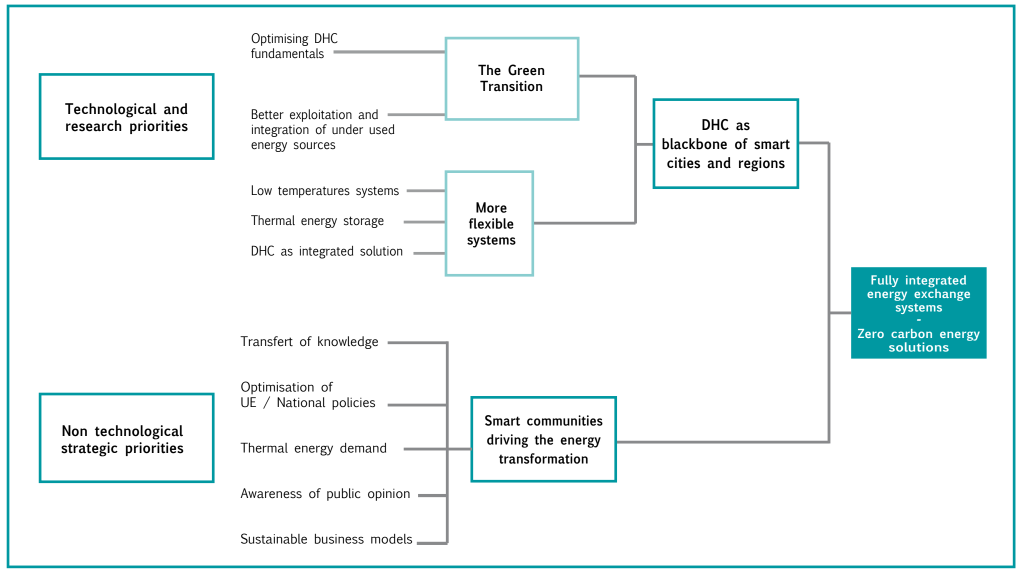

Figure 3 - Timeline and priorities of the strategic research topics for District Heating and Cooling

▶ 2.2 Technological research priorities

Considering the difference in the deployment of DHC technology in Europe, two simultaneous and complementary strategies are foreseen to position **DHC as the backbone of Smart Cities and Regions**: they are presented as ***The Green Transition*** and ***More Flexible Systems***.
This section aims to draw a picture of research objectives and technological expectations for DHC in the short, medium and long term. Scientific and technological priorities are grouped in research areas according to their relevance to the strategies mentioned above.

▶ 2.2.1 The Green Transition

District heating and cooling systems with different characteristics are found across the EU and diverse are the mix of energy sources currently used in its cities and districts. To achieve ***The Green Transition***, short- and medium-term research should focus on optimising DHC fundamentals and on increasing the share and variety of renewable energy sources that DHC can access.

Research Area A: Optimising DHC fundamentals

Due to the central role it will play in the development of Smart Cities and Communities, the DHC infrastructure should evolve and improve itself in all parts, from the thermal source production to the consumption, including the interaction with its customers.

A push for standardisation in all parts of the DHC industry will reduce costs and enable the manufacture of safer and more environment-friendly equipment.
The higher the deployment of DHC, the more important it is for the sector to ensure that the energy is efficiently transformed, stored, transported and delivered. The competitiveness of the heating and cooling sector will thereby be improved. Lower investment and operation costs will in the end result in lower thermal energy price for customers.

Thermal energy production
Large-scale cogeneration plants compete against conventional power plants that do not distribute waste heat to users. The cogeneration plants cost more, hence it is important to improve their electricity yield. More attention should be dedicated to demonstration projects which combine different technologies, like heat pumps to boost the temperature of water circulating in district heating networks[11].

Also more efficient and flexible generation for cooling is needed. Today, sensitivity to the inlet temperature is too high. Too few cooling machines are used in DC applications. To increase their use, they must be made more reliable and achieve higher efficiency.

Transport, distribution and storage
Losses must be reduced in heat transport and distribution. Construction and / or maintenance of the networks may give a bad image of the DHC sector in the public opinion due to the disruptions caused by its works. DHC networks should be easy and quick to install, inconveniencing the population as little as possible, including by reducing the land surface affected by civil works. DHC networks should be constructed or maintained in ways that are less disruptive than at present, for example by improving trenchless technology, or using narrower trenches. Trenches should be filled in with recycled material. Today, pipes are custom-made. For instance, bends are made according to each customer's specific needs. In the same way, the use of distances and alarm threads is done by hand. The development of standardised, pipes that are easier to connect could reduce construction/maintenance time. The connection of low-energy homes requires heat transport in thinner pipes, which with current pipe technology would lead to disproportionately higher heat losses.

Customers must be at the center of the relation cities–customer–energy. The customers' role in decarbonising energy supply needs to be better acknowledged. An efficient system is useless if not properly used. New approaches are needed to fully integrate the citizens in the energy transformation and to support them in their increasing role. The development of smart metering will allow the systems to adapt even faster to the consumers demand, at the same time helping them to make informed choices about their consumption.

A number of white goods[12] use hot water in their operation. White goods with hot water inlets are not so common. Most examples heat water in situ electrically, but studies show that using district energy to supply heat or cold to appliances can displace electricity and save energy. For example, connecting a washing machine to a district heating network may result in electricity saving of up to 62%[13].

Like pipes, substations are generally custom-made. Standardisation should enable high-volume series production, which is a necessary precondition in order to create smarter, safer, more environmental friendly and cheaper substations for the European market. The heat exchangers in the substations of third generation systems (designed to function at temperatures above 70°C degrees) are inadequately suited to the temperature of the water that now typically circulates in a DH network, which is at less than 70°C.

[11] For example, a 1MW CO_2 heat pump that has been delivered to a Danish municipal district heating grid, takes up the heat from the city's sewage waste water before the water is pumped into the sea. The heat is delivered as 80°C warm water directly into the district heating grid.

[12] 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.

[13] "District heating distribution in areas with low heat demand density", Annex V I I I, 2008:8DHC-08-03, IEA and www.carbonfootprint.com

Research Area B: Better exploitation and integration of sustainable energy sources

In or around cities a wide range of energy sources can provide heat including RES, due to their business activities (industry, agricultural waste) or in connection with essential urban functions (sewage, municipal waste). These sources are today under-used and it is in the interest of the DHC industry, but also of the local community, to exploit these resources as much as possible.

Figure 4 - Several sustainable energy sources can be used efficiently in district heating

Renewable energy
Phasing out the direct (and in the longer term also indirect) use of fossil fuels requires improved use of a wider range of RES. DHC offers the possibility to use RES which otherwise would be difficult to use, such as geothermal heat, secondary biomass, algae, heat from sewage, free cooling[14] etc. The experience of many European communities demonstrates that District Heating and Cooling is a viable short-term solution for quickly moving from fossil fuels to more efficient, renewable and competitive energy supply[15]. For example, the use of natural cold sources in district cooling systems substantially reduces the need for individual chillers driven by electricity or gas and having an associated impact on primary energy consumption and GHG emissions.

The temperature, flow and seasonal fluctuations of thermal energy from different RES differ widely. Yet the temperature levels and technological set-up of many existing systems limit the variety of RES that can cost-effectively be integrated (e.g. solar thermal in high-temperature systems). The DHC sector works with the European renewable energy research community on research projects to increase the use of renewable thermal energy in European DHC systems.

Surplus heat from industry using heat pumps
Most industrial sites emit large amount of surplus heat from a number of production processes. This surplus thermal energy can be recovered for use in processes nearby or sent to a district heating network. Newer technologies using heat pumps must be designed to recover heat optimally. Further research activities are needed in order to allow DHC networks to capture and upgrade (for example with heat pumps) any available surplus thermal energy, without jeopardising the quality of the service provided to the consumers.

Waste-to-energy
In addition to the valorisation of municipal waste, DHC offers a vast range of possibilities to valorise renewable waste, like residual forest and agricultural waste and sewage, through energy recovery. This facility must be built into waste plants as they are built. Projects demonstrating the feasibility (and necessity) of optimised waste management (including the final conversion of waste into thermal energy)are essential for future smart cities. These projects have to win public approval.

[14] Free cooling is defined here as the use of a colder outdoor fluid (eg air) which is naturally available to reduce the temperatures of the fluid (e.g. water) which is used in district cooling or for an air conditioning system.

[15] Additional information available on www.districtenergyaward.org

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Research priorities

T.1 Cheaper high efficient CHP plants

- *Objective:* Minimise primary energy use for simultaneous power and heat production. Improve the return on investment of the most efficient plants.
- *Research priorities:* Cheaper and more efficient CHP plants (improved power-to-heat ratio).

T.2 Improved cooling generation technologies

- *Objective:* More efficient and more flexible cooling generation technologies.
- *Research priorities:* Improved chillers and heat pumps; focus on technologies using low Global Warming Potential (GWP) refrigerants.

T.3 Reduction of thermal losses

- *Objective:* Adjust to the downward trend in demand for heating by producing and distributing district heat at lower temperature, thereby enabling efficiency gains.
- *Research priorities:* Better insulation solutions and/or material for thermal transport, improved joints, cost-effective methods for leakage detection and reduction.

T.4 Less invasive works

- *Objective:* Reduce nuisance of civil works related to network construction and maintenance; reduce costs.
- *Research priorities:* Less invasive and cheaper solutions to build / maintain the networks, e.g. plug-and-play solutions.

T.5 Integrated and standardised pipes solutions

- *Objective:* Standardise the fabrication and the assembly of pipes to obtain safer and cheaper networks, using fewer custom-made components.
- *Research priorities:* Develop integrated and standardised pipes.

T.6 Improved, highly efficient substations for both present and future lower temperature networks

- *Objective:* Make substations modular, lower-cost and greener.
- *Research priorities:* Encourage the deployment of substations with similar specifications, using cheaper but also greener materials, more technologically advanced manufacturing methods, containing appropriate heat exchange technology (also at temperatures below 70° C).

T.7 Develop and roll-out DHC driven white goods

- *Objective:* Save primary energy by developing white goods able to use heat/cold from district energy networks, instead of generated in situ with electricity. Reduce costs for these white goods by bringing them from demonstration to mass production. Understand why the market share of white goods having hot water inlets has declined over the last decade.
- *Research priorities:* Demonstration projects of white goods efficiently connected to district energy networks.

T.8 Adaptation of networks to renewable energy supply at different temperature levels

- *Objective:* Investigate and develop versatile DHC networks that can handle multiple input and output temperatures, enhance compatibility of network and user installations.
- *Research priorities:* Innovative system operation technology, innovative network connections / substations / heat exchangers.

2.2.2 More flexible systems

Current district heat distribution networks are appropriate for the today's heat demand, but with greater use of renewable energy and considerably lower final heat demands, this infrastructure must be improved. Lower temperature heat will be used in 4th generation distribution networks. This key change will result in lower distribution heat losses and could allow higher utilisation of available renewable resources such as solar, biomass and geothermal energy. With the next generation of district heating technology, renewable energy supply will become less expensive than is possible at present with 3rd generation networks.

4th generation networks are suitable for buildings with low heat or cold demands. The transformation of 3rd generation networks into 4th generation networks, or the replacement of the former by the latter will follow the transformation of the building stock towards high efficiency. In parallel, the system's borders should be redefined by integrating heating with cooling networks, and through cooperation and interaction with other sectors in the urban environment. This is a strong planning challenge when existing DHC systems are to be expanded and new systems must be established.

Research Area C: Low temperature systems

In future, citizens will need less primary energy for the same comfort. Thanks to the development of low temperature networks, district heating is able to meet this need in an efficient and environment-friendly way. With the connection of an increasing number of low energy house connected to 4th generation district heating, the sector will face a transition phase where both "old" and "new" generation of district heating will be mixed. DHC networks have to demonstrate their flexibility to be able to integrate this new type of buildings. It is expected that this situation will increase in the next 20 years, when low energy buildings will represent the majority of the buildings stock.

Research Area D: Thermal energy storage

Thermal energy storage is a central component of energy-efficient DHC. Storage will play a key role in the future heating and cooling systems, enabling a better use of intermittent resources such as solar energy but also in connection to the development of more integrated electrical and thermal networks. In order to respond to this challenge, thermal storage has to be flexible and innovative to match different types of energy sources and needs.
Thermal stores could be replenished with electricity from RES that would otherwise be wasted and drained when demand for heat or cold is high.

The development and improvement of seasonal storage solutions for heat and / or cold is crucial. Also the development of combined storage for heating and cooling (short term and seasonal) will pay dividends by reaping synergies of storing heat and cold together. Research priorities for thermal energy storage are discussed extensively in Chapter 3 of this publication.

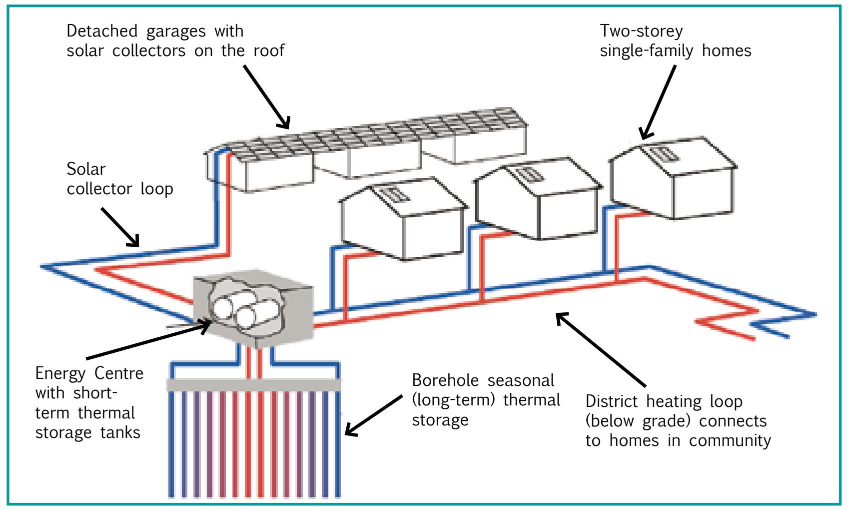


Figure 5 - Example of district heating using short and long term storage (Source: Natural Resources Canada, Drake Landing Solar Community, Okotoks, Alberta, Canada)

Research Area E: District Heating and Cooling as integrated solution

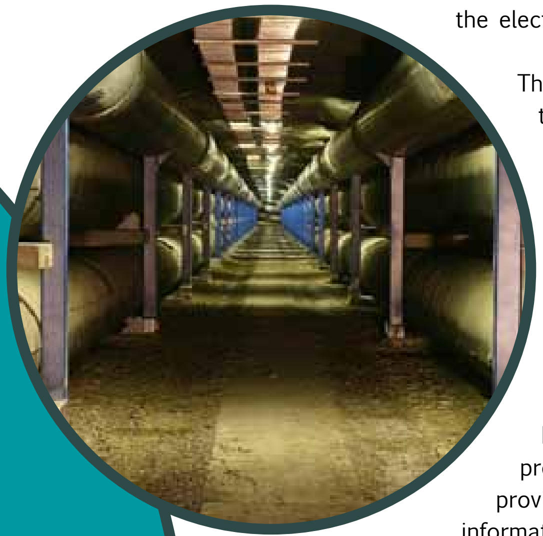
The idea behind the integration and the interaction of different utilities is to be able to provide a package of products, services and technologies that function more effectively as a whole than the individual elements separately. Nowadays, cities are composed of a number of networks – ICT, electricity, heating, cooling, transport, water, etc. – which are developed in parallel and are often competing rather than interacting synergistically. This must change if we are to decarbonise energy supply without negatively impacting on comfort level and economic growth.

When planning a new area, an integrated approach should be applied, namely in terms of heating and cooling, with the perspective of choosing the solutions which best allocate resources to where and when they are needed. Networks can be integrated at different levels: i) between DHC networks and ii) between these networks and networks providing other services (electricity, ICT, water, waste, etc.).

Optimum operation of thermal district energy systems occurs when there is an on-time and integrated management between the production, storage, transport, distribution and consumption. For that, more ICT components should be introduced, helping in the management of the thermal flow. The main expected results are decrease of primary energy use, less losses in the pipes and lower operation costs, making the final thermal energy cheaper for the customers.

Thermal networks will increasingly combine district heating and district cooling. Currently, both networks are often designed and implemented separately. An integrated approach is needed when designing and implemented these networks. The results will be a more efficient service for the customers, provided at lower operation costs and therefore lower prices.

Regarding the interaction with other networks, one way of taking full advantage of thermal district energy systems, is to let them provide balancing power to electricity grids by alternation between electricity generation units (CHP plants) and electricity consumption units (large heat pumps and electric boilers) in the thermal supply. This balancing power becomes more valuable when a high share of the electricity supply comes from intermittent power sources as wind and solar power.



The building stock will impact energy systems. Buildings will increasingly have the capacity to produce and store energy, both electrical and thermal. In order to optimise the energy systems, the conditions for further interaction and integration of buildings, that have thermal storage capacity and have intermittent surplus thermal energy, and the thermal district energy systems need to be further studied. In the same way, interaction between industries must increase. Also, direct interaction between producers, consumers and prosumers (from residential and industrial sector) must be further studied. This solution will allow energy to be transported over smaller distances, reducing losses and making the overall energy system more efficient.

Easy-to-use tools that enable urban planners to identify the best way to provide heating and cooling to the residents of the district of a town, or that provide building owners directly with this information, need to be developed. Public information campaigns promoting DHC are needed in countries where DHC is poorly understood or little known.

Research priorities

T.9 Integration of low temperature DHC with existing network

- *Objective:* Integrate low energy buildings in existing DHC and smooth the transition to 4th generation networks.
- *Research priorities:* Demonstration of various types and sizes of 4th generation technology retrofitted to 3rd networks serving new and old building stock.

T.10 Seasonal storage

- *Objective:* Improve the efficiency and affordability of heat and cold seasonal storage solutions connected to DHC networks.
- *Research priorities:* specific research priorities for seasonal storage are presented in chapter 3 of this publication.

T.11 Using DHC to buffer excess renewable electricity

- *Objective:* Use electricity production that would otherwise be wasted to provide heat or cold to district energy networks.
- *Research priorities:* Elaborate solutions to use DHC systems as short-term storage for excess (renewable) electricity

T.12 Smart tools for urban planners

- *Objective:* Enable smart urban energy infrastructure planning at the level of the whole city.
- *Research priorities:* Develop tools to help urban planners evaluate options and make the most cost-efficient and environment friendly choice.

T.13 Better interaction between thermal production, storage, distribution and demand

- *Objective:* Improve communication of units connected to a district energy network producing, distributing or consuming heat or cold through integration of ICT. Better connectivity among producers, consumers and prosumers.
- *Research priorities:* Development of smart controlling in DHC and demonstration of the advantages of such communication. Applied research to create and develop effective links between thermal energy suppliers and users for both residential purposes and industrial processes.

T.14 Integrated energy networks to couple local energy supply with diverse energy demand

- *Objective:* Achieve self-sufficient communities by coupling local energy sources (electricity, heat, cold, etc.) with diverse energy demand.
- *Research priorities:* Develop systems where DHC is used as infrastructure to provide effective exchange and redistribution of energy.




2.3 REGULATION, ACCEPTANCE, AWARENESS: THE NON-TECHNOLOGICAL STRATEGIC PRIORITIES

Transfer of knowledge, education and training

DHC is a local business, but most DHC systems face similar issues and developers of one system could learn from the experiences of others. Earlier, we insisted on the need for standardised technology. The more widespread the use of standardised technology is, the more relevant each developer's experience could become for another. Particular effort should be directed at transferring knowledge between the operators of different generations of district network and between operators (or aspiring operators) of similar networks in different countries.

To achieve our strategic and technological targets, investment in higher education and vocational training for DHC technology is essential. Nowadays, there is almost no education programme devoted solely to DHC. Engineers, urban planners and architects would be the targets. The new generation should be ready to develop smarter cities presenting integrated solutions using renewable energy. The development of a Master Degree in District Heating and Cooling covering all these topics would be an important step to ensure the long term sustainability of the European energy system.

Optimisation of European / National policies

There are many 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. Politicians evidently do not find them attractive enough. 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.

Cooling demand

Cooling is an increasingly important component of the energy demand. While demand for primary energy for heating is in decline, demand for cooling is increasing in industry, in the service sector and in the residential sector. It's worth noting that cooling demand is not limited to the warm season.
Statistics on the actual overall energy demand for cooling on a European or national level are poor. Building owners or tenants are in most cases unaware of the amount of energy they use for cooling because individual electrically-driven chillers meet approximately 98% of cooling demand in the residential sector in Europe, making it difficult to disaggregate cooling demand in an electricity bill. A lack of awareness affects the owners of municipal buildings, too. Electricity consumption for cooling is in the majority of cases underestimated and so are the consequences of the negative environmental and economic implication of the rising power demand for cooling purposes.

Heating demand

In the last decades, the energy market drastically changed and opened new horizons for the energy consumers. Consumers are more aware of the importance of a good energy management, from economical but also environmental point of view. In some cases, they can themselves be energy producers and interact with the grids. With the development of low-energy houses, individual heat consumption is expected to decrease. The extent of the reduction needs to be understood better, with scenarios making different assumptions on population changes (including the ageing of the population), urbanisation, size of dwelling and reliance on ICT to manage building services.

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Collecting and efficiently using data will be essential. More intelligent heat meters together with active data mining routines will offer new insights into customer demands and consumption patterns and flaws in customer thermal systems. This information will help the thermal network operator to manage the grid in the most efficient way and enlighten consumers as to the options they have to cut energy bills.

Smarter meters and controls will be the core of future integrated energy solutions, including interaction with other networks (ICT, electricity, water, etc.). Smart meters should facilitate this interaction by integrating data from all the different networks. The flow of information should be multi-directional. It should communicate the information to the operators/utilities and at the same time it should also support consumers' choices. Heat meters are now able to sample take-off at higher frequency, but the software to analyse these measurements effectively are not yet available. Load management in customer substations and control units should be further developed with other technologies to time-shift demand from customers.

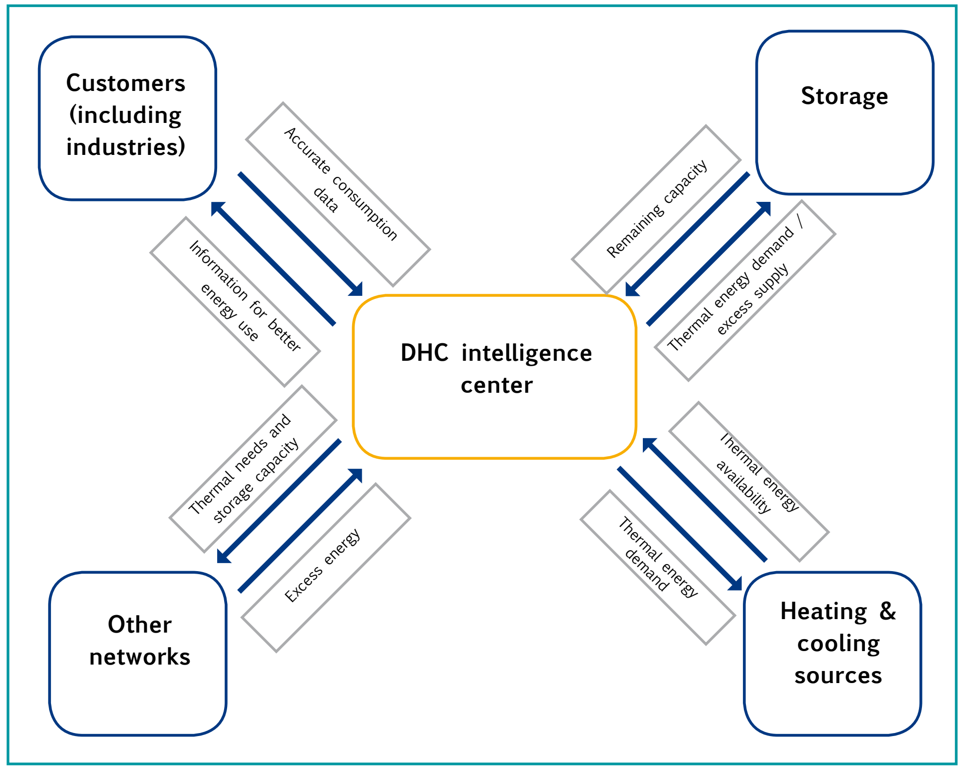

Figure 6 - Information flow

Public awareness of district heating and cooling from RES

Despite its huge potential to reduce CO_2 emissions and to allow large scale use of RES, DHC is not always considered as possible solution. This fact is mainly due to the lack of information of the decision makers / planners and to the lack of informative tools about the real potential at local level. A study applicable to the whole of Europe should be made of the pros and cons of building DHC networks in particular areas. This will enable an assessment to be made of the need for fourth generation of District Heating systems and high-tech heat grids. The results should be presented to potential DHC customers.

Apart from residential demand, DHC can also provide the thermal energy required for industrial processes. The potential to boost DHC use by industry and other economic sectors like agriculture deserves further investigation. In particular, the use of cascading temperature level should be studied.

Developing sustainable business models

Historically, the DHC business model was to produce, transport and deliver heat. Today's business models are based on the quantity of heat or cold transported as the expansion of the DHC 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. These new models must support the integration of strategic thinking and sustainability objectives in decision making processes (e.g. by incentivizing energy savings, delivering capacity and flexibility vs. delivering energy, etc.).

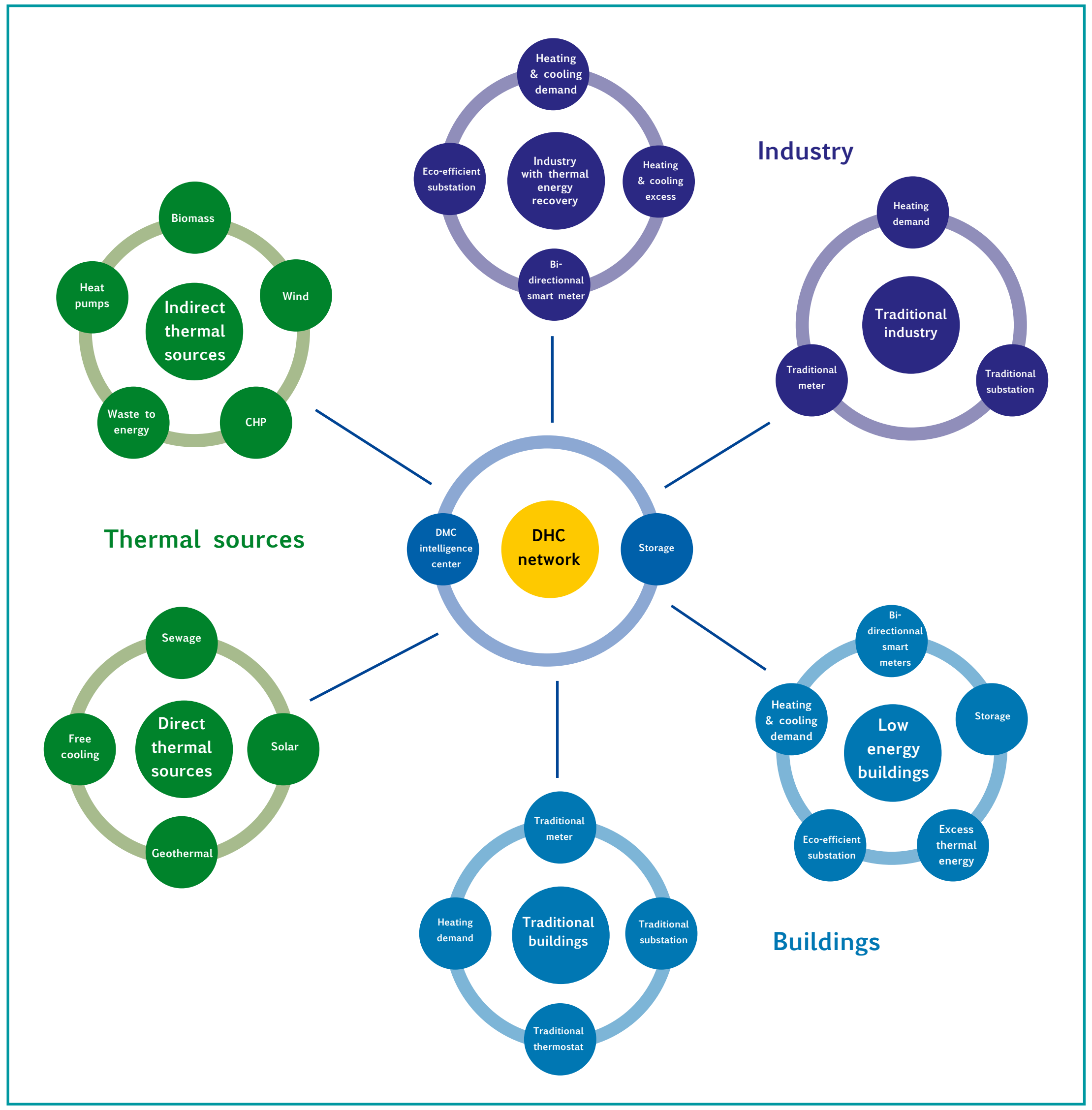

Figure 7 - Scheme of DHC with which new business models shall deal with

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Non technological strategic priorities

S.1 International Heating and Cooling database
- *Objective:* Facilitate the transfer of knowledge in the heating and cooling sector to accelerate the adoption of innovative practice.
- *Research priorities:* Set-up of an international and open database on heating and cooling.

S.2 Assessment tools for thermal energy systems
- *Objective:* Steer customers (residential and industry) and urban planners towards choosing the best technology to meet their heating and cooling needs.
- *Research priorities:* Develop tools to match needs to technologies.

S.3 Improved public knowledge and acceptance
- *Objective:* Develop knowledge and acceptance of DHC.
- *Research priorities:* Dissemination / education campaigns and projects.

S.4 Improve EU and national legislation in order to stimulate and support sustainable thermal energy systems
- *Objective:* Enhance the impact of legislation promoting environment-friendly, cost-effective energy solutions suited to local circumstances. Establish comprehensive, multi-level country strategies addressing all relevant stakeholders.
- *Research priorities:* Identify good examples of local implementation of national or European policies and promote them. Analyse how different policy instruments impact the development of thermal energy systems at local, regional and national level. Study how policy frameworks and instruments should be designed to stimulate and support an extension of sustainable thermal systems.

S.5 Better analysis of cooling demand
- *Objective:* Gain in-depth knowledge of cooling demand, and raise awareness among consumers and policy makers of its share in electricity consumption.
- *Research priorities:* Survey the industry by collecting facts and figures on cooling demand in Europe; qualify and quantify current and future trends.

S.6 Anticipate the future energy demand
- *Objective:* Predict energy and customer demands in light of more efficient buildings and increased energy saving efforts by consumers.
- *Research priorities:* Develop innovative forecasting models

S.7 Smart integrated networks
- *Objective:* Obtain smart, integrated networks, collecting and interpreting data from different sources (heating, cooling, electricity, waste, water, etc.)
- *Research priorities:* Develop new tools allowing efficiently collection, analysis and interpretation of collected data.

S.8 Tools to choose the best thermal energy solutions
- *Objective:* Optimise the connection of local industries with different demands to the district energy network.
- *Research priorities:* Understand the likely effects of an increasing number of industrial users, with diverse needs, connected to the DHC network.

S.9 Synergies between different customer groups
- *Objective:* Obtain knowledge about and showcase innovative and efficient thermal grids integrating multiple thermal energy needs.
- *Research priorities:* Explore the synergies between various customer groups with different thermal needs.

S.10 Development of sustainable business models
- *Objective:* Develop flexible and viable business models in accordance with technological and societal developments.
- *Research priorities:* Research on how to improve the ability to anticipate the evolutionary trends in the energy demand and supply and how to integrate this in business models.

2.4 Conclusions

Modern district heating and cooling can be improved in many ways. Better materials, equipment and processes will boost efficiency, cost-effectiveness and improve the end-customer's experience of the technology. A significant expansion of networks is required to achieve a substantial penetration of RES in urban areas for both heating and cooling, based upon integrated planning of energy generation and access to locally-available sources of heat.

Reaching high penetrations of RES in district heating requires drawing on a variety of heat and cold sources to meet customer demand at any time. New forms of ICT such as smart meters and easy to install intelligent substations for individual customers will be needed to regulate energy inputs and outputs in order to optimise the interaction between sources of energy supply and the various temperature demands of customers. Low temperature district heating systems are essential to meet the demands of low energy buildings with renewable energy sources.

The DHC network, especially if it includes efficient and inexpensive hot and cold stores, can adequately balance the fluctuations of the renewable energy supply. But the network will have to accept feed-in of heat or cold at different temperatures. Solutions to be explored include the adaptation of operational temperature levels throughout the entire network and reconfiguring pipelines.

Older, less efficient networks must be upgraded applying the technology and knowledge found in the most advanced systems. This requires consistent and flexible quality assessment tools and best-practice transfer. To harness RES, DHC networks need to produce, transport and deliver thermal energy with as fewer losses as possible. This will avoid overdimensioning heating or cooling plants in the network. Components and work methods should be standardised to increase productivity. Using heating or cooling plants powered with RES without paying attention to infrastructure close to the customer installations or distribution and transport infrastructure would lead to suboptimal results.

Technological progress in district cooling should lead to the use of a greater variety of natural cooling sources situated further from the customer. Further enhancements in the efficiency of cooling generation need to be pursued. Innovative systems should be deployed. The use of on-site sorption chillers to supply cooling using district heat should also be tested at large scale.

If developed along the lines described in this chapter, DHC systems built within the next twenty years have the potential to be strong allies in the longer term decarbonisation of the energy system. Together with further ICT developments and further integration with other networks and urban functions (waste management, transport, industry etc.) they will increase flexibility and allow communities to become "smart energy exchange systems" in which the primary energy content of any fuel will be exploited to the maximum, the potentials of RES fully reaped and waste minimised – while ensuring a high quality of life to citizens.

2.4.1 Summary table of research priorities

Important: Two aspects are essential when considering research priorities for the DHC sector:

• DHC development varies largely between countries and regions. Research needs will be different in each.
• Due to its cross-cutting nature, the DHC sector is sensitive to changes happening in other sectors and needs to continue reacting to its changing environment

As a consequence, the quantitative targets presented below should be interpreted loosely. Local conditions, interaction with other sectors, socio-economic trends, etc. affect DHC systems and therefore should also be taken into account when investing in the implementation of the research priorities.

Technological research priorities and targets

		Short term	Medium and long term	Short term	Medium and long term	Short term	Medium and long term
T1	Cheaper high efficient CHP plants			Electricity yield of cogeneration plants above 60% for a total efficiency above 90%		Electricity yield of cogeneration plants above 75% for a total efficiency above 90%	
				Pay back of large cogeneration plants <15 years		Pay back of large cogeneration plants <10 years	
T2	Improved cold-generating technologies	Cooling machines 20% more reliable than current models	Cooling machines 20% more reliable than current models		Reduce the sensitivity to inlet temperature of cooling machines by 30%	Reduce the sensitivity of cooling machines by 30%	
T3	Reduction of thermal losses		Reduce thermal losses in pipes by 15%	Reduce thermal losses in pipes by 15%		New thermal carrier and new material	New thermal carrier and new material
T4	Less invasive works	Less invasive and cheaper solutions to build / maintain the networks, e.g. plug-and-play solutions.					
T5	Integrated and standardised pipes		Reduce construction time of district energy networks by 15%	Reduce production and installation costs by 20%			
T6	Improved, highly-efficient substations			Improve efficiency of substations operating at low temperature by 30%		New construction material	New construction material
T7	Develop and roll-out DHC-driven white goods	Demonstration projects of white goods efficiently connected to district energy networks.		Development of efficient white goods driven by DHC – 70% power use reduction			
T8	Adaptation of networks to different temperature levels	Demonstration projects with several temperature level		Modeling of networks having a high number of temperature levels			

T9	**Integration of low temperature DHC with existing network**	Demonstration projects using return flow temperatures	Demonstration projects using very low temperatures	Study on DHC expansion potential			
T10	**Using DHC to absorb excess renewable electricity**		Demonstration projects using DHC to buffer electricity	Study on potential for DHC to buffer excess electricity			
T11	**Smart tools for urban planners**			Smart tools for urban planners			
T12	**Better interaction between thermal production, storage, distribution and demand**	Integration of advanced ICT systems in DHC		New control algorithms for DHC systems			
T13	**Improved interaction with and between producers and consumers**		Demonstration projects combining consumers and producers in a DHC network	Study on feasibility of interaction with and between consumers and prosumers	Modeling of new network configurations		
T14	**Integrated energy networks to couple local supply with various energy demand**		Demonstration projects with DHC as infrastructure to provide effective exchange and redistribution of energy	Modeling the use of DHC as energy infrastructure backbone			

	Research Topic	Research priorities
S1	**International Heating and Cooling database**	Set-up of an international and open database on heating and cooling.
S2	**Assessment tools for thermal systems**	Development of consistent and intuitive assessment tools for thermal systems.
S3	**Improved public knowledge and acceptance**	Dissemination / education campaigns and projects.
S4	**Improve EU and national legislation in order to stimulate and support sustainable thermal systems**	Showcase and draw conclusions for future policies from best-practice in local level implementation of national and EU legislation. Analyse how different policy instruments impact the development of thermal energy systems at local, regional and national level.
S5	**Better analysis of cooling demand**	Survey the industry.
S6	**Anticipate future energy demand**	Build models to study the future trends of thermal energy demand.
S7	**Smart integrated networks**	Develop new tools allowing efficiently collection, analysis and interpretation of collected data.
S8	**Tools to choose the best thermal energy solutions**	Understand the likely effects of an increasing number of industrial users, with diverse needs, connected to the DHC network.
S9	**Synergies between different customer groups**	Obtain knowledge about and showcase innovative and efficient thermal grids integrating multiple thermal energy needs.
S10	**Development of sustainable business models**	Research on how to improve the ability to anticipate the evolutionary trends in the energy demand and supply and how to integrate this in business models.




3. Thermal Energy Storage

Photo © ECN

3. Thermal Energy Storage

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3.1 Introduction – Technology Status

The purpose of Thermal Energy Storage (TES) systems is to store a sizeable quantity of thermal energy (heat or cold) for long periods[16].

The ability to store thermal energy is very important for using renewable energy in heating and cooling systems effectively, since it decouples the availability of renewable energy from the time when it is needed, thus increasing the degree which it can be utilised.

There are three major reasons for using thermal energy storage:

- Improving system efficiency by avoiding partial load operation, or operation at other sub- optimal times, or taking advantage of waste energy (e.g. heat released from chillers). This can involve storage over hours, days or months.
- Shifting demand over time to reduce peak loads. This can improve overall energy system efficiency, reduce investment in energy infrastructure and reduce costs. Storage is typically required for hours or days.
- Facilitating the greater use of renewable energy by storing energy available at a certain time, so it can better cover demand (storing solar thermal energy over days, weeks or months to match water and/or space heating demand).

TES applications are at various stages of development, depending on the technology considered.

The most common example of thermal energy storage today is domestic hot water tanks (DHW), which are usually insulated to reduce heat losses. These vessels are cheap and can store heat for days or even weeks at acceptable cost, but they are bulky and not an ideal solution for long-term storage. The key parameters of thermal energy stores are their capacity, energy density, power rating (ability to discharge), efficiency (losses over time and with charge/discharge) and cost[17].

[16] TES is used in many applications, such as thermal protection (electronics, solar receivers, medicine), thermal regulation (thermodynamic solar cooling), thermal shift from hot to cold (thermochemical storage), power enhancement (thermochemical storage), and buildings.

[17] TES systems are also assessed on the basis of environmental parameters such as embodied GHG, recyclability, eco-toxicity. Other relevant parameters to be considered are flammability, corrosion, thermal stability, compatibility with envelopes and with heat transfer fluids, availability and conflict of use.

As shown in Figure 8, thermal energy storage can be categorised based on the underlying physical principles of the storage technique.

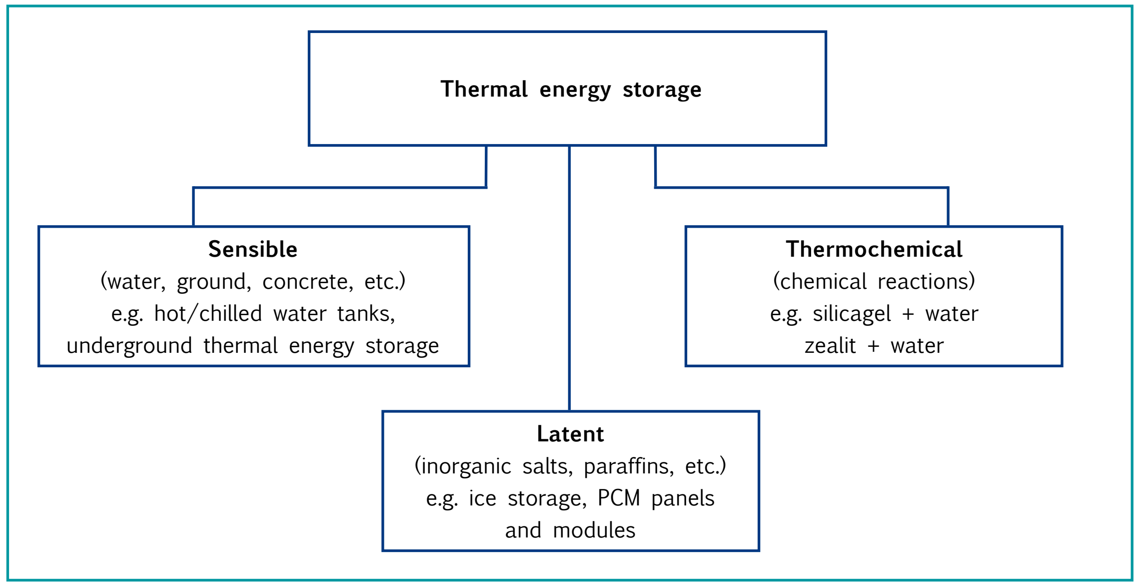

Figure 8 - Thermal Energy Storage characterisation

There are three major types of thermal energy storage, these are:

- **Sensible heat storage:** Where a storage medium is heated up or cooled down (e.g. hot or chilled water tanks). This has a relatively low energy density. Large stores (in the MWh scale) are often placed underground so that they do not take up space on the surface and use the ground as insulation (Underground Thermal Energy Storage). Today other sensible heat storage technologies, such as buried water stores, are also under development, including high temperature (above 120°C) applications which are feasible thanks to their relatively low cost.

- **Latent heat storage:** The phase change of a substance (e.g. ice-to-water, paraffin and salt hydrates), hence the term "phase-change materials", can release energy without any change in temperature. These offer storage densities 5-15 times greater than sensible stores.

- **Thermochemical storage:** The energy is 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 thermo-chemical reaction.

Sensible heat storage systems (e.g. hot and chilled water) and some latent heat stores (e.g. ice storage) are mature technologies[18]. However, developments in advanced PCM and thermochemical materials are opening up possibilities for new applications, such as PCMs embedded in building materials used for bricks, wall boards or flooring. PCMs respond to slight changes in temperature meaning that they are good at buffering changes in temperature close to the temperature at which they change phase. Using ice storage, chiller capacity can be generally reduced by 50% or more thanks to the reduction in the electrical peak loads. Hybrid systems are also possible, for instance plastic PCM modules can be put into a tank where the heat-transfer fluid (usually water) melts or solidifies the PCM. This hybrid system has a higher storage density than that of water, but less than a pure PCM system. The development of thermochemical materials and technologies is still at an early stage.

TES material can be multifunctional, for example, used also as adsorber, and heat exchanger in solar thermal systems reducing the number of components needed, increasing efficiency and saving cost.

[16] IEA (International Energy Agency). Technology Roadmap - Energy-efficient Buildings:Heating and Cooling Equipment (2011)

Stage	Technology	Examples of applications & companies
Commercial	Water storage in solar heating systems	Solvis and many others
	UTES for heating and cooling at low temperature (generally < 40 °C)	Terra Energy (BE) Groenholland (NL) IF Technology (NL) GTN Neubrandenburg (DE) UBeG (DE) SWECO (SE)
	TES with molten salts in power plants	Abengoa
	PCM for products sensitive to temperature (blood transport, art transport, etc.)	BASF (and other) micro-encapsulated (10 to 50 micro meters) PCMs for thermal protection
	Thermochemical for products sensitive to temperature	COLDWAY: autonomous temperature controlled containers at various temperatures
	Solid sensible heat storage	KBA-Metalprint: high temperature sensible heat regenerators using refractory ceramics in the glass and metallurgic industries
	Ice Storage	There are a number of buildings (including Berlaymont, the European Commission's headquarter) that use an ice store to create cold at night which is then used in the daytime for air conditioning. Calmac, Cristopia
Demonstration stage	Phase change materials for thermal inertia in buildings	PCMP, Climator, Rubitherm
	Improved water storage systems (including PCM or other) for solar systems	Solvis
	UTES for heating and cooling at high temperature (about 40-90 °C)	IF Technology (NL) GTN Neubrandenburg (DE) SWECO Malmö (SE)
	PCM for cooling applications	CRISTOPIA proposes commercial PCM macro-encapsulated systems for TES for large scale building cooling systems
	PCM for solar power plants	DLR develops PCM pilot tests for CSP (DSG) in Spain
Early stage	Other TES systems for power plants	Multi PCM TES systems leading to enhanced thermodynamic efficiency
	PCM in heating and cooling systems	PCM composites of high thermal conductivity for high power range PCM based TES
	PCM in PV temperature regulation systems	
	TES for industrial applications (including solar cooling)	
Very early stage	Thermochemical storage for heating and cooling	
	High temperature (up to 1000°C) sensible heat TES using ceramics made of recycled vitrified industrial waste	
	thermochemical systems for heat transport	

Figure 9 - Technology Readiness Levels of TES

The European Technology Platform on Renewable Heating and Cooling considers it fundamentally important to undertake research and development activities to achieve breakthroughs in TES.

Building on the results of a workshop on TES organised on the 10 February 2011 by EUREC Agency in the framework of the activities of the RHC-Platform, the following chapter identifies the key strategic research priorities for the different TES technologies.

3.2 Sensible heat storage

3.2.1 Technology description

Heat stored by changing the temperature of a storage medium (such as water, air, oil, rock beds, bricks, concrete or sand), is stored as sensible heat. The amount of energy stored is proportional to the temperature rise, the specific heat capacity of the storage medium and the mass of the medium. Choices of medium are usually based on the heat capacity of the medium, the range of temperatures at which the store will operate and the space available for it.

Sensible storage is the most common method of heat and cold storage. Properties important in this technology are price and thermal capacity [ρc_p], operational temperatures, thermal conductivity and diffusivity, vapour pressure, compatibility with container materials and heat-loss coefficient. In more recently developed applications, such as large-scale sensible heat storage in solar power plants, other highly valued properties are availability, conflict of use and the lifecycle environmental impact of the plant.

Underground Thermal Energy Storage (UTES) for low temperature applications (at less than 40 °C) has been demonstrated and it's 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,) and Borehole Thermal Energy Storage (BTES, using borehole heat exchangers in the ground). Demonstration projects of ATES, BTES and CTES (TES in caverns) at temperatures in the range 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 is needed for this temperature range.

For ground-side installations, UTES systems make use of geothermal technology (borehole heat exchangers, groundwater wells). This technology is covered in the geothermal SRA, and only some specific items pertaining to the storage aspect are mentioned below.

Storage systems are now classified as "active" or "passive". An active storage system uses forced convection to transfer heat into the storage material contained in one or two tanks. The storage medium itself circulates through a heat exchanger (such as a solar receiver or a steam generator). Active systems are subdivided into "direct" and "indirect" systems. In a direct system, the heat transfer fluid serves also as the storage medium, while in an indirect system, a second medium is used for storing the heat. Passive storage systems are generally dual-medium storage systems: the heat transfer fluid passes through the storage only for charging and discharging a solid material.

3.2.2 Research priorities

• Microbiology in UTES systems

One of the main challenges facing UTES systems is their possible environmental impact. Microbial communities play an important role in the functioning and quality of soils and groundwater. Different microorganisms in the ground are involved in the different nutrient cycles, e.g. the sulphur, phosphorous or nitrogen, which are important for soil and groundwater quality.

During operation in particular of ATES, temperature increases in the earth surrounding the aquifer and the mixing of groundwater due to the temperature gradients may influence the underground ecosystem, for example by increasing the activity and reproduction of microorganisms. Microorganisms close to aquifers used as a cold store are likely to experience a slow down in their activity and mixing of water may also lead to unsuitable redox conditions for growth.

Laboratory testing and pilot studies need to be performed in the following research areas:

- Effects of UTES systems (in particular ATES) on microbiological composition and functioning in the ground and groundwater.
- Anticipated temperature effects on geochemical and biochemical reactions in ATES.

• High temperature underground storage (HT-UTES)

High-temperature energy storage (ATES, BTES, CTES) systems have so far received less attention. HT-UTES applications (using temperatures in the range 40-90°C) can be very useful, especially for storing heat from power plants, industrial processes, geothermal or solar energy. This heat can be used as back-up capacity and be released when demand for it is high.

Despite these advantages, HT-UTES systems are far less common than UTES systems. Only a few commercial projects with storage temperatures > 60 ºC exist in the world[19]:

- The Reichstag building in Berlin (Germany) (70 ºC, ATES)
- District heating in Neubrandenburg (Germany) (85 °C, ATES)
- Flyggt factory in Emmaboda (Sweden) (>60 °C, BTES)

Research funded through the International Energy Agency's ECES (Energy Conservation through Energy Storage) programme between 1995 and 2005 identified the technical challenges of HT-UTES to be:

- large heat losses (low thermal efficiency);
- scaling and clogging of wells, heat exchanger, pipework due to particles, gas bubbles, precipitation of minerals or bacterial growth.
- corrosion of components in the ground;
- unsuitable integration with heating systems.

Future R&D should focus on the following topics:

- Water treatment technology preventing clogging
- Component selection to prevent scaling and corrosion
- Thermal efficiency in different geological conditions
    - Computer modelling
    - Field testing

• Storage container materials

Stores of domestic hot water (DHW) are manufactured from materials chosen for their durability and ease of fabrication. In the UK copper is prevalent as it reduces legionella risk. The price of copper and a need to improve the insulation properties of tanks implies a need to develop better materials and surface coatings for storage materials. If the right materials are chosen, it may be possible to adapt them for use in PCM and thermochemical storage technologies.

• Flexible volume tank systems

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), two

[19] Other HT-UTES projects were conducted in the past and discontinued. These include two ATES projects located in The Netherlands (University of Utrecht and De Bruggen in Zwammerdam) and one BTES project operated in Luleå, Sweden.

times the required volume is used for storage. With today's limitations in space in our cities, the development of tanks with flexible volumes would be of great interest. Concepts such as one tank with flexible diaphragms or with flexible walls should be developed.

• Optimisation of hydraulics in advanced water stores, reduction of mixing and increased stratification

On this subject, several research projects have been performed in the past. Nonetheless, further advancements are possible and sought in the following areas:

- Optimisation of the internal heat exchanger.
- Internal free convection in water tanks
- Heat losses due to parasitic heat convection in pipes.
- Integration of PCM in water tanks to increase energy density.

• Control strategies for integrating sensible stores into the Smart Grid

Heat pumps, combined heat & power and cooling installations could play an important role in smart electricity grids if thermal production can be decoupled from thermal demand. This could be achieved by integrating short term TES. There is a need to develop, in line with Smart-Grid / Smart-Homes technologies, methods to accurately determine the state of charge, controls and control algorithms so that heating and cooling is optimally generated from the RES (e.g. night time excess wind energy / PV) when available, while still providing the consumer with their needs at a time of their choosing[20].

• Reduction of heat losses (materials research)

To improve the energy efficiency of TES, it is essential to reduce heat losses. The development of new insulation materials and new insulation systems (such as vacuum insulation) is a top priority.

• New sensible TES materials for high temperature storage with high thermal conductivity

To improve the efficiency of TES in active systems, thermal conductivity must be increased. In this context, the term "high temperature" refers to the range 120-600 ºC (sometimes up to 1000 ºC), where water cannot be used as a storage medium. Stable materials having high heat capacity and high thermal conductivity should be developed. High thermal conductivity will allow the store to be (dis)charged quickly without the need for features that increase surface area, such as fins. Environment-friendliness is an important parameter to consider in the development of new TES materials.

• New methods to analyse TES materials

Most analytical methods for investigating thermal properties are not precisely tailored to the study of TES materials. There are properties which cannot be assessed through analytical methods currently available for TES applications.
Materials resistant to repeated thermal cycling must be developed and tested. Their physical properties, such as Young's modulus and thermal expansion, must be understood.

• Fluids combining heat transfer and heat storage

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. Molten salts could offer the solution. Some companies[21] are planning to demonstrate the use of molten salt as a heat transfer fluid in concentrating solar power plants.

[20] The establishment of an open source communication protocol for Smart Grids / Smart Homes would enable manufacturers to create and commercialise devices that are compatible with many systems.

[21] Namely Enel Green Power (IT) and Abengoa (ES).

	Short term	Medium term	Long term
Basic research	Thermal conductivity enhancement	Open data base of TES material properties for LCA	
	New sustainable TES materials for high temperature storage with high conductivity ($120^{\circ}C < T < 600^{\circ}C$ and $\lambda > 2$ W/m·K)	Standardized TES Scale up and down methodology	New sustainable TES materials for high temperature storage with high conductivity ($120^{\circ}C < T < 600^{\circ}C$ and $\lambda > 4$ W/m·K)
	Thermo-mechanical assessment technique and methods	In situ thermo-mechanical assessment of the TESM for possible warning under operation	
	New cheaper vacuum insulation materials with at least 50% higher insulation and at least 70% cheaper	New methods for TES materials' analysis	
	High temperature, high pressure material and vacuum storage (250 C)	Additives in water to enhance stratification	
		Fluids combining heat transfer and heat storage (any temperature range, H > 150 kJ/kg and $\lambda > 2$ W/m·K)	Fluids combining heat transfer and heat storage (any temperature range, H > 250 kJ/kg and $\lambda > 4$ W/m·K)
	Stratification enhancers	Pressurized water tanks 120 C	
Applied research & development	Storage/discharge level measurement technique	Open data on fatigue and thermo-mechanical properties of available TES materials	
	TES materials and HTF compatibility procedures and tests	Open data on TESM and HTF compatibility	
	Effect of ATES systems on microbiological composition and functioning of the subsurface, anticipated temperature effects on biogeochemical reaction rates in ATES		
	New materials for DHW that reduce standing heat losses while avoiding microbiological risk.		
	Enabling mechanisms and technologies to integrate storage into the smart grid	Validation of standard In situ probe to assess the storage/discharge level under operation	
Demonstration		Commercial in situ probes for thermo-mechanical and storage level assessment under operation	
	Water treatment technology preventing clogging for HT-UTES		
	Thermal efficiency in different geological conditions of HT-UTES		
	Large scale domestic stores to assess economic viability, construction and installation issues, and manufacturing efficiencies	Flexible volume tanks Target: 70% volume occupancy	

Figure 10: Research priorities and targets for Sensible Heat Storage

▶ 3.3 Latent heat storage

▶ 3.3.1 Technology description

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.).

PCMs are mostly chosen on the basis of cost (which reflects availability). Characteristics of secondary importance include:

- ability not to phase-separate;
- ability not to subcool;
- not to cause corrosion;
- to be stable over long periods;
- to be good conductors of heat.

▶ 3.3.2 Research priorities

• Optimisation of phase change heat storage

Phase-change heat storage can be used widely at a reasonable cost[22]. Its main advantages are higher energy density, simplicity in system design and the delivery of heat at constant temperature.

Nevertheless, to be 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 HVAC 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 ºC< T <1000 ºC.

• 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.

Work in this topic requires mainly basic and applied research expected to be led by research organisations. Environment-friendliness is an important parameter to consider in the development of new TES materials.

[22] Today salts are used with a cost of 700 €/ton, but paraffins at 6000 €/ton are considered too expensive.

• Integration of phase change materials in building element materials

Inclusion of thermal storage materials in building elements increases the functionality of the elements, the possibilities to enhance the storage capacity of the building and reduce thermal cycling of heat pumps or burners, without the need to fit dedicated thermal energy stores.

Collaborative R&D between the building industry (which has knowledge of building materials) and research institutes or universities (which have knowledge of heat storage materials) should focus on the possibility to incorporate PCM in polymers for window frames, drainage systems, etc. and in materials for wall, floor and ceiling. . In parallel research to determine the fire-risk of these materials when embedded into construction materials is required.

• Software algorithms and codes need to be adapted to take account of PCM

The European Energy Performance of Building Directive (EPBD; cf. References: EU 2010), requires constituent countries to develop procedures for the analysis of new and existing dwellings[23]. The development of algorithms, accompanying procedures and (if required) new codes will enable the uptake of PCM technology. These codes will need to be experimentally verified.

• Fluids combining heat transfer and heat storage

Energy consumption for HVAC can be reduced if higher efficiency components are used, including heat transfer fluids and TES. If these two are combined, material use can be optimised, less pumping will be needed and heat transfer will improve. Today, this is being studied for cooling in building with ice slurries (developed) and PCM slurries (at research stage).

	Short term	Medium term	Long term
Basic research	New heat exchangers with PCM included Target: - Energy output: 10 kW - Energy density: 60 kWh/m^3_{system}	New PCM Target: - Better chemical performance - 500% better energy storage than water storage - Energy output: 15 kW - Encapsulation guaranteed for 50 years	New PCM with adjusting melting temperature
	New PCM materials that are not subject to subcooling have greater number of cycles before breaking down – greater lifetime, chemically inert materials		
	Corrosion-resistant storage materials.	Inert, non-combustible PCMs for use in buildings	
	Inert, non-combustible PCMS for use in buildings.		
		Fluids combining heat transfer and heat storage with phase change in the storage	
	Triggering systems (avoiding subcooling and allowing "independent" triggering of the PCM)		
Applied research & development	Heat Exchanger Design between PCM and HTF – power 10 kW	Enabling mechanisms for integrating into existing building systems	
	Enabling mechanisms for integrating into existing building systems		
	PCM embedded into Solar thermal systems	New PCM in polymers Target: 70 $kWh/m^3_{material}$	

[22] For example in the UK for dwellings this is SAP, and non-domestic SBEM.

	Computer models that will integrate into EPBD building analysis software		
	Seasonal storage systems with PCM	New storage solutions with PCM for 10°C to 100°C	
	Increasing power output of PCM for domestic hot water and short term storage systems in combination with CHP and heat pump technology		
	CO_2 hydrates for 0°C storage	PCM in building materials – Energy density > 30 kWh/m³ (of the component as a whole)	PCM in building materials – Energy density 60 kWh/m³ of the component as a whole)
Demonstration	PCM for cooling applications in building	New building systems with PCM included Target: 15 kWh/m3 kJ/kg_{system}	New storage solutions with PCM
	PCMs to control temperature of PV	Seasonal storage systems with PCM	
	PCM embedded into Solar thermal systems		
	Thermal comfort control using PCM in buildings		

Figure 11 - Research priorities and targets for Latent Heat Storage

3.4 Thermochemical storage

3.4.1 Technology description

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 TES. This technology is known as thermochemical storage, and is divided in chemical reactions and sorption systems. Chemical systems offer higher energy density than sensible or latent heat storage systems. In general, the main advantage of thermochemical storage compared to PCM is that losses only occur during charging and discharging, but not over time, making these systems preferable for long term storage[24].

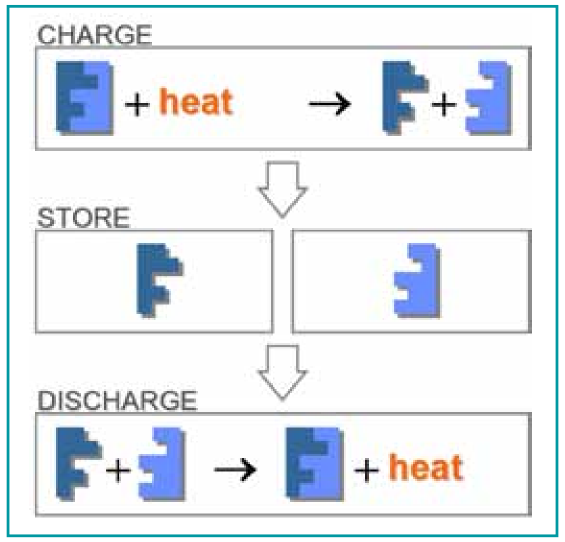

Figure 12 - basic principle of thermochemical storage (source: ECN)

[24] In general, the main advantage of thermo-chemical storage if compared to PCM is that losses only occur for charging and discharging, but not over time, making these systems preferable for long term storage.

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An example of a real reversible chemical reaction is liquid NH3 with BaCl2. In this case NH3 is liquid in an evaporator/condenser volume and the salt is the reactor volume. During the synthesis there is simultaneous production of cold at the evaporator and heat at the reactor. During the regenerative step (heat storage), the reactor is heated and the reaction decomposed, the NH3 goes back to the condenser. The temperature and power levels can be altered through the choice of salt and the internal pressure level.

Sorption systems are divided between adsorption and absorption. In adsorption a gaseous or liquid phase is bonded on the inner surface of a porous material, releasing heat; in the desorption step, heat is added to the material. The most common classes of solid adsorbents are zeolites and silica gels. Zeolites have a crystalline structure and a uniform pore size, while silica gels different a pore sizes. In absorption, the gaseous or liquid material is also taken up by the material, leading to structural changes. These changes can be a change from the solid to the liquid state or a change in crystalline structure, and leads to a higher energy uptake.

Sorption systems can be further classified in closed and open storage systems.

In a closed sorption system the heat is transferred to and from the adsorbent by a heat exchanger, usually called condenser/evaporator. The heat has to be transported to the absorber at the same time that it is extracted from the condenser, to keep the heat transfer fluid (HTF), usually water, flowing from the adsorber to the condenser. This flow of HTF is very important, because if the sorption process reaches the equilibrium the process stops.

In an open sorption storage system air transports water vapour and heat in and out of the packed bed of solid or liquid adsorbents. In the desorption mode, hot air enters the packed bed, desorbs the water from the adsorbent, and leaves the bed cooler and saturated. In the adsorption mode, the humidified cool air enters the desorbed packed bed. The adsorbent adsorbs the water vapour and releases the heat of sorption. The air exits warm and dry.

3.4.2 Research priorities

- **Materials for thermochemical heat storage**

The main bottleneck in the development of compact, seasonal house-scale heat storage is the current lack of stable, high-performance, cost-effective storage materials and processes. Novel thermochemical reactants have to be identified, for example by looking at what micro-electronics, nanotechnology or nature has to offer. Combinations of materials should be included in the search.

Computer simulation of the physical processes governing material behaviour at molecular level, used model bulk properties, is a promising tool for material development. This method could help design new, compact storage materials. These materials can then be tailored to the application, which will have a specific requirement for temperature level, energy and power density, an open or closed reaction process, reversibility, cost and toxicity.

The study of novel thermochemical materials should result in a better understanding of the structure, composition and performance characteristics of these materials. Knowledge of how to synthesise, characterise and compare materials and their performance must be gained. Environment-friendliness is an important parameter to consider in the development of new TES materials.

Work in this area is best described as basic and applied research, and is expected to be led by research organisations.

- **Optimisation of thermochemical heat storage processes**

Thermochemical and sorption materials, processes and chemical reactions are already being developed today, moreover new materials are expected to be developed in the near future (cf. Section 3.1). Process design and optimisation is needed. Simulations of molecular and ionic interactions, reaction kinetics and bulk scale mass flow are needed.

Additional research activities ought to be conducted concerning heat storage processes in order to optimise both power and energy, with the design of novel reactor and heat exchanger principles. The compromise between heat power restitution and energy density in reactor and heat exchanger designs has to be studied in detail. Applied research should be carried out on closed and open processes, both integrated with and separated from the reactor, for liquid and solid reaction. Here stability and cyclability are important.

Applied research should focus on:

- Design of process
- Control of the system
- Predicting annual performance, especially in seasonal storage applications.
- Integrating the storage system in the building (roof, araldite, etc.) and in the heat/cold distribution system.

This topic requires mainly applied research, and is expected to be led by research organisations in close collaboration with industry.

• Fluids combining heat transfer and heat storage

An example for this combination is the design of novel solar thermal collectors that serve as a reactor for charging thermochemical materials directly.

• High temperature thermochemical systems

At high temperature, thermochemical systems with NH_3 or with hydroxide/oxide reactions need additional pilot validation and cost reduction. They have high potential for energy storage and upgrading power, for example in applications where heat is converted to cold or heat at higher temperature; or discharge power > charge power. These systems also offer an opportunity for energy to be transported.

At very high T (900°C to 1400°C – temperatures generated in solar furnaces), basic research is needed in thermochemical TES with metal oxides.

	Short term	Medium term	Long term
Basic research	TCM target: 4 times more compact than water at system level	New materials for TCM Target: factor 6	New materials for TCM Target: factor 8 better than water, i.e. 560 kWh/m³
	Novel TC solar collector: first prototypes New principles for state-of-charge developed Numerical models:	Fluids as heat transfer and heat storage Target: energy density> 90 kWh/m³ First numerical models available for designing new materials	Fluids as heat transfer and heat storage Target: energy density > 180 kWh/m³
		TCM in bottles and in pipes	Very high temperature thermochemical systems (T > 1000 ºC; energy density> 180 kWh/m3))
		Numerical models that connect molecular modeling with larger-scale material properties modeling.	
Applied research & development	Control of TCM systems: new sensors developed	Seasonal storage Target: solar fraction well above 50%	Integration of TCM system in the buildings construction system
		TCM systems with optimised/ dedicated reactor technologies	
		Validation and cost reduction of thermochemical systems (by 30% of today's cost)	
Demonstration		State-of-charge methods demonstrated	
		TCM systems on the market with energy density better than 4 times water (280 kWh/m3)	
	Improved solar TCM solution for single-family houses	Improved solar TCM solution for multi-family houses	

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Figure 13 - Research priorities and targets for Thermochemical TES

3.5 Research priorities at system level

• Advanced monitoring of storage systems

Control of storage systems is of great importance to make operations more efficient for their deployment in the market, also in the framework of the recent evolution of robotics, smart meters, and other intelligent control systems.
Specifically for latent and thermochemical systems, low-cost sensors of pressure, composition and internal energy are needed (the latter to assess stage of charge). Sensors and algorithms are required that provide a better temperature profile within a given space and hence greater accuracy of comfort control. The more information on the state of the system is available to the controller the better able it is to know when to trigger (i.e. start) the phase change or the chemical reaction/adsorption/absorption of the materials in the TES. There is much potential for innovation in this topic.

• Optimised integrated collector storage

In solar thermal applications, having the store and the solar collector as different components has the disadvantage of taking up more space and making the system more complex. The development of integrated collector storage (ICS) entails developing a new product with complete new concepts of collector and storage. This development requires optimisation in the design and geometry of the system, and storage concepts with higher power and storage density, achieving improvements in weight, area, mechanical and chemical stability, etc. Integration of the system into building components is also a key aspect. This topic requires research led by industry, in close collaboration with architects, construction industry and research institutes.

• System development of underground thermal energy storage (UTES) systems

The system performance of large underground thermal storage systems is determined by system configuration, site geology and hydrogeology and by system long-term charging and discharging profile. Poor integration into heating systems is the reason for some demonstration projects being abandoned. System optimisation is only possible when integrated models that incorporate all parameters are developed and validated.
The potential complementarity of ATES and/or BTES in densely populated areas and the combination of such systems with shallow geothermal heat storage should be investigated.

- **Advanced control strategies**

The storage of heat or cold is typically a time-dependent process. New strategies should be developed that correctly model the time-dependent and system-dynamic behaviour of systems with TES. These strategies could be based around algorithms that improve as they accumulate experience of system operation, predictive control or distributed control systems.
Advanced control strategies could be applied to:

- Heat demand of industrial buildings with buffer storage elements.
- Industrial heat production systems incorporating seasonal storage systems.
- Use of industrial surplus heat.
- District heating with seasonal storage.
- Combinations of different short and long term thermal storage systems.
- Innovative concepts to increase the temperature difference of demand circuits by reducing the return temperature as much as possible while utilising heat to the fullest extent.

- **Distributed thermal energy storage for smart electricity grids and smart cities**

Distributed TES incorporated into structural elements (like the building mass) or non-structural elements (like stand-alone storage devices) can be a part of a smart electricity grid, storing heat or cold in response to the cost of electricity.
Activity in this topic includes the development of control elements for thermal storage devices, technologies for effectively measuring of the state of charge of thermal storage devices and algorithms for the inclusion of the thermal devices in the smart grid supervision and control system. At the macro-scale, research is needed on the optimal use and control of distributed energy storage in thermal and electricity networks.

- **Storage of rejection heat in solar cooling process and solar power plants**

Solar cooling is a technology that can reduce electricity demand during summer, especially in southern Europe. One of the obstacles it faces is the need for a cooling tower, but instead of a tower, a TES could be used. A TES could also store low-temperate heat dissipated from thermochemical storage systems. Such stores could be:

- Short-term, releasing the low temperature heat at night, for example, when ambient temperatures are colder.

- Long-term, releasing heat when there is demand.

The integration of such store in cooling systems, with their particular dynamics, needs to be demonstrated at pilot scale. Integration on either the hot side or the cold side of the absorption chiller could improve efficiency.

The concept could also be applied in solar power plants, where today waste heat has to be extracted at the condenser (1 MWth of waste heat at 60 ºC for each MWe power output). This is today achieved by wet cooling towers consuming a lot of water (in desert areas) in the range of 4 m3/MWh or fan-assisted dry-cooling leading to high electricity consumption and an efficiency loss. One solution is to store the waste heat during the day to discharge it during the night when the ambient temperature is lower, which could also lead to more even utilisation of the power block, allowing it to be smaller and correspondingly cheaper.

- **Materials for storage containment**

The deployment of TES materials has been held back by the difficulty to encapsulate them. New storage materials need to be developed, including cheap thin polymeric materials, with properties such as:

- High thermal insulation.

- High mechanical strength and thermal stability

- Unreactive with the material they encapsulate

- **System evaluation**

A number of research priorities relevant to all TES systems are:
- Methods and criteria to transfer research results from laboratories to industry or expected performance from one scale to another.

- Lifecycle Assessment (LCA) and of different TES concepts.

- Integration of the TES sub-system in the complete system.

- Business models for storage, on district and individual level (include “biomass pellet model”, i.e. physical distribution of charged material), contracting issues in district heating with storage.

▶ 3.6 Non-technological priorities

- **Education and training**

The increase in the market for renewable heating and cooling technologies, including TES devices, will create demand for experts in the TES field and trained engineers for the manufacturing, installing and maintaining the systems. An extra challenge in the future market for technical specialists is the increasing imbalance between people retiring and the inflow of young people on the labour market in Europe in general. Without proper measures, this will cause an increasing shortage of scientific and technical experts.

Computer tools, assessment techniques and design guides are required that are easy to understand but do not simplify things to an extent that installation and operation are compromised by lack of knowledge. Knowledge of TES principles should become a standard part of energy education in schools and university curriculum. Vocational training programmes in any renewable heating and cooling technologies should include a component of TES.

- **Knowledge of system performance**

A drawback of thermal systems, including thermal storage systems, is the lack of feedback to the users about the performance of the thermal system. TES systems need to be better at reporting their performance to their owners and users. This can help faults to be detected earlier and remedial action taken before they become more serious. More data on performance will enable a statistical base for the performance of a population of systems to be built up.

- **Labelling or certification of thermal energy storage devices**

TES products need to demonstrate their compliance with standards, especially in building-integrated applications. New labelling or certification standards need to be developed to evaluate and compare new storage materials, products, and systems as they will become available on the market. Moreover, TES equipment should be included in European building codes.

- **Legal framework UTES (ATES/BTES)**

The expected growth of UTES in Europe requires a clear legal status and policy. Although improvements are still desirable, in general the legal framework for BTES is fairly well developed in Europe (with the notable exception of HT-BTES which is still banned in a number of EU countries).

The use of groundwater for energy storage is generally poorly regulated and in some countries there are significant barriers to ATES. Rules that are harmonised across Europe and that recognise the contribution of ATES to a sustainable energy supply, especially in the built environment, should be the aim.

- **Public awareness**

In order to deploy TES at large scale, it's critical to raise awareness on the existence and benefits of integrating TES into the energy system. A broad range of actors should be addressed: architects and engineers, installers, manufacturers, policy makers and the public.

3.7 Conclusions

Thermal energy storage can hugely increase the technical potential of renewable energy sources by allowing heat (and cold) to be utilised when there is demand for it, rather than at the same time that it is generated. The emphasis of scientific research, development and demonstration activities must be focused towards storage technologies that enhance the performance of energy systems and facilitate the integration of RES.

A wide range of technologies exist at laboratory-scale, some of them with significant and imminent commercial potential. 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.

Several technological solutions should be supported in parallel: advanced sensible heat storage, PCM, sorption and thermochemical. The most promising areas of R&D are in latent heat storage and novel thermochemical concepts. 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.

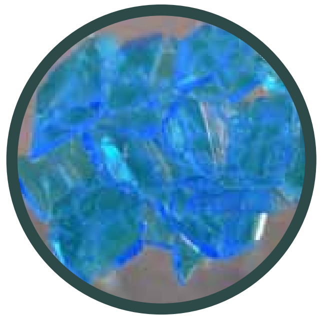
Realising the great potential of TES will require research focused on the integration and optimisation of heat/cold stores with renewable energy technologies. A "system-level perspective" is needed, taking into account the heat demand patterns of all consumers connected to the system, as well as the interaction with the building envelope and the energy networks.

	Basic research	Applied research & development	Demonstration
Sensible TES	• Materials research for the reduction of heat losses • Materials research for high temperature storage with high thermal conductivity • Fluids combining heat transfer and heat storage	• Microbiology in UTES systems • Flexible volume tank systems • Development of new methods of TES materials' analysis	• Optimisation of hydraulics in advanced water stores, reduction of mixing and increased stratification • Control strategies for integrating sensible stores into the Smart Grid • High temperature underground storage (HT-UTES)
Latent TES	• Optimisation of phase change heat storage • Fluids combining heat transfer and heat storage	• Integration of phase change materials in building elements	• Software algorithms and codes for EPBP enabling software packages
Thermochemical storage	• Materials for thermo-chemical heat storage • Fluids combining heat transfer and heat storage	• Optimisation of thermo-chemical heat storage processes • High temperature thermo-chemical systems	
Research priorities at system level	• Materials for storage containment	• Advanced sensoring in storage systems • Distributed thermal energy storage for smart electricity grids in smart cities	• Optimised integration of UTES systems • Advanced control strategies • Storage of rejection heat in solar cooling processes and solar power plants • System evaluation
Non technological priorities	• Education and training • Knowledge of system performance • Labelling or certification of TES devices • Legal framework UTES (ATES / BTES) • Public awareness		

Figure 14 - Synoptic table of strategic & research priorities for TES








4. Heat Pumps

Photo © Thomas Nowak

4. Heat Pumps

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4.1 Introduction and state of the art

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 all the time. 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 75% 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.

> Heat pumps can be highly efficient, although their overall primary energy efficiency depends on the efficiency of electricity production (or other thermal energy source) they use. Using the average efficiency of electricity production in Europe, a ground-coupled heat pump with a seasonal performance of 4 reaches a primary energy efficiency of 160%. Air-source units achieve efficiencies of around 140%. Heat pumps using heat from the direct combustion of gas as auxiliary fuel can achieve a similar efficiency.

The European Union's "RES" Directive 2009/28/EC[25], credits heat pumps as using renewable energy sources, as long as they result in reduced primary energy consumption (minimum primary energy efficiency of 115%, which is the result of a seasonal performance SPF[26] 2,875 at an average efficiency of the electricity production of 40%), that is they provide more useful cold or heat than the electricity or thermal energy input.

[25] The "RES" Directive 2009/28/EC on the promotion of the use of energy from renewable sources states in art. 2: "The following definitions also apply: a) 'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases;"

[26] Heat pump efficiencies can be described by their performance under laboratory conditions by a coefficient of performance (COP). For example, a heating COP of three indicates that the use of one unit of auxiliary energy results in three units of useful heat. Test procedures vary, with many being based on operation under estimated actual operating conditions, for instance over an entire year or heating season. If climate variations and part load operation are included, the resulting value is a seasonal COP (sCOP, which can be calculated according to the EN 14825). Results of field measurements are usually referred to as seasonal performance factor (SPF).

Heat pumps can be categorised according to the medium from which they extract renewable energy (air, water or ground[27]), the heat transfer fluid they use (air or water) and their purpose (cooling, space heating, and water heating).
Heat pumps can be driven by mechanical energy, produced by an electric motor (electric compression heat pumps) or a combustion engine (gas/motor driven heat pumps), or by thermal energy using the principle of sorption. The structure of this chapter reflects the distinction between electrically and thermally driven heat pumps. The key elements of these technologies are:

- **Electrically-driven heat pumps** mostly follow the principle of **mechanical vapour compression**. A refrigerant is exposed to ambient energy (this is the heat source). It evaporates, transferring energy from the environment to the refrigerant cycle. A compressor driven by an electric motor increases the pressure of the refrigerant resulting in the required increase in temperature. Heat is then transferred via a heat exchanger to the target for heating (the heat sink). During this process, the refrigerant vapour is turned to a liquid again via condensation. After de-compressing the liquid, it can be used again. The cycle is closed.

The **efficiency of heat pumps** is inversely related to the required temperature lift. The higher the source temperature and the lower the required (sink) temperature, the better is the efficiency. Heat distribution systems like DHC could supply high source temperatures. The direction of the cycle can be switched so the same machine can be used for heating and cooling giving it an economic advantage over separate systems in cases where both processes are needed. Contrary to this general rule, the use of CO_2 as a refrigerant in a transcritical cycle requires a high temperature difference to be efficient. CO_2 is suitable for heating water from the water mains (at 10 ºC) to 60ºC or higher. CO_2 is also suited to cooling operations.
The total global warming impact (TGWI) is much better than that of traditional fossil fuel heat generators, a fact that makes them useful not only for increasing the share of RES, but also to reduce greenhouse gas emissions from heating, cooling and hot water production.
Electrically-driven heat pumps are the predominant technology for space cooling, either in simple or reversible air conditioners or chillers.

- **Thermally-driven heat pumps** use the same thermodynamic cycle as electrically driven compression heat pumps, however the compressor is replaced by a thermal sorption closed-cycle. Electricity is needed only for auxiliary components like pumps to circulate the working fluid. Thermally driven heat pumps are mainly used for cooling in combination with waste heat or heat from renewable sources (eg solar). However, they can also produce large quantities of medium temperature heat with high efficiency.

Generally, a heat-driven heat pump/chiller works at three levels of temperature: the machine is driven by a heat source at high temperature, heat is rejected at medium temperature and collected at low temperature (cf Figures 15, 16 and 17). Heat rejected at medium temperature is the relevant output when heat is required from the system. The cold produced at low temperature is the relevant output in chilling mode. The most widely used technologies in heat-driven cooling systems are absorption and adsorption closed-cycles[28]. Sorption chillers can make use of heat above 45°C for the production of cold for air conditioning or, with driving temperatures >100°C, for refrigeration purposes. In heat pump mode they boost the Coefficient Of Performance (COP) of the heating system through the exploitation of low temperature (renewable) heat sources that transfer heat to the low temperature part of the system.

Heat pumps can be installed as single energy appliances as well as in large energy systems and DHC. Heat transformers are a variant of sorption systems which can pump waste heat at medium temperature up to a higher temperature, with rejection of remaining heat to the low temperature sink.

Thermally driven heat pumps / chillers, using environment-friendly refrigerants, have primary energy efficiency in the range 120% to 160%. Three categories of thermally driven heat pumps can be distinguished, each with their own definition of efficiency:

[27] For the purposes of the RHC-Platform's activities, strategic and research priorities for the development of the ground-source heat exchanger to be used in geothermal heat pumps, are presented in a separated document (namely the SRA for Geothermal Technology).

[28] In addition to these two categories, open sorption cycles so-called desiccant systems, also represent an effective technological solution. The principles of ad- and absorption were also described in Chapter 3.

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(1) Thermally driven cooler

A thermally driven cooler uses the temperature difference between the heat source and the ambient temperature as driving force to pump heat from a low-temperature source to the heat sink at ambient temperature. The efficiency of such a system (COP) = Cooling power / (Waste) heat power. The value is typical 0.5-0.9, depending on temperature differences.

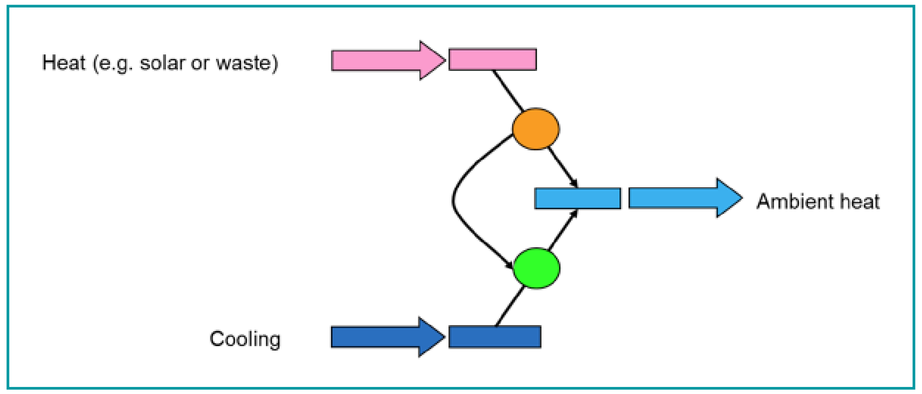

Figure 15 - scheme of a thermally driven cooler

(2) Thermally driven heat pump

This kind of heat pump uses the temperature difference between a high-temperature source and the required useful output temperature as driving force to pump heat from a low-temperature ambient heat source (air, water, geothermal, district heating, industrial waste heat) to the required useful output temperature. The efficiency of this system = Process heat / High-temperature heat. The value is typical 1.2-1.8 or even higher, depending again on temperature differences.

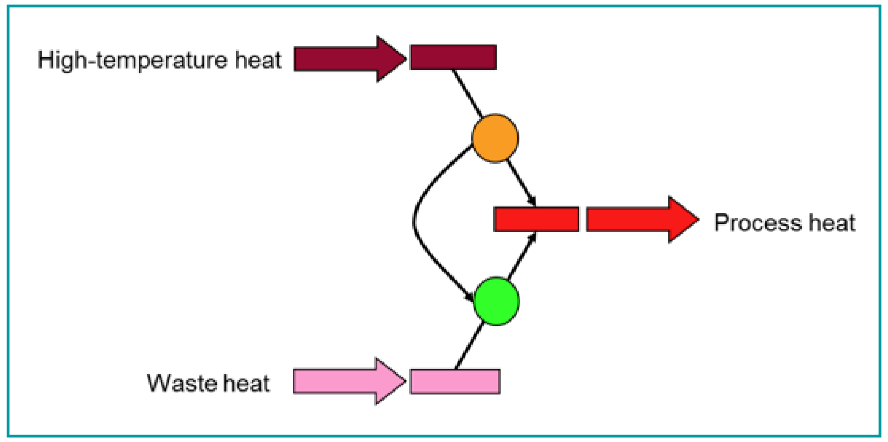

Figure 16 - scheme of a thermally driven heat pump

(3) Thermally driven heat transformer

This heat pump uses the temperature difference between a waste heat source and the ambient temperature as driving force to pump heat from the same waste heat source to the required output/process temperature. The efficiency of this system = Process heat / waste heat. The value is typical 0.2 – 0.5, depending again on temperature differences.

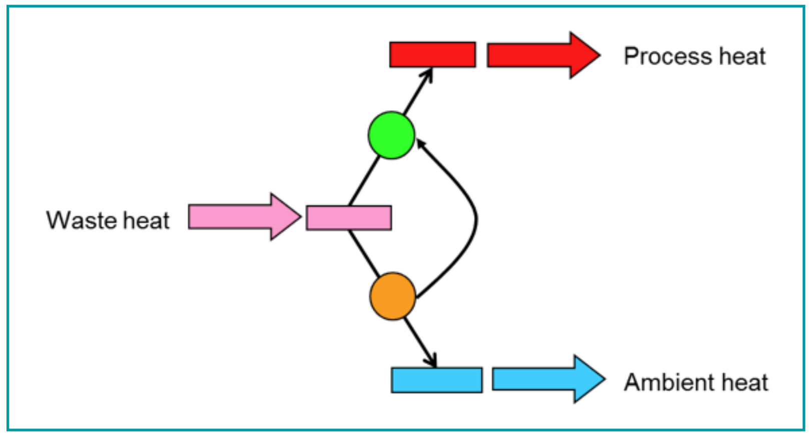

Figure 17 - scheme of a thermally driven cooler

Heat pumps are proven, technologies that have been available for decades. Over the time, these systems have become more efficient, but considerable room for improvement still remains[29]. The Ecodesign of Energy related products Directive (ErP) is expected to push up heat pump efficiency[30].

Heat pump technology has tended to be installed in new buildings as they are built but with the slowdown in the construction of new buildings, the renovation segment of the residential, commercial and industrial segments will become increasingly important. The sanitary hot water segment in both residential and commercial applications also looks set to grow in the coming years assisted by favourable legislation changes.

In terms of technology development, manufacturers continue the relentless drive for improved overall system performance, achieved in general through optimized components and more attention to the delivery of completely integrated solutions. 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. It also enhances possible fields of applications to nearly 100% of the market.

To the requirements of low energy buildings (i.e. which have efficient heating and cooling, are more air-tight and less ventilation), systems integrating heat pumps, heat recovery and ventilation are now becoming increasingly common. In the broader context, heat pumps are seen as an enabling technology in the emerging 'smart grid' infrastructure and smart cities initiative. Pilot programs and extensive field tests abound in many European countries, with utilities becoming convinced of the role heat pumps can play in grid balancing, supply and demand side management, and smart energy storage.

4.2 Electrically driven heat pumps

Electrically driven heat pumps are a highly efficient technology to provide space heating and cooling, as well as hot water in buildings. They are today's predominant solution used for space cooling whether in simple air conditioners, reversible air conditioners or chillers.

Most heat pumps use a vapour compression cycle driven by an electric motor. The electrical energy needed to run the compressor and the pumps can be cut by reducing the temperature gap between the heat source and the heat sink. Therefore low-temperature heat distribution systems play a major role in allowing heat pumps to work efficiently. As the heat pumps refrigeration cycle always produces heating and cooling concurrently, the same machine can (depending on its design) provide heating and cooling in alternating order or in parallel. This can be economically interesting where both services are needed. Electrically driven heat pumps based on the vapour compression cycle have improved considerably in the last decades in terms of efficiency, flexibility and reliability; they now constitute one of the pillars with the highest potential for reducing primary energy consumption in all heating/cooling applications in buildings as well as in industrial processes.

Yet, there remains a significant room for further improvement. For the heat pump to become widely accepted, efforts are needed to increase its efficiency, reduce its environmental impact and decrease costs of production as well as price per installation. Moreover, research should look at how to develop efficient high temperature solutions (above 65°C) to cater to the renovation segment. Efficiency is not only essential to reduce energy consumption and global CO2 emissions but also to cut operating costs. If lowered, this will partly offset the considerable investment costs to the consumer. Given that a heat pump system remains more expensive than existing fossil fuel alternatives, especially gas condensing boilers, limits market growth as many consumers focus on the investment and not on the total cost of ownership.

Market development of electrically driven heat pumps

The analysis of data from 20 European countries reveals an annual market exceeding 700,000 units. Since 2005, a total of 3,778,246 units with a heating function were installed. They provided 29.14 TWh of renewable energy from air, water and ground. In addition, they saved 6,8 Mt of Greenhouse gas emissions. {EHPA 2011} These units are mainly sold in the market segment of new, single family residential buildings (approx. 80%).

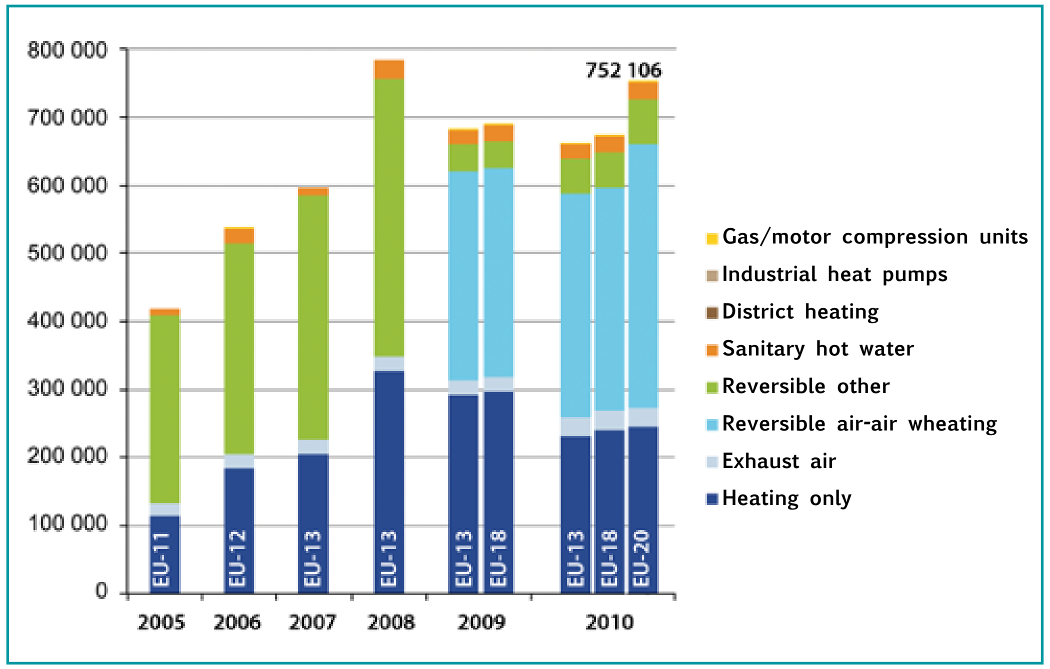

Figure 18 - Sales of heat pumps with heating function in Europe divided by type. (Source: EHPA Outlook 2011)

[29] For instance, the coefficient of performance (COP) of the best air conditioners has increased to between 6 and 7.23 Similar progress has occurred with sanitary hot water heat pumps,, with the COP of these devices in Japan increasing from around 3.5 in 2001 to 5.1 in 2008.

[30] Directive 2009/125/EC "establishing a framework for the setting of ecodesign requirements for energy-related products (recast)". In particular, implementing measures of Lots 1, 2 and 10).

4.2.1 Research priorities for electrically driven heat pumps

Manufacturers optimise the design of components and equipment only for the applications with the largest market, which for much of history of heat pumps has been air-conditioning. Now a lack of development of specific components for other kinds of heat pump 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:

I. Heat exchangers. The aim is to minimise the difference in temperature between the refrigerant and the secondary fluid needed transfer a given quantity of heat at a given temperature and the amount of refrigerant they contain, while keeping the cost low. This requires:

- Enhanced heat transfer surfaces
- Minimising refrigerant volume
- Even distribution of the secondary fluid flow and refrigerant
- Efficient draining of the condensate
- Efficient approaches to defrosting (air-source units)

Mini-channel aluminum technology shows excellent features for high efficiency at minimum refrigerant charge but there are still some important issues to be solved, especially in its application as the evaporator of a heat pump:

- Even distribution of the refrigerant among the channels
- Efficient draining of condensate
- Optimisation of design to minimize the deterioration of performance caused by frost formation, and corresponding defrost at low ambient temperatures
- Possible dual use as an efficient condenser in reversible units

II. Compressors. Design varies depending on the refrigerant used. There is optimization potential for all types of compressors to achieve higher efficiency. More research is necessary for compressors to be used with hydrocarbons and CO2 to facilitate and promote the use of natural refrigerants as an efficient solution. For the minimization of the refrigerant charge it is important to reduce the amount of oil and to reduce the solubility of the refrigerant into the oil provided that adequate lubrication is guaranteed. On the other hand, the incorporation of the latest electrical motors ("electronically commutated motors") will increase efficiency considerably in all applications and increase the potential for efficient capacity regulation through speed variation. Initial impact is expected from the introduction of the implementing measures in Lot 11 of the ErP Directive, but more work needs to be done to integrate standard products into heat pump systems. This applies in particular to enhanced and optimised control systems. R&D on two-stage compressors will be needed to reach more efficient high-temperature heat pumps (capable of reaching high temperatures even at low outdoor temperatures).

III. Fans and pumps are used to transport the different media inside and outside the heat pumps. While these components generally benefit from the introduction of ErP, Lot 11, R&D will be helpful to tailor them to heat pumps. In particular, air source heat pumps need to be improved with regard to noise emission of the outdoor unit. This can be done by better fans and better control strategies.

IV. Expansion valves. Highly cost-effective **electronic expansion valves** are necessary for air-source heat pumps. The optimal trade-off between lowest possible amount of steps in the step motor and the ability to adjust mass flow precisely should be found. As an important measure to improve the sizing of fluid distributors and using synergy effects for the two processes of throttling and distributing, a better understanding of the atomisation process at the valve outlet and of new geometries are necessary. **Thermostatic expansion valves** could be improved for air-source and other heat pumps:

- by suppressing any kind of hunting at very low superheat and
- by minimizing the correlation between heat source temperature changes and the superheat temperature difference to better fit the minimum stable signal of the evaporator.

However, improving the components does not automatically translate into better performance. Seasonal performance, which is what matters in the global objective of minimizing operating costs (by reduced primary energy consumption) and CO2 total emissions depends on the combination of these components in a system, which may include solar collectors, TES, DHC and complex control technology.
In summary, the next generation of heat pumps should:

- Be more efficient.
- Use refrigerant with very low TGWI at comparable efficiency to today's units, preferably, using natural refrigerants.
- Prevent leakage of this refrigerant entirely
- Use quantities of refrigerant of 25 gram/kW for hydrocarbons in hydronic circuited heat pumps and about 30-40 gram/kW in air-to-water heat pumps.
- Be cost and energy effective safety technologies for flammable refrigerants.
- Have efficient and flexible modulation of capacity.
- Apply improved strategies and designs for defrosting.
- Apply improved strategies and designs for noise handling.
- Be designed to maximise seasonal efficiency.
- Enable maximum integration with other heat sources / sinks (simultaneous production of chilled water and hot water at various temperatures).
- Integrate smart controls, also able to integrate electricity from intermittent RES.
- Have standard communications interface to the internet and to smart meters/smart grids.
- Be as small as possible.
- Be highly reliability.
- Be less expensive.
- Be easier to install and operate.
- Minimise maintenance needs.

Research leading to the improvement of these areas will result in much better efficiency and performance as well as to a higher satisfaction of the end user, which is essential for the future market penetration. It will also provide a more incisive contribution of heat pumps to the EU energy and climate change targets.

Figure 19 - heat pump components (© Thomas Nowak, EHPA)

As mentioned, manufacturers optimize the design of components and equipment only for the applications with the largest market. This results in components and pieces of equipment available and used for heat pumps that were originally optimized for Air Conditioning (the A/C market is much greater than the heat pump market, which has for a long time justified the cost for optimization of components). **Component R&D is of utmost importance as the lack of optimized parts represents a major barrier to the future improvement of heat pump technology**.

The European Industry should focus on application areas in which Asian manufacturers do not already dominate (i.e not split heat pump appliances or VRV systems). Both offer good performance at low cost resulting from mass production and generally lower manufacturing costs.
Europe's efforts should be focused on areas in which the superior quality of integrated solutions is requested and where market opportunities exist. Therefore, four different heat pump applications are identified (A, B, C and D) which should receive further support for research and development.

If a system is large, integrating many inputs and outputs, centralised control can lead to efficiency savings. Such systems are found in **large buildings** (e.g. municipal buildings, offices, hotels). Heat pumps for hot/chilled water production are relevant here, and European manufacturers retain a great share of the market. Both air-to-water and ground-coupled heat pumps are suitable for this market. In such buildings it is likely that in the short future three or four water distribution networks at different temperature will exist:

- Sanitary hot water. This water should come from solar thermal collectors, and only in very cloudy days and in winter time be assisted to increase the water temperature with a dedicated heat pump.
- Water for heating and cooling (2 or 4 pipes configuration): water for space-heating at 40 ºC and chilled water at 10 ºC.
- Neutral temperature. This is the neutral temperature loop, which will be employed to recover heat wherever it is available from low-temperature sources and to cool machinery or to condense remote chillers. It can be balanced by cooling towers, dry coolers or ground source heat exchangers, or excess solar energy.

This scenario requires the development of a **new technology of high efficiency heat pumps simultaneously producing chilled water, working with natural refrigerants, 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**. Two different heat pumps are proposed for this area:

A. Heat pump for simultaneous chilled/hot water production

High efficiency heat pump of around 70 kW (20 tons) able simultaneously to satisfy demand for water for space-heating at 40 ºC for chilled water at 10 ºC, by automatically rejecting/taking the necessary heat to/from the neutral temperature loop.

B. Heat pump booster for high temperature hot water production

50 kW heat pump booster for sanitary hot water production at 60 ºC using water with an input temperature of around 30 to 35 ºC. Water at this temperature will be produced by solar collectors on cloudy days or by using the waste heat.

The residential building sector demands heat pumps with low investment costs. For the European industry to maintain its leadership in this segment, new developments must be targeted to relatively inexpensive solutions, allowing considerable savings in yearly energy consumption. New buildings are very well insulated leading to much reduced winter thermal load, while older ones are not, implying the different kinds of heat pump will be needed for each. Highly efficient houses will need to be well-ventilated in summer, or even actively cooled. In winter, any ventilation system will probably incorporate a low cost form of heat exchanger to capture the heat of indoor air before it is expelled.

In these new houses, the focus of applied research ought to be on heat pumps for sanitary hot water exceeding the minimum seasonal performance (according to EN 16147) of 3,3. Demand for sanitary hot water does not vary depending on the overall efficiency of a building. Solar collectors can also produce sanitary hot water however, if comfortable indoor temperatures are to be maintained year-round, heat pumps are needed. An interesting option is the use of PV technology to power heat pumps. The solar panel generates renewable electricity and the heat pump provides 100% of the required heating and cooling. Specific research priorities for hybrid systems are presented in Chapter 5.
Therefore, technological research should focus on developing heat pumps with the following characteristics:

C. Domestic heat pump for new houses

- Low cost Air to Water reversible heat pump of small capacity (around 2 kW), designed to provide reasonable seasonable performance (consistently >3) in all three climate zones (cold, average warm) and operate even under freezing conditions.
- Coupled with system for circulating the warmed/chilled water using small wall-mounted heating/cooling elements.
- New houses will be ventilated in a manner that enables heat recovery.
- In winter water will be circulated at low temperature (e.g. 40 ºC) and in summer at around 17 ºC to avoid condensation.

Europe's building stock is made up of poorly insulated homes with high heating demand. Substituting the boiler of those houses by a heat pump is technically possible but uneconomic if water for space-heating must continue to be supplied at the relatively high original temperature and if the overall capacity of the system is unchanged. Such houses must first be better insulated, then their radiators must be replaced by radiating panels with higher surface area. With those changes in place, heat pumps could even play a more prominent role in meeting heat demand.

Alternatively, a hybrid system could be put in place. This would see a heat pump raise the temperature of water from ambient to, say, a few tens of degrees above ambient, at which point a boiler would heat the water the rest of the way to the required temperature. Only a small, low-cost heat pump would be required for such a system[31]. In order to have a high COP at outside air temperatures above 2˚C (at which the majority of heating is done in Europe), the heat pump should not raise the temperature of the water it heats beyond 50ºC. The characteristics of the proposed heat pump are:

D. Domestic heat pump for existing houses with gas boiler

- High efficiency Air to Water heat pump producing heating water at 35 to 50 ºC depending on the ambient temperature.
- Capacity of 4 to 8 kW. With this capacity it should be able to provide the required heat most of the time.
- The existing boiler will only work as a back-up system under extreme ambient conditions when the heat pump is not able to attain 50 ºC or to increase the temperature of the sanitary hot water which will be first preheated by the heat pump.
- Compact design, easy-to-assemble and connect with the boiler heating system.
- Integrated control with the boiler.

Figure 20 - integrated control of the heating system (© Thomas Nowak, EHPA)

[31] On the other hand, if the heat pump is able to cover the total heating demand most of the days and it is only helped by the existing boiler at low ambient temperatures or to reach high demand peaks, the primary energy savings along the year are going to be extraordinarily high.

New technologies: beyond the compression cycle

Refrigeration systems exist with higher efficiencies than classical vapour compression systems, however most of them are still in their infancy including magnetic refrigeration[32]. Research should be supported in this field.

Overview

The following table summarises the research topics in electrically driven and the relevant time-scale

	Short term	Medium term	Long term
Basic research	REFRIGERANTS: Safe Refrigerants with 0 Ozone Depletion Potential (ODP) and almost 0 TGWI	REFRIGERANTS: Safe Refrigerants with 0 Ozone Depletion Potential (ODP) and almost 0 TGWI	NEW CONCEPTS New cycles/concepts for refrigeration and heat pumping
	BASIC PROCESSES • Enhanced heat transfer on plate heat exchanger evaporators and condensers • Condensate and icing formation processes on heat exchanger fins	BASIC PROCESSES • Enhanced heat transfer on minichannel evaporators and condensers • Reduction of the oil circulation rate	
	MATERIALS Improved materials for magnetic refrigeration	MATERIALS New materials (e.g. polymers) for heat pump components (e.g. heat exchangers)	
Applied research & development	COMPONENTS ·Enhanced high eff. compressors for Hydrocarbon refrigerants • High eff. compressors for CO_2 • High eff. compressors with variable speed ECM motors • Minimum charge heat exchangers • Even distribution of refrigerant in evaporators. Especially in minichannel evaporators • Reversible minichannel evaporator/condensers • Cost-effective safety technologies for hydrocarbon refrigerants • Expansion valves (TEV and EEV) with improved capacity control • Low noise air heat exchangers • High efficiancy auxiliaries: pumps, fans... • Advanced controls of heat pumps and interaction with other energy systems	COMPONENTS • high eff. two stage units for high temperature lifts • Improvement of condensate drain and defrosting of air evaporators, especially minichannel evaporators • Minimum charge heat exchangers with enhanced heat transfer CONTROL & INTEGRATION • Development of function and yield control concepts for heat pump systems • Development of methods for interaction of heat pumps with smart electric grids • Development of control methods optimizing the integration of intermittent RES electricity	
	NEW HEAT PUMPS High efficiency heat pumps with natural refrigerants and minimum charge	NEW HEAT PUMPS High efficiency heat pumps with minimum TGWI, affordable cost, easy installation and operation, and low maintenance	NEW HEAT PUMPS Ultra-efficient heat pumps with minimum TGWI, low cost, easy installation and operation, and low maintenance
	SPECIFIC HEAT PUMP SOLUTIONS A. Heat pump for simultaneous chilled/hot water production B. Heat pump booster for high temperature hot water production C. Domestic heat pump for new houses D. Domestic heat pump for existing houses with gas boiler • High eff. heating/AC system for electrical vehicles	SPECIFIC HEAT PUMP SOLUTIONS • Prototype solutions based on promising new cycles/concepts for refrigeration and heat pumping • Prototype solutions for magnetic refrigerator/heat pump in different applications sectors.	
Demonstration	OPTIMISATION, CONTROL & INTEGRATION • Demonstration and assessment of efficient heat pumps • Optimal control of capacity modulation and supply temperature	OPTIMISATION, CONTROL & INTEGRATION • High efficiency heat pumps, affordable cost, easy installation and operation ·Heat pumps with natural refrigerants and minimum charge • Specific solutions for applications A, B, C, D described above. • Heat pumps and air conditioning for electrical vehicles • New heat pumps with high temperature lift • Optimal integration of heat pumps with other heating/cooling systems	OPTIMISATION, CONTROL & INTEGRATION • Ultra efficient heat pumps with minimum TEWI, cost effective, easy installation and operation, and low maintenance • Optimal integration with the smart grid

Figure 21 - Research Priorities for electrically driven heat pumps

4.3 Thermally driven heat pumps

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. 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.

The most important representatives of heat-driven cooling/heat pump systems are absorption and adsorption closed-cycles.
Liquid **absorption** and solid **adsorption** cycles are based on a working pair of a refrigerant and a sorption medium. In absorption devices the refrigerant is absorbed, i.e. dissolved, in the liquid sorption medium changing its concentration. Most common working pairs are Lithium Bromide/Water and Ammonia/Water. In case of solid sorption heat pumps/chillers, the refrigerant is either adsorbed in the

[32] 5th IIR/IIF International Conference on Magnetic Refrigeration at Room Temperature - THERMAG V, Grenoble - France, 17 - 20 September 2012: http://thermagv.grenoble.cnrs.fr/

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pores of the solid adsorption medium, or chemically absorbed into the crystal lattice of the solid. Most common adsorption working pairs are Zeolite/water, Silica Gel/water, Activated carbon/ammonia, and Activated carbon/methanol. Chemical absorption working pairs are mostly based on salt/ammonia or salt/water combinations.

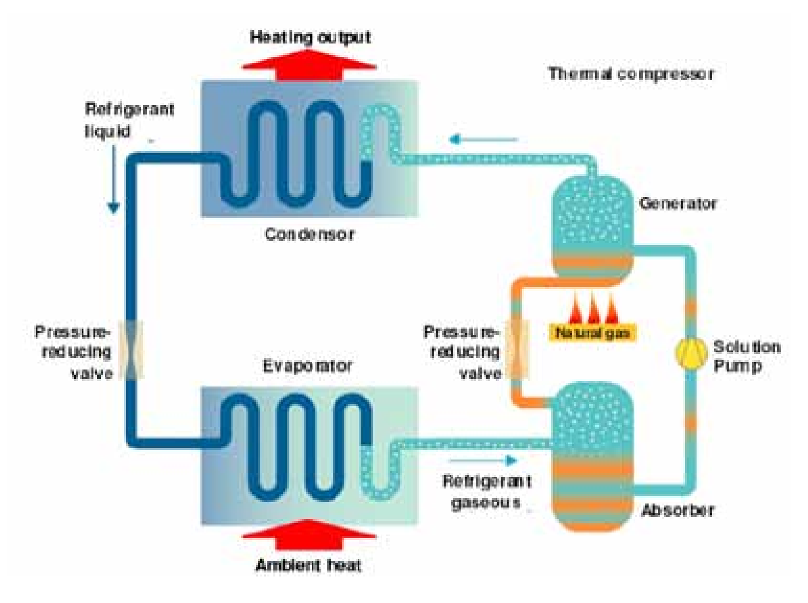

Figure 22 - scheme of an absorption heat pump (source: EHPA)

Both liquid and solid sorption heat pump technologies are thermodynamically similar and have analogous basic configurations. This consists of four main components: a reactor called generator, where the sorbent (liquid or solid) is heated at high temperature; the condenser, where the desorbed refrigerant vapour is condensed into liquid; the evaporator, where the cooling effect is produced; a reactor called ab/adsorber that receives refrigerant vapour from the evaporator. In the case of liquid absorption machines, a pump is used to continuously circulate the concentrated solution from the absorber to the generator and the dilute solution back to the absorber. The two reactors of a solid adsorption machine operate in counter-phase to ensure continuous useful cooling effect and are alternatively heated for desorption and cooled for adsorption. Differently than an absorption machine, a circulation pump is not required.

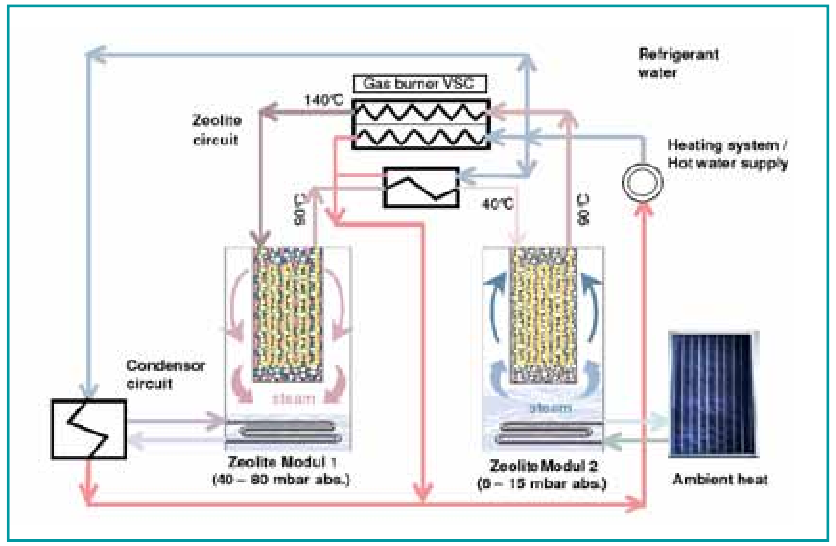

Figure 23 - scheme of an adsorption heat pump (source: EHPA)

To order increase performance configurations such as double and triple effect liquid absorption machines and multi-bed or thermal-wave solid adsorption machines have been developed. Such configurations are thermodynamically more efficient but need higher driving temperatures and usually require complex hydraulics and sophisticated control. The following Figure summarises the technologies, the working pairs used and compare the main properties and performance of the most used thermally driven heat pumps.

Process	Adsorption		Absorption		
Refrigerant/sorbent	water silica gel	water zeolite	water/LiBr single-effect	water/LiBr double-effect	ammonia water
Temperature Heat source [°C]	60-90	45-95	75-110	135-200	65-180
Capacity [kW]	7.5-500	9-430	10.5-20000	174-6000	14-700
COP heat pumping	1.4-1.6	1.3-1.5	1.4-1.6	1.8-2.2	1.4-1.6
COP cooling	0.5-0.7	0.5-0.6	0.6-0.7	0.9-1.3	0.5-0.7

Figure 24: Characteristics of today's thermally driven heat pumps

In general, liquid absorption machines offer high COP both in cooling/heat pumping mode. These devices face problems such as crystallisation of the sorbent and corrosion and efficiency losses from the circulation pumps. Ammonia/water machines require adapted pumps. Solid adsorption machines have lower thermodynamic efficiency but can be driven by lower temperatures, making the technology interesting for utilising low temperature waste heat or solar energy. Solid sorption machines are not affected by motion making them an appropriate technology for /air conditioning in vehicles or boats.

Market development of thermally driven heat pumps

There are several products available on the market of gas fired absorption heat pumps that are generally tailored to small-medium capacity of the sorption devices. Among these products, one of the most interesting is that based on ammonia/water pair, produced by Robur (Italy) that is integrated with the boiler and is able to supply heat for ambient heating and cooling with efficiency as high as 140%.
Several lithium bromide/water absorption machines have been commercialized for many years, in single or double effect configuration and driven by many heat sources (direct fired, hot water, solar heat, district heat, waste heat of CHP units, process heat and steam). Triple-effects machines have been developed only as a pre-commercial prototype, which requires very high driving temperature (>200°C). Many manufacturers of LiBr/water machines are located especially in Asia (Sanyo, Yazaki, Broad, LG, Hitachi, etc.) and USA (Carrier, York, TRANE, etc.). Frequently, LiBr–water absorption chillers are integrated with cogeneration plants or solar-assisted systems. Moreover, several ammonia / water absorption machines are available from Asia, USA and Europe (Thermax, Energy Concepts, AGO, Tranter Solarice, Makatec, Mattes, Pink).
Historically, first silica gel/water adsorption chillers produced by HIJC (USA, formerly Nishiyodo) and Mayekawa (Japan), appeared in the market in the late 80's. Such chillers, still available on the market, have different cooling capacities (30-470 kW) and can be efficiently driven by hot water at 60-90°C, ensuring COP of up to 0.6. Since 2010 Mayekawa offers only water-zeolite adsorption chillers. Recently, Germany is the country most active in the development and construction of solid sorption heat pumps/chillers especially for small capacity systems, exploiting thus one of the most interesting properties of solid sorption devices that is a non-reduction of performance for small capacity systems.
Nowadays there are few small German companies (SorTech, Invensor) producing chillers based on silica gel –water and zeolite – water with cooling capacity starting from 8,5 and 9 kW respectively. Furthermore, Viessmann and Vaillant are entering the market with a product consisting of a boiler integrated with a solid adsorption heat pump for a single apartment heating that would have an efficiency around 120%.

A special contribution, at material level, was provided by Mitsubishi Chemical (Japan) with the development of a new class of adsorbent materials (AQSOA-FAM), specifically designed to be used in adsorption chillers. These new adsorbents, having a crystalline structure, are preferred to the amorphous silica gel and can be regenerated with a thermal source in the range 60-90 °C.

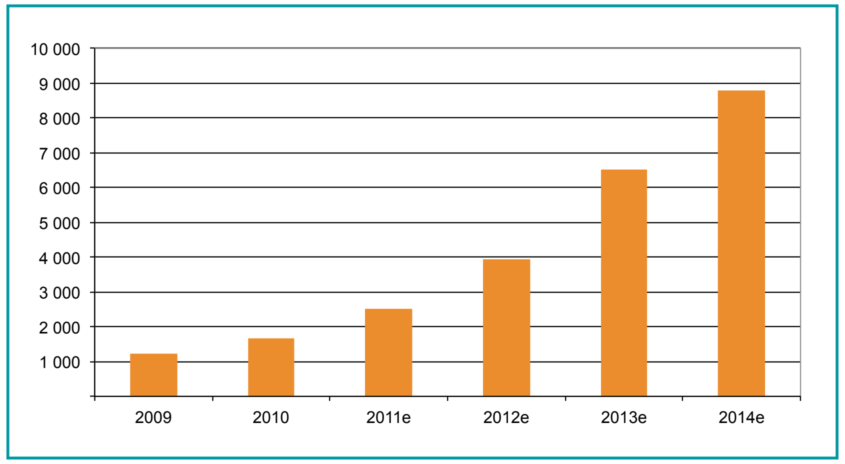

Figure 25 - Annual sales of thermally-driven heat pump units in Europe (Source: EHPA)

4.3.1 Research priorities for absorption heat pumps

Absorption chillers/heat pumps have been extensively studied and it is considered a mature technology. High quality absorption chillers/heat pumps already exist on the market. Absorption heat pumps for space heating and cooling are indirectly heat driven (hot water, solar heat, district heat, waste heat of CHP units, process heat, steam, etc.) or often gas-fired, i.e. are integrated with a gas boiler that produces the driving thermal energy of the sorption heat pumps; in this case a good integration of the condensing boiler with the sorption device is needed to obtain a good efficiency overall.

From the technological point of view, R&D in the following three main fields is required:
1) Combined and multi-stage thermodynamic cycles
2) Mobile application
3) Building-integrated sorption systems

On the one hand side there is an overlap between all these fields (multi-stage cycles, for example, can be used in stationary, mobile or building integrated systems). On the other, each field has specific demands related to:

- Heat and mass transfer
- Storage
- Working fluids
- Construction

Short-, medium- and long-term research activities are needed for each field.

Research field: Combined and multi-stage thermodynamic cycles

Development of a generic power and heat transformer (PHT) including thermo-chemical/physical storage capacity.

1st step: Reversible heat pump (for heating and cooling).
2nd step: Reversible heat transformer (i.e. can be used as reversible heat pump and heat transformer).
3rd step: Generic power and heat transformer (i.e. can be used as reversible heat pump and heat transformer. Moreover, it can be used for power production or uses power as back-up).

Development and implementation of power input/output devices as well as internal storage capacity should proceed in parallel.

Research field: Mobile application
Development of devices to be thermally-drive by the waste heat of engines.

1st step: Study of heat and mass transfer
2nd step: Compactising heat exchangers
3rd step: Testing

Research field: Building-integrated sorption systems

Sorption systems for stationary air-conditioning must be integrated into the building envelope.

1st step: Study on heat sinks and sources
2nd step: Test of breadboard systems with compact heat exchangers
3rd step: Implementing cycles

The following table summarises the topics where R&D on absorption heat pumps is needed and the relevant time-scale.

	Short term	Medium term	Long term
Basic research	NEW CONCEPTS Study of potentiality and solutions for different heat sinks and sources	NEW CONCEPTS • Investigation into combined storage and heat pumping cycles (Honigmann cycle) • New cycles/concepts	
	BASIC PROCESSES Heat and mass transfer at sub-atmospheric and super critical pressure and elaboration of more general correlations (including natural refrigerants as well as new fluids e.g. Ionic liquids)	BASIC PROCESSES • Investigation of working fluids under real operating conditions • Heat and mass transfer of new working fluids	BASIC PROCESSES Investigation of chemical reactions for the application to sorption processes
	MATERIALS • New working media for elevated temperature levels for application in industrial processes, district heating and cooling. Target: no corrosion and no crystallisation • Development of new working fluids	MATERIALS • Characterisation and development of new working fluids	

Applied research & development	COMPONENTS • Compacting heat exchangers • Heat exchangers for the new fluids • Solutions for working below freezing with water • Improvement of life and reliability	COMPONENTS • Improved and more compact heat exchangers • Low cost components	COMPONENTS Advanced components for new cycles, working pairs
	CONTROL • Development of smart dedicated control • Optimal operation and adaptation to the thermal demand	CONTROL • Development of function and yield control concepts • Optimal integration with other systems	
	NEW HEAT PUMPS • Test of breadboard systems with compact heat exchangers • Multistage cycles • Hybrid heat pump (absorption/compression) • Reversible units: heating and cooling • Reduction of parasitic losses	NEW HEAT PUMPS • Reliable, compact and cost effective absorption heat pumps • Development of liquid desiccant systems (open absorption cycles) for dehumidification and cooling applications. • Reversible heat transformer • Low cost production techniques	NEW HEAT PUMPS Heat pumps with advanced cycles and control strategies
Demonstration	OPTIMISATION, CONTROL & INTEGRATION • Demonstration and in field assessment of absorption heat pumps in different climates • Advanced low energy heat rejection systems • Applications with different renewable heat sources	OPTIMISATION, CONTROL & INTEGRATION • Demonstration of advanced absorption heat pump technologies for use in industrial applications (e.g. waste heat recovery) and in district heating and cooling (CHPC systems) • Demonstration of Plug&Play High efficient absorption heat pumps • Optimal integration with other heating/cooling systems • Application of absorption heat pumps/chillers in mobile applications (cooling and heating from waste energy)	

Figure 26 - Research Priorities for absorption heat pumps

4.3.2. Research priorities for solid sorption heat pumps

Solid adsorption systems have been less studied and are less developed than liquid absorption ones, meaning they still have significant potential for improvement. The current market penetration of solid sorption heat pump technology is negligible compared to electrically driven heat pump systems. Several

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hundreds of large silicagel water adsorption chillers are in operation, and over the last three years a few hundred small (10 kW range) adsorption chillers have been installed.

The current market for solid sorption heat pumps is very small. The main reasons for this are:

- High cost of the heat pump the overall installation.
- Solid sorption heat pumps are too big and too heavy to compete with conventional heat pump systems.
- Solid sorption systems generally have lower thermal efficiency than liquid sorption systems.
- Solid sorption systems operate within a narrow window of operating temperatures. Outside this window, their performances drops off too quickly.

Generally speaking, solid sorption systems are to be found where access to the electricity grid is limited or electricity supply uncertain and where a heat source is abundant. Progress is expected in solid adsorption technology in regard to heat transfer intensification, improved cycles, development of novel adsorbent materials with advanced sorption properties, size, and understanding the trade-off between cost and performance.

Research, development and demonstration activities are required to advance the market penetration of environmentally sound solid sorption heat pump R&D. The research needs to cover the range of fundamental materials research and development, system engineering and design, development of manufacturing technology, up to practical field trails and demonstration of the technologies in various applications.

Materials level

The properties of solid sorption materials such as zeolites and silica gels determine the performance of heat pump systems in which they are included. Today a very limited number of materials is used, limiting the application of the technology. R&D effort is directed at modifying and improving these materials. New potential sorption systems, such as Metal Organic Framework, using SAPO and ALPO materials[33] and chemiosorbents such as salt/ammonia and metal hydrides are being investigated. The sector aims for:

- Sorption materials capable of very high refrigerant uptake leading to improved heat pump efficiency and thermal power density
- Sorption materials accepting wider window of driving temperatures to improve seasonal efficiency performance
- Sorption materials stable over several thousand cycles
- Characterising and cataloguing the properties of sorbent materials
- Evaluating different working fluids for different source temperatures

Components for sorption heat pumps

Heat and mass transfer of sorption materials govern the operation of solid sorption heat pumps. The repeating sorption and desorption requires heat and mass transfer from and to the solid sorption materials. The most recent designs of sorption reactors use large surface-area heat exchangers coated thinly with active sorption material. Designs of sorption reactor, evaporator and condenser must become compacter.

R&D priorities in the area of components for sorption heat pumps are:

- Compact, lightweight, high surface area sorption heat exchanger/reactor.
- Compact, efficient and low cost, evaporator and condenser concepts for different working fluids at very low pressure

[33] SAPO stands for Silico-Aluminophosphate. It is a micro pore zeolite characterised by water absorbing capacity and bronsted acidity. ALPO stands for Alumino-Phosphate.

- Coated sorbent reactors permitting compact design
- Nanostructured heat exchangers
- Heat exchanger surface modification techniques to increase heat transfer rates
- Production cost optimisation of improved design concepts for energy-efficient heat exchanger designs
- Scale-up of coating techniques for sorbent reactors
- Evaporator concepts allowing the use of ambient temperatures below 0°C

Solid sorption heat pump systems

Combining the improved sorption heat pump components into an improved system requires a well-balanced design of the individual components. Further to that, improvement of the system performance will be achieved by adopting more advanced thermodynamic cycles. New cycles and control strategies will be able to adapt to changing operating conditions and user requirements. Control strategies need to be flexible to optimise the performance in terms of bothoverall thermal efficiency and customer satisfaction as well as carefully addressing all the parasitic energy consumption of auxiliaries.
R&D priorities are:

- Advanced thermodynamic cycles with combined internal heat and mass recovery schemes for improved system efficiencies
- Advanced system control strategies to adapt to changes in operating conditions and user requirements
- Compact and modular system designs
- Advanced innovative heat source/sink (rejection) systems (with low parasitic energy)

Combination of sorption/compression technology

Thermal sorption technology and mechanical compression technology, can be combined to create a system with very broad range of operational flexibility for heat pumps (the mechanical booster compressor can adjust the system pressure to compensate driving temperature that are too low).

System integration

The operation of a solid sorption heat pump system requires a connection to a heating source, a heat or cold demanding system and a heat sink/source to ambient. For solid sorption systems to become easily installed and operated in many different applications, it's necessary to further develop easy to install modular systems. Specific measures are also required to develop a more integrated approach to assess the feasibility of integrating different heat sources and technologies in a single system.

From a system perspective, an important research priority is the combination of thermally-driven heat pumps with low temperature district heating (temperature below 70°C).

The following table summarises the topics where R&D on solid sorption heat pumps is needed and the relevant time-scale.

	Short term	Medium term	Long term
Basic research	NEW CONCEPTS Hybrid sorption/compressor heat pump cycles	NEW CONCEPTS New cycles/concepts	
	BASIC PROCESSES Heat and mass transfer	BASIC PROCESSES Heat and mass transfer	
	MATERIALS • Modified zeolites, SAPO, ALPO • Surface modification of heat exchangers-nanostructures ·Sorbent coating techniques development	MATERIALS • Salt based chemi-sorbent development • Metal hydrides • Metal Organic Framework materials • Surface modification of heat exchangers-nanostructures	MATERIALS Designer Sorbent working pairs
Applied research & development	COMPONENTS • Compact sorption heat exchanger/reactor development • Compact evaporator / condenser • Improved low cost valves • High efficiency compressors for sorption/compressor systems	COMPONENTS • Sorbent coating scale-up • Improved reactor and heat exchangers • Improved compactness • Low cost components	COMPONENTS Advanced components for new cycles, working pairs
	SIMULATION TOOLS • Detailed thermodynamic models to assist design and control development • Design tools with standardised components	SIMULATION TOOLS Simulation tools for new cycles and concepts	
	CONTROL • Development of smart dedicated control • Optimal operation and adaptation to the thermal demand	CONTROL • Development of function and yield control concepts • Optimal integration with other systems	
	NEW HEAT PUMPS • Compact modular system designs • Improved tightness • Low cost production techniques	NEW HEAT PUMPS • Reliable, compact and cost effective adsorption heat pumps • Hybrid sorption/compression heat pumps systems	NEW HEAT PUMPS Heat pumps with advanced cycles and control strategies
Demonstration	OPTIMISATION, CONTROL & INTEGRATION • Demonstration and in field assessment of adsorption heat pumps in different climates • Advanced low energy heat rejection systems • Applications with different renewable heat sources	OPTIMISATION, CONTROL & INTEGRATION • Demonstration of "Plug&Play" highly efficient adsorption heat pumps • Optimal integration with other heating/cooling systems, including low temperature district heating	

Figure 27 - Research Priorities for solid sorption heat pumps

4.4 Heat pump applications in industrial processes

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. Figure 28 plots the driving temperature ("source heat") against the delivered temperature ("heat demand") for various heat pump technologies. Temperature rises of max. 50°C are possible. Driving temperatures can be up to 120°C. Heat can be delivered in the range 50-150°C. Development work is directed at extending these ranges.

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. There is not one single heat pump technology that can cover this entire range of demands, meaning different heat pump technologies should be developed in parallel.

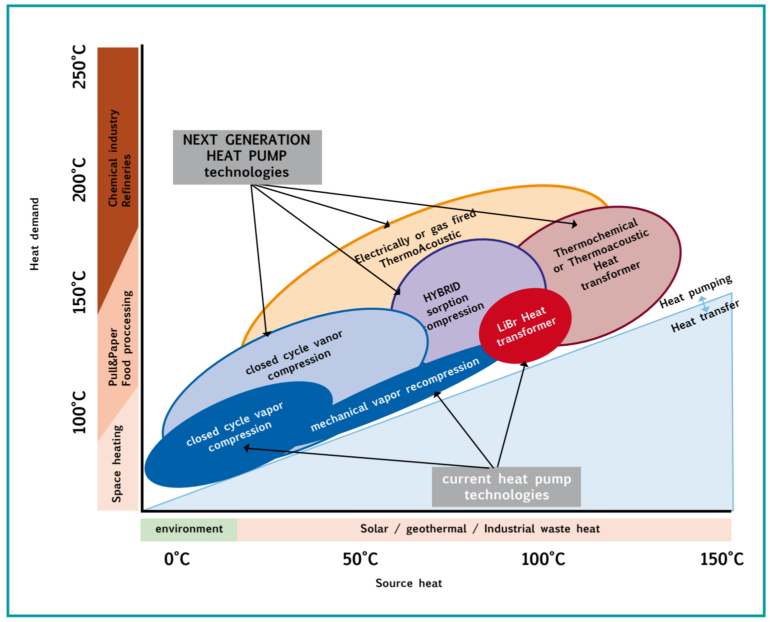

Figure 28 - Heat pump technologies and their operating temperatures

The Figure above shows four types of technology that can potentially overcome the aforementioned limitations in terms of temperature range and lift. Not only these improvements will allow larger energy savings, but simultaneously it will unlock the benefits of economies of scale for the European heat pump industry.
Apart from their operating temperatures, these technologies have different levels of maturity. They form a chain of new heat pump technologies in which the mechanical vapour compression systems with new working fluids are the next generation to be tested at a small scale in real applications for higher delivery temperatures. The salt-ammonia sorption and thermoacoustic heat transformers are in the development stage of laboratory prototypes, proofing the concept of the system. The hybrid sorption-compression systems and gas fired thermoacoustic heat pumps are in the stage of proofing the principle.

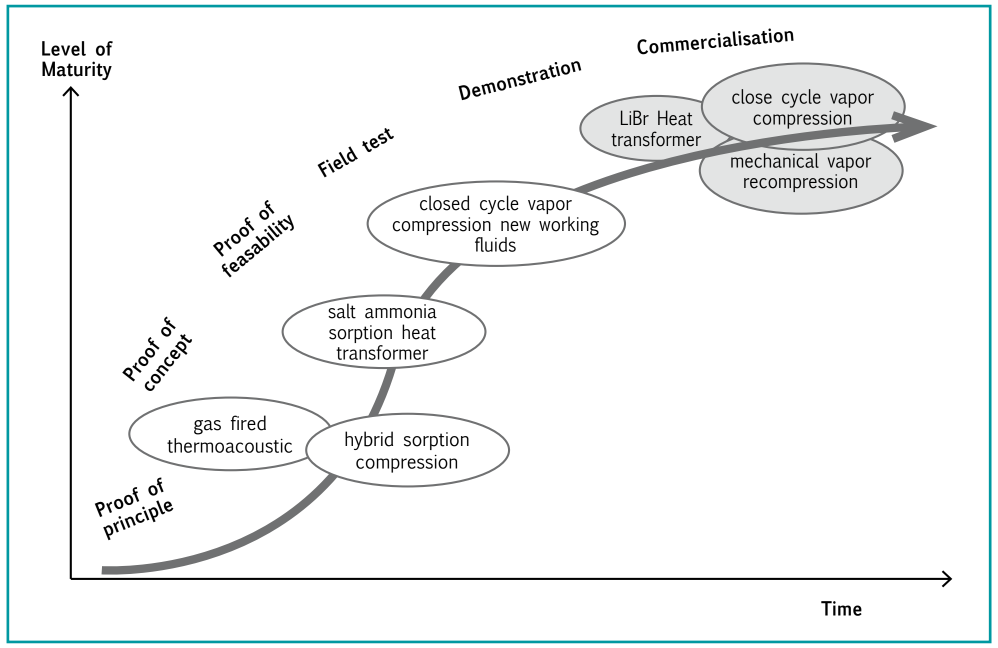

Figure 29 - Development stages of the next generation heat pump technologies

4.4.1 Research priorities for industrial heat pumps

Current vapour compression systems deliver heat at a maximum temperature of ~80°C. New vapour compression systems should use low TGWI synthetic refrigerants or natural refrigerants (such as butane or water) in order to increase delivery temperature to 150°C. Components and materials should be developed to achieve temperature lifts of up to 70 kelvin (K)[34]. The use of water as working medium allows the heat pump to be integrated into industrial heating processes.

Heat transformers are interesting when a heat source of more than 90°C is available. Current systems use the thermally-driven compression step and can upgrade waste heat from 100°C to 140°C. Reversible solid sorption reactions, such as the reaction of salts and NH_3 are applicable for heat transformation at temperature levels up to 250°C. Sorption heat transformer components need to be developed that can operate up these high temperature levels with temperature lifts up to 70 K.

Thermoacoustic systems can accept a range of driving temperatures and output heat also in a wide temperature range, but at low temperatures, typical of waste heat, their efficiency is low. Heat exchangers in such systems have to be especially compact and operate in an oscillatory flow.

Heat pumps that combine thermal energy and mechanical compression as driving input exist only at laboratory-scale. They have similar flexibility to thermoacoustic heat pumps. They should be able to deliver heat at up to 180°C with temperature lifts of up to 100 K. Careful control is needed in these systems to achieve good interaction between the sorption system, which operates batch-wise, and the compressor, which operates continuously.

[34] The kelvin is a unit of measurement for temperature. In this publication, the Celsius scale and the kelvin are used respectively to indicate a specific temperature (Celsius) and a temperature interval (kelvin).

Figure 30 - A thermoacoustic heat transformer (© ECN)

A thermoacoustic heat pump system can achieve a larger temperature lift than is usually possible with conventional heat pumps. Hot gases from a gas burner can be used as a high temperature heat source for thermoacoustic systems, but transferring the heat from these streams to the regenerator is not straightforward. Output temperatures of up to 250°C should be achievable from input temperatures of 150°C. Alternatively, a piston can be used to drive the thermoacoustic heat pump. This requires applied research to adapt existing piston compressors to suit the needs of thermoacoustic systems.

The technologies required for industrial heat pumps are the ones described in the previous sections, i.e. vapour compression and thermal driven heat pumps, but adapted for this specific application. Research priorities presented above are summarised in the table below.

	Short term	Medium term	Long term
Basic research	NEW CONCEPTS Exploration of different alternatives of heat-pumping, heat transforming for different applications	NEW CONCEPTS New cycles/concepts	
	BASIC PROCESSES Fundamental understanding of the thermoacoustic process	BASIC PROCESSES Heat and mass transfer of new working fluids	BASIC PROCESSES
	MATERIALS • High temperature (up to 150 °C) refrigerants for industrial compression heat pumps. No flammability, low GWP • Improved materials for heat exchangers and other heat pump components at high temperatures (>150 C)	MATERIALS • Characterisation and development of new working fluids	
Applied research & development	COMPONENTS • Improved compressors for vapour recompression systems • Compressors and lubrication methods for high evaporating temperatures (up to 70°C) • Heat exchangers at the different operation temperatures • Improved design of heat exchangers for direct use in condensing gases (flue gas, exhaust air of drying processes etc.)	COMPONENTS • Heat exchangers based on advanced materials for application in severe operating conditions (e.g. corrosive media) • Thermoacoustic heat pump components	COMPONENTS Advanced components for new cycles, applications
	CONTROL Optimal operation and adaptation to the required load and temperature	CONTROL • Development of function and yield control concepts • Optimal integration with other systems	
	NEW HEAT PUMPS • Development of advanced high temperature electrical heat pump cycles for heat recovery applications in industrial processes applications. Target: temperatures up to 150 °C and higher (e.g. based on new synthetic refrigerants or natural refrigerants like water); COPs similar to low temperature heat pumps • Thermoacoustic heat pump prototypes	NEW HEAT PUMPS • Development of industrial hybrid heat pumps for target temperatures around 180 °C. • Development of high efficiency thermally driven heat pumps operating at elevated temperature levels in heat recovery applications and industrial processes. Target: COPs > 0.7, re-cooling temperature > 50 °C. • Development of heat transformers for industrial waste heat recovery. • Thermoacoustic heat pumps	NEW HEAT PUMPS High efficiency heat pumps for different industrial applications
Demonstration	OPTIMISATION, CONTROL & INTEGRATION Demonstration of electrically and thermally driven heat pumps operating at high temperature levels in industrial applications in combination with district heating and cooling including thermal energy storage	OPTIMISATION, CONTROL & INTEGRATION • Demonstration of advanced absorption heat pump technologies for use in industrial applications (e.g. waste heat recovery) and in district heating and cooling (CHPC systems) • Demonstration of hybrid systems in industrial applications • Optimal integration with other systems	OPTIMISATION, CONTROL & INTEGRATION • Demonstration of thermoacoustic heat pumps

Figure 31 - Research priorities for industrial heat pumps

4.5 Non-technological priorities

The renewable heating sector's potential is largely untapped and so is the potential of heat pump technology. A number of non- technological aspects influence the outlook of heat pumps in Europe:

I. Economic aspects with a direct impact on the total cost of ownership

- Energy price levels
- Energy price ratios
- Price level of technology (in absolute and relative terms)
- Quality of products
- Efficiency of products

II. Image and technology awareness aspects

- Public opinion
- Installers, architects and planners
- Policy makers, politicians and decision makers

Both aspects are related and influence customers' choices. Analysis of decision making processes for heating systems reveals that a decision to invest depends on the investor having sufficient knowledge of heat pump technology (to compare it with its alternatives) and:

- the recommendation of the architect, planner, project developer or installer
- investment costs
- operation costs (less important than investment costs)
- environmental benefits of the heating system (more important than cost considerations for some consumers)

Once the investment decision is taken, there are still obstacles, mostly of administrative nature, that may revert the original choice. Barriers to invest in heat pumps include:

- time to receive a drilling permit (in case of geothermal heat pumps)
- drilling restrictions around water protection areas (sometimes not evidence-based)
- local restrictions for the installation of specific geothermal technology
- regulatory obstacles, for example with different authorities having control for different depths beneath the surface, and insufficient coordination between them
- requirements to install equipment that, from a technical point of view, is unnecessary, like for heat meters

The most efficient heat pump technology generally has higher upfront investment cost than incumbent technology so reducing such costs will improve the uptake of these. Financial incentives will help to speed up the development of the heat pump market, allowing for economies of scale and eventually resulting in a reduction of final energy prices. Financial Incentive Schemes (FIS) have been used for year in several countries of the European Union in order to support market penetration of heat pump technology. Successful results have been obtained with the following schemes:

- Feed-in tariff for heating (RHI in the United Kingdom and Czech Republic). Two options for refinancing exist: via a levy on the use of non-RES or via government budget
- Direct grants
- Fiscal incentives (deduction from taxable income, reduction of tax burden, VAT reimbursed)
- Soft loans
- Incentive on price of fuel (preferred tariffs for heat pumps)
- Incentive linked to housing subsidies

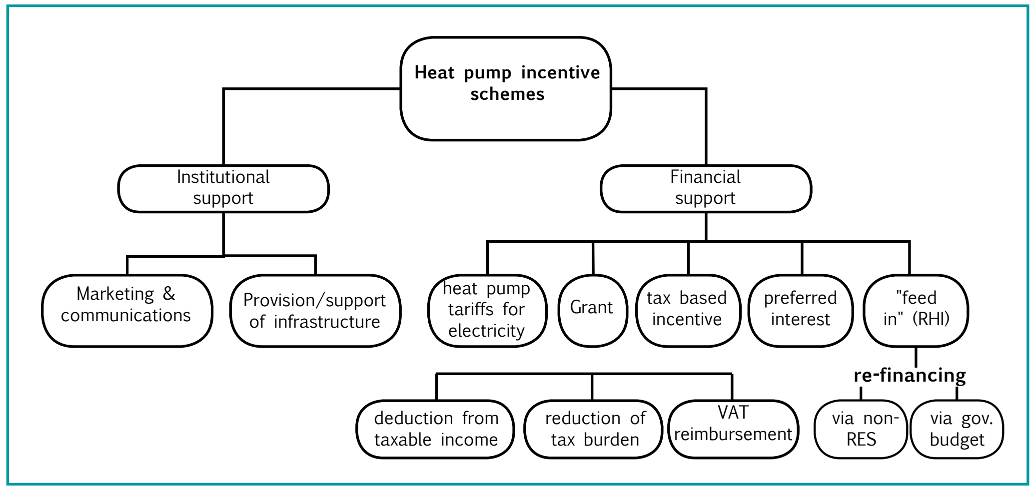

Figure 32 - Categories of institutional and financial support for heat pumps in Europe. (Source: Thomas Nowak, EHPA 2010)

Financial incentives need to be accompanied by the following supporting measures:

- Quality assurance to consumers (in the ability of installers, on installed products and systems)
- Standard-setting (European standards to enable benchmarking)
- Raising awareness. Figure 32 shows examples of measures that are implemented in EU countries[35]

Overall, the EU and national legal frameworks as they stand do not provide enough support for the employment of technologies with higher energy efficiency or for a shift in energy use from non-renewable to renewable energy sources. Strong policy coordination is required to overcome the existing non-technological barriers.

Public money is needed to contribute to funding short- medium- and long-term research into all parts of the value chain, as well as into socio-economic and regulatory issues. **Adequate support to the products' deployment should be provided by policy makers.** R&D funding schemes and research priorities should be defined involving a broad range of stakeholders to address the non-technological barriers to deployment as well as technology advancements.

4.6 Conclusions

Research priorities for electrically-driven heat pumps depend on the size and application but generally concentrate on the development of improved components with two objectives: to allow higher efficiencies; and to optimize the control and integration of heat pumps with other heating/cooling systems making it possible to reach a Seasonal Performance Factor (SPF) greater than 6.

To make the technology cost effective and fully competitive with condensation boiler systems, the cost of HPs must come down thanks to lower electricity consumption. In this regard, it is important to target specific high-potential applications which offer interesting opportunities for the European heat pump industry. From an environmental perspective, it is essential to employ refrigerants with 0 ODP and very low TGWI, preferably natural refrigerants, which requires the development of tight systems with minimum refrigerant charge. The introduction of compact heat exchangers such as brazed plate heat exchangers (BPHE) and mini-channels is envisaged as the best solution, but will require considerable efforts in terms of development, especially of evaporators. Being at the heart of vapour compression systems, the efficiency of compressors, at full and part load, must be improved e.g. with the incorporation of low-cost

[35] The state of North Rhine Westphalia operates a "Heat pump marketplace" that gathers stakeholders to provide factual information on the technology, manufacturers and experienced installers. It is operated by industry and financed as a public-private partnership. As a second example, the geological surveys of many German States provide geological maps making the assessment of the potential for ground source heat pumps easier to assess.

electronically commutated motors (ECM) in future heat pumps. This would also present the advantage of allowing for a flexible and efficient modulation of the capacity which entails higher COPs at part load and corresponding higher SPFs.

Magnetic refrigeration appears to be a promising new technology, with good potential for performance and reliability, provided that permanent magnets and magnetocaloric-effect materials could be produced at sufficiently low costs. Research should therefore concentrate on the development of the materials, possibilities for reducing production costs, and the setting up of operating prototypes for various applications, mainly heating and cooling, and electric vehicles.

Research priorities for thermally-driven systems generally target the reduction of unit size and cost on one hand, and the improvement in the life-time and reliability of the systems on the other.

The development of new working pairs and materials can make heat exchangers more compact, more efficient and more consumer-friendly. For this, a better characterisation and knowledge is required together with better modelling and design tools to optimize design and operation. Heat rejection is another issue that needs improvement and reduction of cost. Finally, modularity, smart control and good integration with other systems will lead to better performance and lower cost.
Combined compression-thermal systems appear to have good potential to improve the performance of thermally-driven systems thereby extending their scope for application. To ensure reliable and highly efficient operation, research into the system components, especially on the compressor side, and at overall system level will be necessary in the coming years.

In industrial applications, research is needed across all technologies to increase the efficiency and reliability of heat pumps and to take maximum advantage of the potential for heat recovery at different available temperatures. Given that heat pumps with higher rejection temperatures and higher temperature lifts are needed, research priorities should be focused accordingly. Each application has its most suitable technology but more efficient and reliable components will have to be developed. Heat transformers have opened up a new range of high temperature applications with promising characteristics in terms of efficiency and feasibility. Thermoacoustic heat pumps could be a good solution for a broad range of industrial applications so attention should be dedicated to their development to realise the technology's potential.

Finally, with the expansion of the electric vehicles' market an important field of application has emerged for heat pumps. Yet for such applications to materialise, highly efficient, low weight and compact heat pumps are needed, as are new low TGWI refrigerants, preferably using natural fluids. Research should target the areas of minimum charge, reduced leakage, and high efficiency of the system as a whole and of all its components. Moreover, systems will have to be reversible, being able to produce also cooling, and will have to work under low ambient temperatures which implies that research on efficient evaporators, two-stage cycles and compressors is required. Development of a smart control for the management of the system, and for the recovery of heat from the electronics and batteries when available, is also needed. Last but not least, conventionally fuelled vans and trucks offer good potential for the recovery of engine heat and its utilization to produce cooling of the vehicle or of the load. Research and development of specific components and systems for this application therefore also offers interesting prospects.

Figure 33 presents a summary of the above-mentioned research priorities, highlighting the most important characteristics of the systems and specific performance targets for the selected applications.

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	Application	Technologies	Medium term targets
Buildings	Small scale	Compression	Low TGWI refrigerants, minimum charge, high SPF (>5), able to work efficiently at low temp. (-10ºC), low cost[36], easy installation and operation, low maintenance
		Combined heat pumps thermacoustic	Assessment of the potential and feasibility
		Sorption	Cost and size reduction, improved operation and control, high SPF, development of reversible units
		Magnetocaloric	Assessment of the potential and feasibility
	Large scale	Compression	Natural refrigerants, minimum charge, high SPF (>6), sanitary hot water production at high efficiency (SPF >3.5), simultaneous production of hot and chilled water (SPF >9), low cost[37], highly reliable, optimized control, optimal integration with other systems
		Sorption	Size reduction, high SPF, improvement of reliability, optimized control, optimal integration with other systems, cost reduction
Industrial processes	Food Paper	Compression	Natural refrigerants, high temperature heat pumps with temperatures up to 150 °C for heat recovery with temperature lifts of up to 70K. COP > 5. Reliability.
	Chemical separation	Sorption	High temperature heat pumps with temperatures up to 150 °C for heat recovery. High COP, re-cooling temperature > 50 °C.
	Refinery Dairy	Combination of thermal/mechanical technology	High temperature combined heat pumps with temperatures up to 180 °C for heat recovery.
		Heat transformers	Heat rejection at high temperature with temperatures above 200 °C with temperature lifts of up to 70K
		Thermoacoustic	Highly efficient, burner driven TA and high temperature lift/ low temperature heat-driven TA system development
		Magnetocaloric	Assessment of potential and feasibility at different applications and temperatures
Mobile	Electric cars	Compression	Low TGWI refrigerant, minimum charge, tight containment, high heating COP (>3), able to work efficiently at low temp. (-10ºC), low weight, very compact, low cost, reliable
		Thermoacoustic	Low weight, very compact, reliable
		Magnetocaloric	Assessment of potential and feasibility
	Fuelled Vans/Trucks/ships	Compression	Air conditioning system: Low TGWI refrigerant, minimum charge, tight containment, high cooling COP (>3), low weight, very compact, low cost, reliable
		Sorption Hybrids	Air conditioning and refrigeration system driven by waste heat. Very high electrical COP, low weight, compact, low cost, reliable

Figure 33 - Overview of strategic research priorities for heat pump technology

[36] The reduction of energy cost along 15 years with the heat pump system should be able to almost compensate the extra cost in comparison with a condensation boiler system.

[37] The reduction of energy cost along 5 years with the heat pump system should be able to compensate the extra cost in comparison with conventional systems.

5. Hybrid Systems

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5. Hybrid Systems

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5.1 One definition, countless combinations

Hybrid systems are defined as those systems which provide heating, cooling and/or domestic hot water through the **combination of two or more energy sources into a single system**, therefore 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 effiency depends strongly on the way the two different sources are combined. This introduction gives already some information on the research needs of hybrid system technology. In fact in order to get efficient hybrid systems several aspects have to fit well together:

- Highly efficient individual components
- Well designed hydraulic scheme
- Well executed installation
- Centralized control unit including an optimized control for the specific components, climatic area and customer behavior.

Although in the past decades the **single components have been stepwise improved** – leaving still many possibilities for further optimization and improvements – **scant attention was given to the system level**. This is also reflected in the fact that hardly any testing procedures, standards or efficiency labels are applied to overall systems.

This situation leads to the fact **that final customers have few means to compare the efficiency of two hybrid turnkey systems** with each other. Furthermore, the producers of hybrid systems have limited possibilities to **optimise their systems towards certain performance levels** and it leaves the performance claimed by or reported by a system open to interpretation.

In parallel to the individual research needs expressed in the previous chapters of this publication, it is therefore of utmost importance to achieve improvements in the way these technologies are combined in hybrid systems. Above all, it's important to support the **definition of unified simulation procedures, monitoring procedures, laboratory test cycles, performance indicators and efficiency labels**.

5.1.1 Small-scale vs large-scale hybrid systems

One way to distinguish the hybrid energy systems' scale is by means of installed capacity. In literature, systems with capacities higher than 50 kW are often referred to as "large scale".[38] However, a

[38] [IER 2008] Lambauer et al., Industrielle Großwärmepumpen – Potentiale, Hemmnisse und Best Practice Beispiele, Forschungsbericht, Institut für Energiewirtschaft und rationelle Energieanwendung, Universität Stuttgart.

definition based on a "fixed" capacity range is very rigid and it does not take into account the purpose for which the system is used. Additionally, custom-design should be included in the definition.[39] Following this route, a **large-scale hybrid system** is defined by these simultaneous conditions:

- Capacity higher than 50 kW
- Systems suitable for applications requiring complex conceptual solutions and tailored designs.
- Systems requiring individual planning, non-standardised calculations and often simulation work.
- Systems specifically manufactured for particular applications resulting in single-unit production rather than off-the-shelf products.
- Systems designed by engineers rather than installers.

In contrast, **small-scale hybrid systems** are typically used in residential buildings, and are manufactured with an industrial production process based on a number of defined and standardised layouts. This means that small-scale systems are standardized products available in certain capacity ranges from which an installer selects a suitable size depending on the actual heating and cooling demand. Following this approach, this chapter distinguishes large- and small-scale hybrid systems according to the type of thermal energy demand they satisfy, the thermal capacity being a feature of secondary importance.

Typical applications of large-scale hybrid systems for heating and cooling include:

- Energy infrastructure like district heating and cooling networks.
- Large buildings for commercial or industrial use.
- Industrial processes.

Small scale hybrid systems are mostly applied in:

- Single-family houses
- Multi-family houses
- Small buildings used for commercial purposes

▶ 5.2 SMALL SCALE HYBRID SYSTEMS: THE BUILDING AS AN ENERGY SYSTEM

Primary energy use in buildings accounts for almost 40% of the total energy consumption in the EU[40]. In residential buildings, approximately 80% of the energy used is required for space heating & cooling and sanitary hot water[41]. A significant number and variety of energy supply technologies can be integrated into the built environment. Many of these technologies can be combined in highly efficient hybrid heating (and/or cooling) systems.

Hybrid systems, and in particular systems using two or more renewable energy sources[42], have a huge potential to reduce CO2 emissions in the building sector through a wide range of applications, depending on the technology chosen, its overall efficiency and the avoided environmental impact of the relevant fossil fuel alternative.

Until recently, the most common hybrid application was the combination of a fossil fuel burner (mainly gas or oil) and solar thermal collectors. 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 are:

[39] [BFE 2006] Bundesamt für Energie (BFE), Potenziale von Gross-Wärmepumpen besser nutzen - Konzeption, Anwendungen, Kundensicht, 13. Tagung des Forschungsprogramms Umgebungswärme, Bundesamts für Energie (BFE).

[40] European Union. EU Energy in Figures – Statistical Pocketbook 2010 [EU 2010]

[41] US Department of Energy, Buildings Energy data book 2011. Data available on http://buildingsdatabook.eren.doe.gov/

[42] Systems using one renewable and one non-renewable source are considered by the RHC-Platform as a merely short term (ie by 2020) technological option.

- Electrically-driven heat pumps[43] and solar photovoltaics.
- Electrically-driven heat pumps and solar thermal.
- Thermally-driven heat pumps in combination with solar thermal.

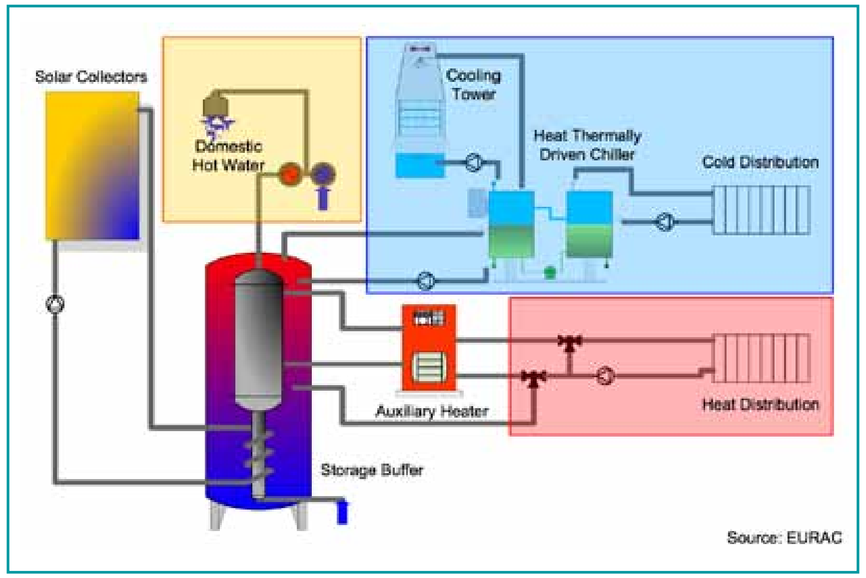


Figure 34 - Typical setup of a hybrid system for heating and cooling, combining solar, biomass and heat pump technology

One major challenge of hybrid systems is to maximise the combined efficiency of the energy sources employed, and at the same time to minimise the operating cost and the environmental impact. This can be only achieved if the system as a whole is considered and not just its various components in isolation. The trade-off between system performance and cost (both related to complexity) is the key thing to understand about hybrid system technology.

Improving the relative performance of the individual components is necessary to achieve highly efficient hybrid systems, however it is not sufficient. In the past decade several European projects and international collaborations have been conducted to improve the global efficiency of hybrid systems, albeit with limited resources. Additional research and development activities are therefore required to optimise these systems and realise their commercial potential.[44]

To successfully implement scientific research and technological development in small scale hybrid systems, it is highly important to establish close links with the building and construction industry. In the near future, the built environment needs to be designed, built and renovated with a clear vision of integrating multiple RES and energy efficiency measures.

Within the 160 million residential and commercial buildings in Europe, the current housing stock can be divided in three categories (Fig. 35):

- Single-family houses which include individual houses inhabited by one or two families. Terraced houses are included in this group.
- Multi-family houses, which contain more than two dwellings in the house. The distinction from the third group varies from country to country. Buildings with eight or fewer storeys are regarded as multi-family buildings.
- High-rise buildings, which are defined as buildings that are higher than eight storeys.

[43] Whereby the electrically driven heat pumps can use aerothermal, geothermal and hydrothermal low temperature heat sources.

[44] In the framework of international research activities, some tasks or annexes of IEA programs (such as HPP and SHC) have addressed the topic of hybrid systems. A number of projects have been funded by the European Commission under the Framework Programme for Research and Development (eg HIGHCOMBI; SUNSTORE4; E2PHEST2US; ALONE) and Intelligent Energy Europe (eg Sunflower; Optipolygen; Combisol, ICOSAW).

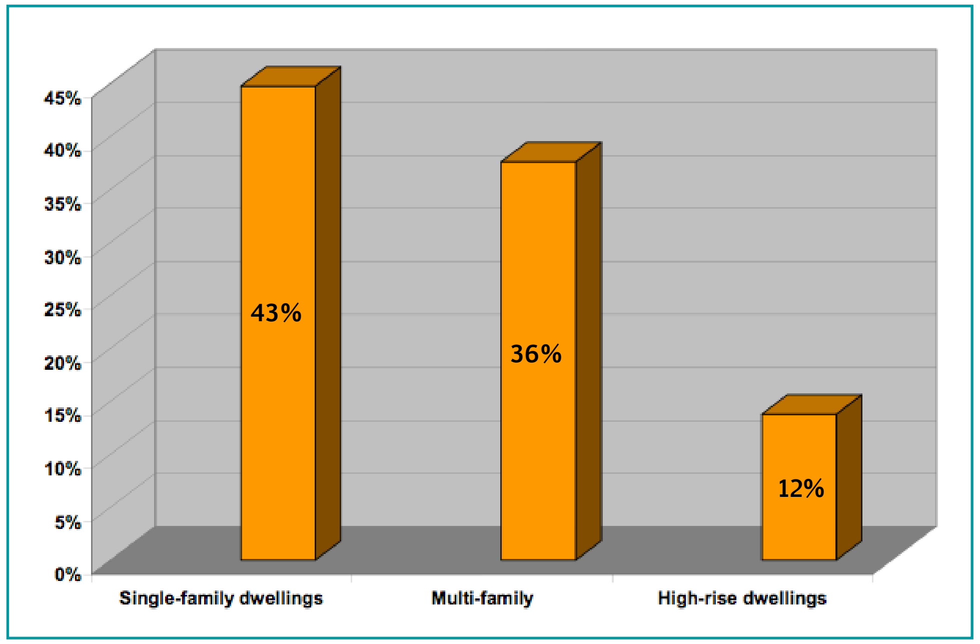


Figure 35 - Breakdown of housing according to typology (in the EU 27; year 2010)[45]

According to housing statistics[46], nearly 30% of these buildings were realised between 1946 and 1970. The annual growth rate of new buildings added to the housing stock is currently estimated at around 1-1.5% of the housing stock[47]. The number of buildings removed from the stock is about 0.2-0.5% of the housing stock per year. It is assumed that this trend will continue in the period ahead. Refurbishments affect roughly 2% of the housing stock per year. **Hybrid systems are replaced at a rate which is faster than the rate housing stock is renewed or buildings are refurbished. The systems in about 5% of buildings are replaced each year.** A similar phenomenon is observed in non-residential buildings with the replacement rate depending on the type of building.

Non-residential buildings account for the remaining 25% of Europe's building stock and together make up a more heterogeneous group[48], used for a great variety of functions, each with different energy demands per unit and each built according to different standards. Retail and wholesale buildings account for most of the non-residential stock while office buildings are the second biggest category with, floor space corresponding to one quarter of the total non-residential floor space. Variations in usage pattern (e.g. warehouse versus schools), energy intensity (e.g. surgery rooms in hospitals versus to storage rooms in retail), and construction techniques (e.g. supermarket versus office buildings) are some of the factors adding to the complexity of the sector. One peculiar characteristic of this typology of buildings is the higher cooling loads in comparison to housing, which is due to specific appliances (such as computers) and on average higher comfort requirements.

While new buildings can be constructed with high performance levels, it is the older buildings, representing the vast majority of the building stock, which are predominantly of low energy performance and in need of renovation work. The energy performance of each building defines the technical options that can be used to achieve comfortable temperature levels.

[45] [JRC 2008] Joint Research Centre – Institute for Prospective Technological Studies. Environmental Improvement Potentials of Residential Buildings (IMPRO-Building.

[44] In the framework of international research activities, some tasks or annexes of IEA programs (such as HPP and SHC) have addressed the topic of hybrid systems. A number of projects have been funded by the European Commission under the Framework Programme for Research and Development (eg HIGHCOMBI; SUNSTORE4; E2PHEST2US; ALONE) and Intelligent Energy Europe (eg Sunflower; Optipolygen; Combisol, ICOSAW).

[46] [OTB 2010] Research Institute for the Built Environment. Housing Statistics in the European Union 2010.

[47] [ECTP 2010] Ad-hoc Industrial Advisory Group of the European Construction technology Platform, European Commission (DG RTD Unit G2) 1609 final: Energy-efficient Buildings PPP Multi-annual Roadmap and longer term strategy.

[48] [BPIE 2011] Buildings Performance Institute Europe. Europe's Buildings under the microscope.

The research priorities of this chapter are therefore formulated taking into account the typology of buildings in Europe, and focus on the most effective way to implement efficient hybrid solutions. Figure 36 presents a broad characterization of the type of thermal energy demand by type of building. R&D activities are required for each of these areas to achieve effective implementation of system which can significantly help to reduce the energy consumption and replace fossil sources with renewable energy hybrid systems.

		Heating	Cooling	DHW	
New Buildings	Residential purposes	Low demand for space heating thanks to a good insulation. Low / Medium temperature of the heating fluid	High cooling loads in southern climatic conditions	DHW load : same order of magnitude as heating load on an annual basis	One system per house
	Commercial purposes		High simultaneous heating and cooling loads in most of service buildings	DHW loads depending on the service, but in general, DHW loads are limited	One system per block but requirements on control in order to separate the different flats
Existing buildings	Residential purposes	Higher demand for space heating, even if retrofitting of building envelope may reduce the space heating loads. Medium / High temperature of the heating fluid Very limited cooling loads	Very limited cooling loads	DHW load : much lower than heating load on an annual basis	One system per house One system per block but requirements on control in order to separate the different flats
	Commercial purposes	Higher demand for space heating, but energy consumption reduced by equipment	Cooling loads in most of service buildings	DHW loads depending on the service, but in general, DHW loads are limited	

Figure 36 - characterisation of thermal energy demand by type of building.

5.2.1 Research priorities

Short-term research activities should focus on tackling the current drawbacks, which can be summarised as follow:

- Cost is too high
- Limited thermal efficiency
- Installation process is too complicated and time-consuming
- Insufficient user-friendliness
- Complexity and high cost of design and modeling, which may prevent optimization (especially in

small systems)

To overcome these problems, the following priorities are identified:

I. Prefabrication and integration

Efforts should be put into developing **compact / prefabricated hybrid systems** with the following characteristics:

- Improved efficiency through:
  - well-designed systems (having small heat or cold store, good hydraulic layout, being exergetically optimized,...);
  - control systems that optimise the energy consumption and take advantage of the availability of renewable energy (optimise solar gain, increase COP, increase mean boiler 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, signaled, for example, by excessive primary energy consumption and notification of the user and or service company.

- Simplified installation to reduce breakage in installation and cost.
- Adapted to the various configuration of heating systems (low/high temperature) and climates.

II. Automation and control

Within the development of such hybrid systems, special attention should be paid to the **automation and control of systems**. The scope of this research includes:

- 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' behavior.
- 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 behavior of systems operating under particular conditions it should be possible to develop performance guarantees.
- Fault detection: intelligent analysis of the system behavior should be included to quickly detect possible malfunctioning and to alert the end-user or service company.

We expect 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.

III. Development of new standards and testing procedures

In parallel with system development, new standards should be developed. Nowadays, standards are available for specific components (heat pump, collector, heat/cold store, boiler, ...) but do not capture the operation of the complete system. Research is thus needed to reach a consensus and global methodologies to have new standards which are able to provide a clear assessment on the efficiency of systems. A standard set of tests for hybrid systems should be developed to certify their thermal and electrical efficiency and CO2 emissions. Transparent, comparable information will persuade more people to buy hybrid systems.

IV. Next generation hybrid systems – towards 100% renewables

In the medium to long term, research should focus on hybrid systems based wholly on renewable energy

sources with improved performance/cost ratio. This next generation should take advantage of:
- innovation in components (collectors, biomass boilers, ...) and cross-cutting technologies (heat pumps, TES, DHC);
- uptake of R&D results from other fields of research (ICT, material science, production processes, electricity and/or thermal smart grids, buildings, ...)

Figure 37 - Central element of an hybrid system combining geothermal and solar thermal technology (© EHPA)

V. Integration of building components in hybrid systems

For new buildings as well as for existing buildings which undergo a deep energy refurbishment, **multi-functional façades and components** will become an alternative to traditional construction techniques. If buildings with a net or nearly zero energy balance are to be realised, the intensive integration of solar energy (PV and solar thermal) in the building envelope becomes necessary.
In addition to their primary purpose, components could provide the dual service of insulation and static stability (passive functions) and solar energy collection, sun protection, ventilation, hydraulic distribution systems (active). Multifunctional components can reduce the construction or refurbishment time improving the quality of life of inhabitants and others nearby.

Research is needed in the field of development, design, simulation and testing of these components. Only by scaling up the production will it be possible to achieve significant cost savings. Furthermore the monitoring of demonstration projects and experimental buildings is needed in order to get feedback on functionality, durability and customer satisfaction.

As the façade is usually more visible than the roof structure, a very important aspect is the architectural integration of these multifunctional components. This leads to additional challenges on the technical level. Strong collaboration between designers, architects and engineers is needed from an early stage of development to reach acceptance among public opinion and decision makers.

Costs and performances vary widely between hybrid heating and cooling technologies and also in each individual system because of differences in end-use applications, climate, technology specifications, user requirements and building occupation profiles. Variations within each country are even more pronounced at EU level, so it is difficult to present meaningful results that are directly comparable at highly aggregated level. For these reasons, unlike in the other chapters of this publication, the following table does not present specific quantitative targets for R&D activities.

	Short term	Medium term	Long term
Basic research	Basic research is only required on the single components of the hybrid systems. Research priorities and the relevant quantitative targets are presented in the other chapters of this study and in the technology specific publications of the RHC-Platform.		
Applied research & development	Development of simulation and testing procedures for whole systems	Development of heating/cooling and sanitary hot water load forecast, based on the learning of system operation and occupants behavior	Development of advanced control equipment for hybrid systems, responsive to weather forecast with self-optimising procedures
	Development of an energy efficiency labelling scheme for whole systems	Application of new materials for hybrid systems in order to reduce cost, weight and size of the overall system	
	Development of next generation hybrid systems, able to operate at medium/high temperature, targeted at the refurbishment of existing buildings		
	Development of advanced control strategies including weather forecast.		
	Development of best practices, technology selection guidelines, training for designers.		
Demonstration	Demonstration of prefabricated pre-engineered turnkey hybrid systems	Demonstration of next generation hybrid systems	Demonstration of advanced control strategies including weather forecast.
	Large scale field tests and monitoring campaigns for the most common hybrid solutions in different climate conditions	Demonstration of multifunctional building components including RES and energy distribution technologies	

Figure 38 - Research Priorities for small-scale hybrid systems

5.3 Large scale hybrid systems for large buildings, industrial processes and at district level

To realise the full potential of renewable heating and cooling technologies, it is of utmost importance to achieve significant advances in large-scale hybrid systems. The importance of stimulating R&D and demonstration efforts in this field is evident, as large scale systems are typically found in complexes of buildings, **urban areas** and **industrial applications**.
The majority of the world population lives in urban areas and it's expected that proportion will increase to 60% by 2030.[49] Already today, approximately 70% of the world's energy related CO_2

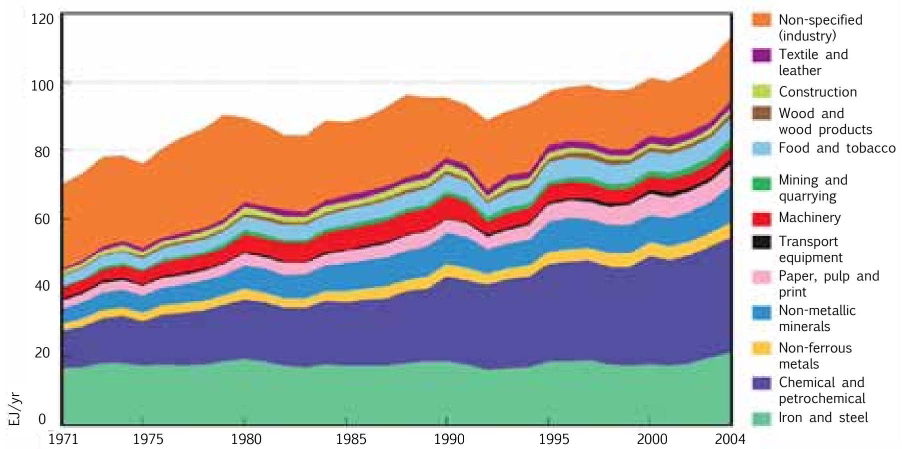
[49] [UNDP 2007] United Nations Population Division. Report on World urbanization prospects: the 2007 revision.

emissions are generated in towns and cities with an increasing trend. By 2030, energy-related CO_2 emissions from cities will reach 76% according to a business as usual scenario by the IEA.[50] In absolute numbers, this corresponds to an increase from around 20 Gigatonnes CO_2 in 2006 to over 30 Gigatonnes in 2030. It is thus obvious that it is necessary to develop and push competitive large-scale hybrid systems based on renewable energies that are capable of supplying heating and cooling in urban areas with highest possible efficiency and minimum local and global emissions.

Large scale hybrid systems are also used to supply thermal energy required by industrial processes. In the EU, industry consumes about 30%[51] of all final energy. A substantial share of this final energy consumption is for heating and cooling. The main energy consumers in the industrial sector are (Figure 39):

- Iron and steel industry
- Chemical and petrochemical industry
- Non-metallic minerals industry
- Pulp and paper industry
- Food industry

The specifications of large-scale hybrid systems in industrial applications are diverse, as different industrial sectors require different energy systems. At the top end, the metal or chemical for example demand heat at temperatures above 400 °C. High temperature heat accounts for 43% of the all industrial heat demand[52]. At the bottom end, around 30% of the heat demand is below 100 °C which is for instance typically found in the food industry. The remaining 27% of heat demand is in the mid-temperature range between 100 °C and 400 °C. The required temperature affects system design. Industrial systems can in certain cases be linked to district heating network. In this case, an overall design that optimally meets the needs of both sets of users should be found.



Note: The discontinuity around 1990 is caused by developments Easter Europe and the FSU that resulted in a rapid decline of industrial production.
Source: IEA data.

Figure 39 - Industrial final energy use from 1971 to 2004 (source: IEA)

The application of large scale hybrid systems for heating and cooling in the context of urban areas and industry is very often closely related to each other as industries are often located in or near urban areas and thus part of an urban infrastructure. It is thus important to employ a **holistic view when designing large scale hybrid energy** systems. Obvious examples which are already often employed today

[50] [OECD/IEA 2008] International Energy Agency. World Energy Outlook 2008.

[51] Source: Interactive database on Energy Saving Potentials in EU Member States, Candidate Countries and EEA Countries : www.eepotential.eu (2009)

[52] Euroheat & Power, „Ecoheatcool – Final Report, Work Package 1", IEE Project, Final Report, www.euroheat.org, 2006; Figures based on 2003 data for the EU 27 plus Iceland, Switzerland, Norway, Turkey and Croatia.

include the use of waste heat of industrial processes for district heating or the use of combined heat and power on both district and industrial level. However, when it comes to substantially increasing the share of advanced high-efficiency heating and cooling systems based on RES in densely populated areas and industrial processes, additional R&D and demonstration efforts are required. Increasing the overall energy efficiency beyond the state-of-the-art and using RES often means introducing new technologies. These systems are unproven and usually more complex, increasing investment costs.

Reaching payback targets is particularly challenging in industrial applications where payback periods smaller than five years are commonly found. While high-efficiency large-scale hybrid systems based on RHC technologies have already reached competitiveness in terms of overall lifetime cost, in many cases payback targets are still difficult to achieve. However, the application of advanced systems offers advantages that will become significant in future. The high volatility of energy prices is dissuading investors from investing in fossil-driven heating or cooling systems and driving them to accept a moderately longer payback period from a system with known running costs.

Figure 40 - Large-scale hybrid system combining solar thermal and heat pump technology to provide space heating with high solar fraction to a commercial building (© Austrian Institute of Technology).

▶ 5.3.1 Research priorities

Large scale hybrid systems based on multiple fossil fuels or on the combination of fossil and renewable sources have been in use for years due to the reliability, flexibility and cost-effectiveness of these hybrid solutions.
As for other technological applications described in this report, research priorities for large scale hybrid systems are focused on improving the system efficiency and reducing both upfront and operational costs. These activities must be directed towards the overarching long term objective (beyond 2030) of phasing out fossil fuels from large scale applications. In the short and medium term however, hybrid systems combining RES and fossil energy sources are included in the research agenda because incremental improvements in these systems may expand the range of cost-effective applications and therefore accelerate the transition.

Research, development and demonstration activities need to be focused on the following areas:

I. Development of tools to support decision-making that allow optimal selection and configuration of hybrid systems in urban areas

- Incorporation of hybrid RHC systems including heat pumps and thermal storage into support tools for decision making to optimize smart cities' energy planning.
- Selecting and designing hybrid systems by evaluating the characteristics of spatially-distributed energy demand and supply.

II. Development of dynamic simulation tools that allow optimal design of hybrid systems combining energy supply to urban areas and industrial processes

- Dynamic simulation tools for the design and control of system configurations and hydraulic schemes.
- Development and validation of component models for the system simulation tools.
- Research on advanced control strategies to adapt the operation of heat pumps and hybrid systems to variable energy supply and demand to achieve optimum annual performance.

III. Development of advanced monitoring methods including function and yield control for hybrid systems in urban areas and industrial processes

- Development of methods that allow for a comparison and evaluation of the performance of hybrid systems in urban and industrial applications.
- These new methods should promote new financing schemes such as energy service contracting (ESCO) and new funding schemes.

IV. Development of hybrid system configurations including heat pumps and large thermal energy storage for operation in low temperature district heating and cooling networks and industrial processes

- Combination of heat pumps with direct supply of renewable heat from geothermal, biomass and solar thermal sources to thermal grids.
- Upgrade of heat from large thermal stores through heat pumps.

V. Enhanced interaction of hybrid systems with smart grids (electrical and thermal)

- Evaluation of "centralized" vs. "decentralized" approaches
- Development of appropriate system configurations (e.g. integration of heat pumps with thermal energy stores) and hydraulic schemes
- Development of communication interfaces that allow for communication with the energy distribution networks and energy management systems on the demand side

VI. Research on the combination of multiple sustainable heat sources to use hybrid systems in densely populated areas

- Exploration of waste heat sources (such as sewage water, waste heat from processes and buildings, etc) in combination with RES
- Investigation and optimisation of the heat transfer characteristics of waste heat sources

VII. Development of highly integrated hybrid systems for heating and cooling in urban areas

- Development of hybrid system featuring a high degree of building integration (e.g. integration into façades/building structure/basement)
- Development of “all-in-one” units (including at small-scale) integrating different RHC technologies and heat or cold stores for decentralised application in cities

VIII. Research to improve the efficiency and cost of Stirling engines in hybrid heating, cooling and power refrigeration systems[53]

- Further development of Stirling-engine systems and their hybridisation to achieve highly efficient tri-generation.
- Research on high temperature materials in the hot-end components of the Stirling engine system.

IX. Research on the next generation of CHP systems combining RES with fuel cells

- Basic and applied research to reduce costs and improve durability and operational lifetime through better fuel-cell system design, new high-temperature materials and an improved understanding of component degradation.
- Research to reduce the balance-of-plant system costs by improving the power conditioning system and developing less expensive catalysts, membranes and bipolar plates.

	Short term	Medium term	Long term
Basic research	Development of multi physical modelling and simulation tools that allow for a detailed dynamic simulation of multi domain energy systems (e.g. other energy domains like electricity).	Development of advanced control algorithms for hybrid energy systems (e.g. multi agent systems) that allow for an optimum operation and interaction with the overall energy system.	Hybrid heating, cooling and refrigeration systems based on highly efficient Stirling engines
Applied research & development	Development and validation of tools to select and configure RHC systems in urban areas and industrial processes		Basic research to reduce costs and improve durability and operational lifetime of fuel-cell hybrid systems.
	Development of appropriate system configurations (e.g. integration of heat pumps with thermal energy stores) and hydraulic schemes for the interaction of large scale hybrid systems with smart grids.	Development of advanced monitoring algorithms including function and yield control for hybrid systems in urban areas and industrial processes.	Research to reduce the cost of balance-of-plant CHP systems combining RES with fuel cells.
	Investigation of spatially distributed energy demand and supply using GIS tools as a basis for the selection and design of large scale hybrid systems.	Development of new heat recovery concepts that enable low temperature heat recovery from buildings	

53 Stirling engines are external combustion engines, noted for their high efficiency compared to steam engines, quiet operation, and the ease with which they can use almost any heat source (including RES). A Stirling engine can function in reverse as a heat pump for heating or cooling, as well as producing combined heat and power. They are not widely developed although a growing number of commercial units exist and more are being developed.

	Development of smart heat metering concepts for large scale hybrid systems.	Development of hybrid systems with very high degree of building integration (e.g. into façade etc.).	
	Development of large scale hybrid systems for interaction with smart girds; evaluation of “centralised” versus “decentralised” approaches.	Development of new communication interfaces and protocols that allow for communication of large scale hybrid energy systems with smart grids and energy management systems on the demand side.	
Demonstration	Demonstration of large scale hybrid energy systems based on state-of-the art technologies with advanced hydraulic schemes and control strategies.	Demonstration large scale hybrid energy systems in industrial applications at temperature levels between 100 °C and 400 °C.	Demonstration of advanced control algorithms and strategies

Figure 41 - Research priorities and targets for large scale hybrid systems

5.4 Non-technological priorities

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.

In the **building sector**, the choice of heating and cooling supply technology is often given secondary priority by planners, builders and home owners. At small-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 and plumbers. **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.

The market penetration of effective hybrid systems could be supported by more robust **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.

There is also a need for **public acceptance**. The provision of clear and objective information on the performance and limitations of the individual technologies (as opposed to hybrid systems) can boost customers’ acceptance and accelerate market penetration. It is therefore necessary to **develop effective communication campaigns** not only to ensure that tenants and home owners can easily obtain **reliable, tailor-made, and “easy to understand” information**, but also that they are aware of the long-term implications of choosing a sub-optimal technological solution in terms of costs and environmental impact.

In particular for small-scale hybrid systems, the associated technology must be thought of in terms of the behaviour required from the user and the thermal energy it needs to satisfy. **Additional social research is needed into the relation between the energy user and the supply system**. This should lead to the development of new knowledge on how to effectively realise changes of attitude and behaviour for the end user.

The future energy needs of cities will be met with RES and low-carbon hybrid systems. In addition to the research priorities associated with urban planning which were explored earlier, greater attention should be given to developing regulation for renewable heat at local level. The adoption of a holistic approach is fundamental to creating a favourable policy framework for large-scale hybrid systems. Strategic infrastructure planning must rely on a diversified renewable energy supply adequate for both the total thermal energy demand and its consumption patterns.

5.5 Conclusions

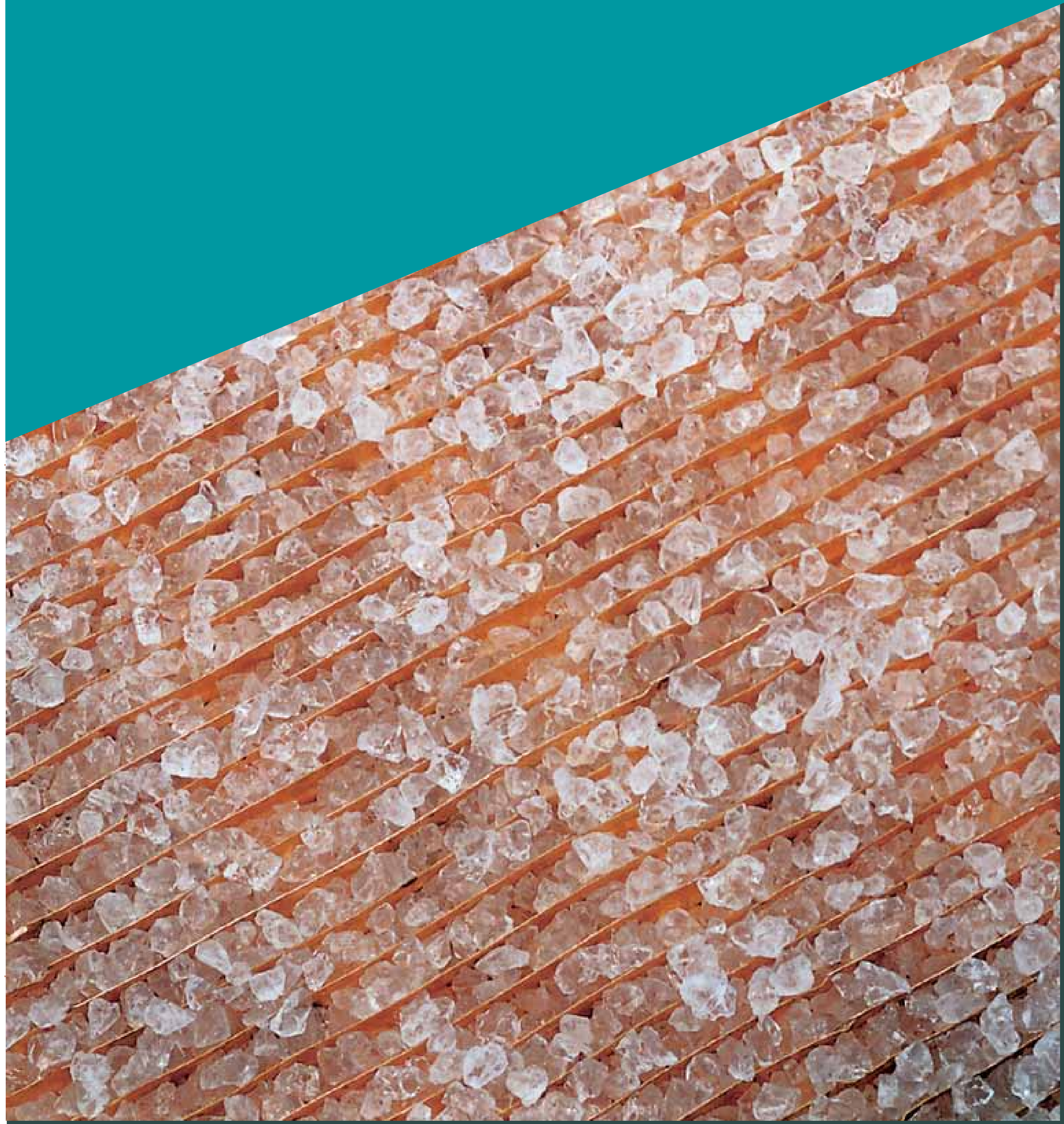
A wide range of hybrid systems for heating and cooling can be found in commercial production and in the laboratory, each having different performance characteristics and costs and each combining two or more energy sources in a single system. These hybrid solutions hold a huge potential to efficiently and conveniently satisfy the energy demand of single users or multiple users simultaneously with different needs.. This is true for 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.

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 applications in buildings. This research should also address energy performance monitoring as well as early fault diagnosis for continued high performance over the system's lifetime.

This chapter also explores the strong link between buildings and hybrid systems. There are gaps in the current approach of the construction industry to refurbishment, building design, choice of energy technology and quality of installation. Research, development and demonstration activities should be conducted in the form of a close collaboration between the construction sector and RHC technology manufacturers with due regard taken of the views of final energy consumers. Systemic approach is needed to produce innovative integrated solutions with higher energy efficiency and optimized use of stochastic RES.

Large-scale hybrid systems allow diverse sustainable energy sources and end consumers to be brought together in one system. There is a need for the development of new decision support tools for hybrid systems. Breakthroughs are needed in the efficiency of CHP technology combining solar, biomass and geothermal energy with industrial heat pumps. Given the pivotal role played by energy infrastructures, DHC networks should be developed and modernised in tandem with research conducted for hybrid systems.

6. Enabling research areas



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6 Enabling research areas

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This chapter presents what the authors believe are key research areas for enabling the achievement of the full potential of cross-cutting technology for renewable heating and cooling. The first part of the chapter is dedicated to research areas in ICT while the second part looks at research in materials science.

6.1 Information and Communication Technology

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%.[55] ICT can also address the complexity of measuring energy performance at a system level[56]: 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.

In urban areas, DHC is expected to play a key role in future energy systems provided that its design and implementation evolves along the guidelines defined for modern energy districts integrating state-of-the-art ICT.

According to recent literature , five major areas can be identified where ICT research priorities may have a direct impact on the performance of the thermal energy system:

I. Reduction of the overall primary energy consumption
II. Optimisation of the use of renewable energy sources
III. Exchange of energy in energy hubs and smart grids
IV. Storage of energy on a daily, weekly, seasonal scale
V. Efficient use of imported energy and fuel in cases of shortage in renewable energy generation and/or of emergency.

The intelligent integration of innovative ICT in DHC networks is fundamental for the efficient integration of heterogeneous RES (including surplus coming from industries and plants) and storage sub-systems. The price to pay lays in the unavoidable greater complexity of the resulting system, whose overall efficiency is strictly related to the quality of planning and the optimal management of the overall thermal flows. An essential requirement for the energy transformation represented by the evolution of the energy districts is the involvement of local communities, which should be provided with tools to

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

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

evaluate the different options available and choose the best possible energy mix (as also presented in Chapter 2).

To address Europe's energy challenges and accomplish the strategic vision outlined, strong support for research and development of ICT tools and systems is required. Such tools can be grouped into categories which represent the proposed research priorities for ICT in RHC systems as outlined below .

• ICT tools for decision makers and planners of integrated thermal energy systems

Planning and design tools are today normally available for each "vertical" subsystem of an energy district. In a closely integrated scenario these different components will be integrated with each other and with other urban systems and networks in order to maximize the resulting efficiency.
Decision makers, planners and users need to be able to evaluate the integrated system as a whole, including the non-technological aspects such as sustainability, acceptance by communities and other socio-economic issues.
Research priorities for future planning and simulation ICT tools should e.g. consider the following elements:

• The stochastic nature of RES, caused by the dependency on external factors such as weather conditions. Optimal use of RES requires either immediate use of the produced energy or its storage for later consumption (when demand arises).

• Energy exchange in energy hubs: thermal energy coming from various sources including surplus heat from industrial plants, waste management etc. can feed into the DHC network. The systems and the corresponding simulators need to be equipped with adaptive ICT to cope with the heterogeneity of sources in terms of type, temperature, and flow.

• Daily and seasonal storage technologies necessary to ease peak loads and collect all energy (particularly stemming from RES) when available

• The future role of the building sector: buildings will increasingly be producing energy. Thermal energy-storage materials (e.g. PCM) integrated in the building envelope and connected to an intelligent communication system will enhance the role and functionalities of TES (cf. section 3.1). Different kinds of buildings may be connected to an ICT-based DHC network influencing its performance and behaviour.

• Integration with other urban systems and networks such as the power grid (the DHC itself could serve as energy storage) and the waste management sector (including biomass). Energy district planning will be one of the many components of future smart city planning.

• New business models associated with future integrated, heterogeneous energy systems.

Due to the wide variety of applications, ICT tools for integrated planning and simulation need to be able to model the complex systems in a modular way thereby allowing for a flexible, high-level (behavioural) design and simulation of heterogeneous systems. Operational processes of the newly incorporated components may have peculiar aspects which need to be factored in when developing the model (and simulator) of the overall system. An example is the highly time-dependent heat storage process: systems incorporating thermal energy storage must be carefully modelled from the dynamics and time-dependency points of view (cf. section 3.5). It is likely that such complex simulators will not be able to incorporate all technological details of the various components into the models. In such cases, the detailed design of individual systems can be done using conventional specialised tools.

• Integrated data collection and management systems

Advanced data collection enables smart services dedicated both to operators/utilities and to consumers: smart meters help operators to adapt energy systems to user demand and users to understand their consumption thus creating the awareness level required to stimulate a wiser use of energy. As mentioned in section 3.6, a drawback of thermal energy systems is the lack of feedback on their performance. Such information would be beneficial to users, installers, producers, utilities and would raise public awareness about the systems.

Meters able to sense and transmit energy-related information should be installed in all sections of future energy networks in order to collect data useful for both end users and policy/decision makers. In the majority of households, there is currently no easy way to separately identify the energy consumption dedicated to heating and cooling and consumption for other purposes. To create awareness, the installation of sub-meters must therefore be strongly encouraged. Moreover, meters should be installed to collect usage information from all the different networks (gas, water, electricity etc.) and sensors should be included in the components of heterogeneous systems which traditionally have been less equipped with electronics, such as storage systems. Further details on sensors needed for such systems can be found in Chapter 3.5. Finally, data communication standards should be developed and adopted by all smart meters.

Smart meters will tend to generate a massive amount of information which will need to be integrated with other data streams from weather forecasts, demographics, socio-economic information etc. Modern data management systems based on cloud computing architectures and more traditional, distributed, hierarchical data mining algorithms based on grid computing represent solutions with the appropriate levels of reliability and performance.

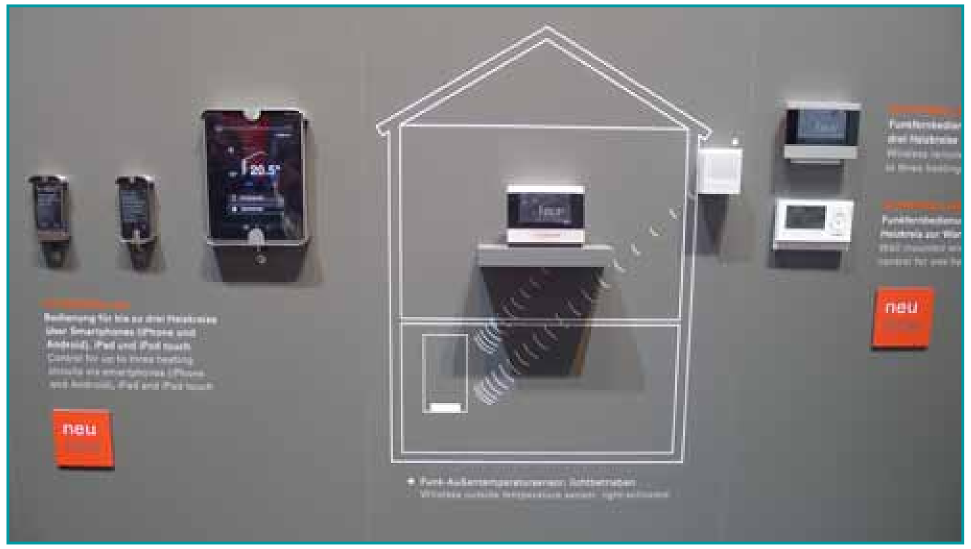

Figure 42 - ICT for remote control of the heating and cooling system (© Thomas Nowak, EHPA)

• Involving the communities

Due to its central role in the Smart Cities and Communities development, DHC should seek to create stronger links with its current and potential customers. The information provided by ICT systems and tools can be strategic to raise acceptance levels and create 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 very 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 behavior. As argued in Chapter 2.2.1, an efficient system is useless if not properly used.

• Thermal flow control for integrated, hybrid systems

Optimal operation of future thermal districts requires real-time, integrated management between production, transport, distribution and consumption. Similarly to planning and simulation tools, the operation of integrated energy district networks requires the simultaneous integration of their (existing) management tools and equipment. The situation is further complicated by the numerous connections that DHC systems have with non-energy systems and sectors (cf. section 2.1.3). To achieve optimal flow control, the definition (where not already available) and adoption of standard data format and communication protocols are a must.

As previously pointed out (3.2.2), the introduction of RES in energy grids can be fully exploited only if the grid is extended including systems such as heat pumps and energy storage systems. In particular, combined hybrid systems will play an important role under the condition that thermal production can be decoupled from thermal demand through thermal energy stores. It is therefore necessary to develop methods to accurately determine the state of charge as well as control algorithms so that heating and cooling is generated from RES when available while providing the consumer with their needs at a time of their choosing. As control and management tools designed for complex integrated systems need to be able to manage all the involved components, future generation heat pumps and energy storage systems need to be equipped with modern meters and a standard, open interface.

Modern control and management information tools must be designed to perform a number of complex functions, among which (cf. sections 2.1.1 and 5.2):

• anticipate future energy demand in the short as well as long term based on the analysis of past energy consumption

• take into account accurate weather forecasts

• apply new processing algorithms to supervise the complete system (cf. section 5.2)

• predict faults through pattern analysis of multiple information streams

• communicate via an easy, intuitive user interface

• Knowledge base and training tools

In general, there is little knowledge about heating and cooling systems. Educational material (including online courses) should be developed, mainly targeted for a general audience, covering the main principles and technologies for renewable heating and cooling supply, distribution and management. Raising awareness and knowledge about these systems is a fundamental step towards a better acceptance of modern technologies and a better individual use of energy. Information about best practices already implemented and about ongoing projects should be made easily available and linked through dedicated portals.

	Short term	Medium term	Long term
Basic research	• Improvement of Wireless Sensor Network protocols (scalability, interference management, spectrum agility) • Low power sensors as required by thermal networks • Models and algorithms for the involvement of communities (energy consumption awareness, information about modern energy systems)	• Energy scavenging and long-lasting rechargeable batteries to power wireless sensors • Algorithms and models for integration of energy networks with other city networks	
Applied research & development	• Simple energy planning and design tools for hybrid integrated energy systems • Data management and visualization • Integration of business models and social aspects in planning tools	• Development of sophisticated energy planning and design tools for detailed analysis of complex energy systems • Tools to support community involvement in the overall energy efficiency process	
Demonstration	• ICT infrastructure (sensors) of hybrid small/medium energy plants (districts/small cities) • Data collection, data mining and visualization techniques applied to energy systems (simulation, planning, information and awareness creation)	• Simple hybrid energy systems control based on integrated ICT • ICT support for integration of small scale energy + other networks	• Fully integrated district simulation and planning systems (incl social/business elements) • Operational control of hybrid systems, integrated with city networks Decision making systems extended to community participation and consensus

Figure 43 - ICT-related research priorities for renewable heating and cooling

6.2 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 cross-cutting technologies explored in this report. Materials science is ubiquitous and it is extremely difficult, even detrimental to break it up by specific application. Materials research presents countless opportunities for complementarity and synergies between different applications both within and beyond the energy sector. One example is the research results generated for 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"[58]. Regrettably, materials research for heating and cooling technologies has largely been overlooked in the EC Roadmap. The added-value of novel functional and structural material 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.

[58] [EC 2011] European Commission staff working document SEC(2011) 1609 final: Materials Roadmap Enabling Low Carbon Energy Technologies.

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 cross-cutting 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 Strategic Research Agenda. Economies of scale and scope can be realized 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 identified in the previous chapters that are relevant to materials science, using different colours to indicate the cross-cutting area to which they primarily (though not exclusively) relate.

	Short term	Medium term	Long term
Basic research	Better insulation solutions and/or material for thermal transport	Fluids combining heat transfer and heat storage	New materials and/or mixtures that adjust the melting temperature
	Thermal conductivity intensification	New phase change materials with higher storage density	Very high temperature thermochemical systems
	New sustainable TES materials	New encapsulation and stabilisation methods for PCM, especially for salt hydrates	
	New PCM materials that are not subject to subcooling	Developing microencapsulated PCM at medium (300 °C) and high temperatures (up to 1000 °C)	
	Materials for thermochemical heat storage	Materials for thermochemical heat storage	Materials for thermochemical heat storage
	Safe refrigerants with 0 ODP and almost 0 GWP	New insulation materials / Vacuum insulation	
	Improved materials for magnetic refrigeration	New materials designed based on numerical modelling	
	Fundamental understanding of heat and mass transfer at sub-atmospheric and super critical pressure	Investigation of performance of new working fluids	Investigation of chemical reactions for the application to sorption processes
	New working media for thermally driven heat pumps for elevated temperature levels	Metal hydrides	

	Modified zeolites, SAPO, ALPO	Salt based chemisorbent development	
	Heat exchanger surface modification-Nanostructures	Metal Organic Framework materials	Designer Sorbent working pairs
	Sorbent coating techniques development		
	High temperature refrigerants for industrial compression heat pumps (temp. up to 150 °C)	High temperature refrigerants for industrial compression heat pumps (temp. > 150 °C)	
	Improved materials for heat exchangers at high temperatures (>150 C)	Characterisation and development of new working fluids	
Applied research & development	Development of integrated and standardised pipe solutions	New PCM in polymers	
Applied research & development	Materials for storage containment	Liquid desiccant systems for dehumidification and cooling applications	
Applied research & development		Heat exchangers based on advanced materials for application in severe operating conditions (e.g. corrosive media)	
Demonstration		Flexible volume tanks	

LEGEND:
- District Heating and Cooling;
- Thermal Energy Storage;
- Heat Pumps

Figure 44 - research priorities for materials science addressing the needs of RHC technology

7. Concluding Remarks

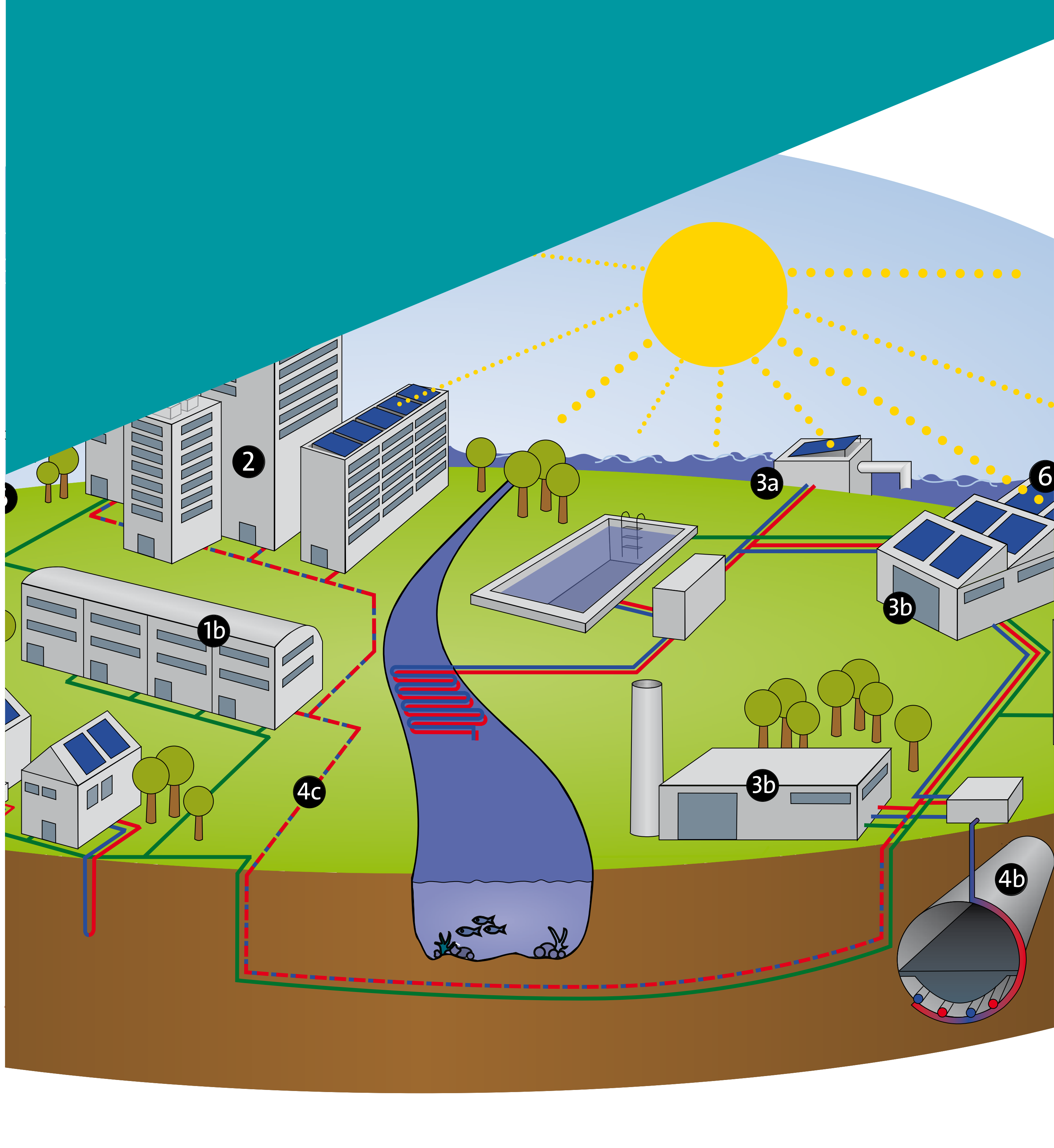

Photo © EHPA: Future cities / heat pump cities

7. Concluding Remarks

Reliable and sustainable energy supply is fundamental to the functioning of modern society, economy and industries, to the quality of life of people, and to the geo-political stability of countries. The use of renewable energy sources for both domestic and industrial heating and cooling applications is the most effective way to achieve long-term emissions reduction and to improve the security of our energy systems.

This publication presents the priorities for cross-cutting technology and short-, medium- and long-term research targets for the integrated production, distribution and storage of thermal energy from RES. Throughout the four main chapters, a comprehensive set of research and innovation requirements is put forward to support the decarbonisation of the heating and cooling sector in the EU.

The present document emphasises the need for a system perspective in the implementation of the research and innovation priorities. Numerous applications of cross-cutting technologies are identified which are at various stages of development; they all however require R&D support to **reduce costs** and **improve relative performance**.

There is a need of finance for **demonstration** of innovative **district heating and cooling** infrastructure. Modern DHC systems can still benefit from technological advancements in the generation, distribution and customer sides. Together with further ICT developments and further integration with other networks and urban functions (waste management, transport, industry etc.) they will increase flexibility and allow communities to become "smart energy exchange systems", representing a zero carbon solution.

Thermal energy storage can hugely increase the technical potential of RES by allowing heat (and cold) to be utilised when there is demand for it, rather than at the moment it is generated. **Basic and applied research** for several technological solutions should be supported in parallel, with the aim of enhancing the ability to efficiently shift energy demand and to facilitate the integration of RES.

Heat pump technology is rapidly gaining market shares in Europe; however it still needs support in terms of **development** of better and cheaper components and to optimise the performance at system level. More demonstration is necessary to bridge the gap between concept and implementation of **hybrid systems**, including applied research into innovative building concepts. Large scale hybrid systems interconnected with local grids must be the focus of specific research to unlock their potential and to enable the systems to simultaneously satisfy residential and industrial energy demand with minimal losses.

All R&D activities on cross-cutting technologies must be accompanied and supported by additional research on **ICT** and **materials science**. The present report does not specifically address **energy efficiency**, which is now a hot topic for EU and national policy makers. Nevertheless, the importance of reducing the energy demand is fully recognised and supported by the RHC-Platform as a necessary complement to renewable energy generation.

In addition to this comprehensive agenda for scientific and technological research required to maintain Europe's first mover advantage in renewable heating and cooling and our technological leadership, it is important to ensure a stable and positive investment climate across the EU. Private investors need the right signals today – from the EU and national governments – to make Europe a resource-efficient and renewable energy economy by 2050.

The next European Budget (2014-2020) is being decided in troubled economic times, however the global downturn ought not to divert the ambitions of European policy makers to secure enough resources for the research, development and deployment of renewable energy technology. To this end, support is required at the EU level through different funding instruments, first and foremost HORIZON 2020, the next European Framework Programme for Research and Development.

European research efforts currently suffer from being dispersed and insufficiently coordinated to fully realise the performance potential and ensure long term EU leadership on renewable heating and cooling technologies. Whilst this report concentrates on research requirements for cross-cutting technology for renewable heating and cooling, it should be recognised that a close collaboration is needed with the strategic research agendas for biomass, solar thermal and geothermal technology. At the time of publishing, the RHC-Platform is working on the production of a single shared Strategic Research Agenda for Renewable Heating and Cooling Technologies. The RHC-SRA will rely on the information provided in the present publication to propose a set of consolidated priorities for the coming two decades and beyond.

APPENDIX 1: TERMS AND ABBREVIATIONS

ALPO: Alumino-Phosphate
ATES: Aquifer Thermal Energy Storage (part of UTES)
BTES: Borehole Thermal Energy Storage (part of UTES)
BPHE: Brazed Plate Heat Exchangers
CHP: Combined Heat and Power
CO2: Carbon Dioxide
COP: Coefficient of Performance
CTES: Cavern Thermal Energy Storage (part of UTES)
DHC: District Heating and Cooling
DHW: Domestic Hot Water
EC: European Commission
ECM: Electronically Commutated Motors
EGEC: European Geothermal Energy Council
EHPA: European Heat Pump Association
EPBD: European Performance of Building Directive. Reference [EU 2010]
ETP: European Technology Platform
EU27: The 27 Member States of the European Union
EUREC: European Renewable Energy Research Centres Agency
GHG: Greenhouse Gas
HP: Heat Pump
km2: Square kilometre
kWh: Kilowatt hour
LiBr: Lithium Bromide
Mtoe: Million tons of oil equivalent
MW: Megawatt
MWh: Megawatt hour
ODP: Ozone Depletion Potential
PCM: Phase Change Material
R&D: Research and Development
RES: Renewable Energy Sources
RES Directive: European Directive 2009/28. Reference [EU 2009]
RET: Renewable Energy Technology
RHC: Renewable Heating and Cooling
RHC-Platform: European Technology Platform on Renewable Heating and Cooling
SAPO: Silico-Aluminophosphate
SPF; Seasonal Performance Factor
SRA: Strategic Research Agenda
ST: Solar Thermal
TES: Thermal Energy Storage
TGWI: Total Global Warming Impact
UTES: Underground Thermal Energy Storage

APPENDIX 2: REFERENCES

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Appendix 3: Secretariat of the RHC-Platform

This document was prepared by the European Technology Platform on Renewable Heating and Cooling (RHC-Platform).

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SEVENTH FRAMEWORK PROGRAMME

The Secretariat of the European Technology Platform on Renewable Heating and Cooling is coordinated by the European Renewable Energy Research Centres Agency (EUREC)

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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