District & Heating Cooling

STRATEGIC RESEARCH AGENDA

DHC+
TECHNOLOGY PLATFORM

Colophon

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DHC+ Technology Platform

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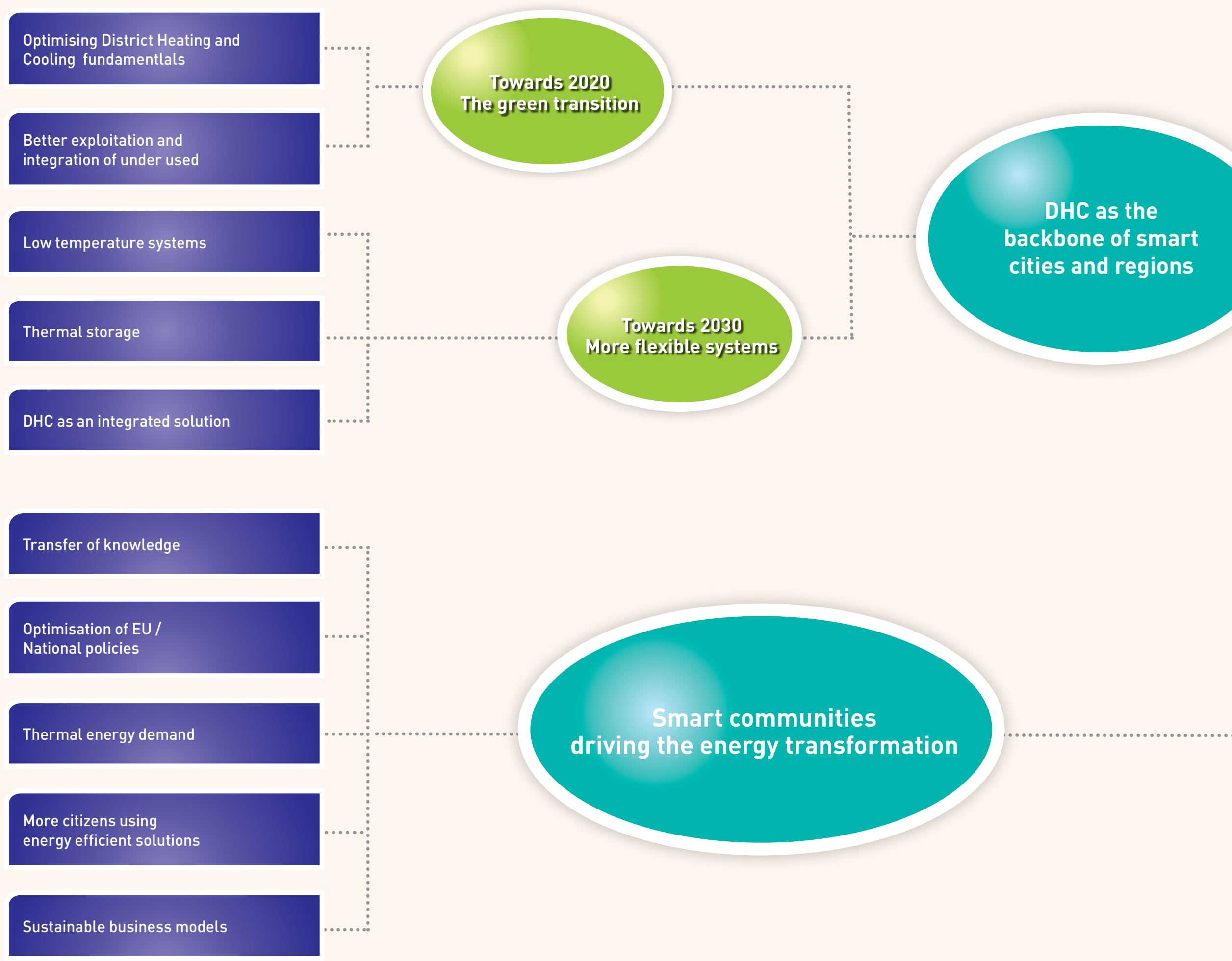
Executive summary

To achieve its objective of almost **zero carbon energy solutions by 2050**, the EU needs to accelerate the development of and focus research efforts on integrated, flexible, highly efficient and environmental friendly solutions. As outlined in the document "A vision towards 2020, 2030 and 2050", published by the DHC+ Technology Platform[1], the District Heating and Cooling sector fully shares these goals.

The District Heating and Cooling sector has all the ingredients necessary to play a central role in achieving both 2020 and longer term EU objectives. District Heating and Cooling systems represent smart, sustainable and inclusive solutions. Yet, as an interface with many other energy and non-energy processes and with ever-faster changing customer expectations, District Heating and Cooling must continue to

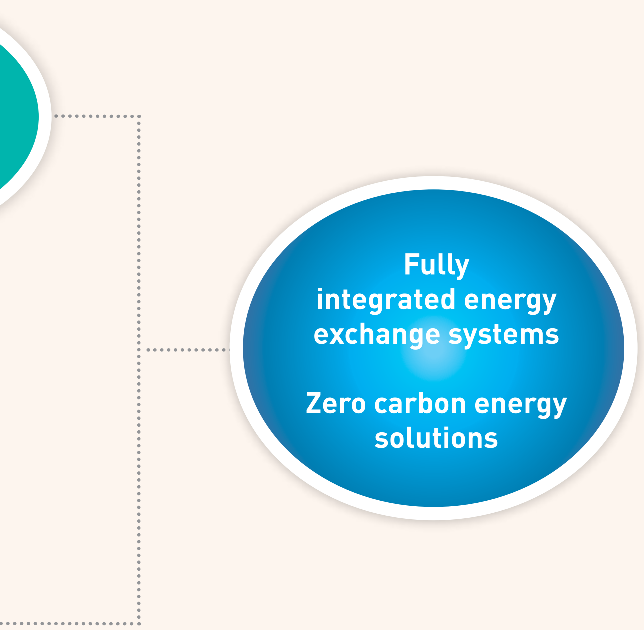
Timeline and priorities of the strategic research topics for the district heating and cooling sector



evolve within the changing context. To enhance the possibilities of District Heating and Cooling to reach its full potential in a future energy landscape, further research, demonstration and technological development are needed.

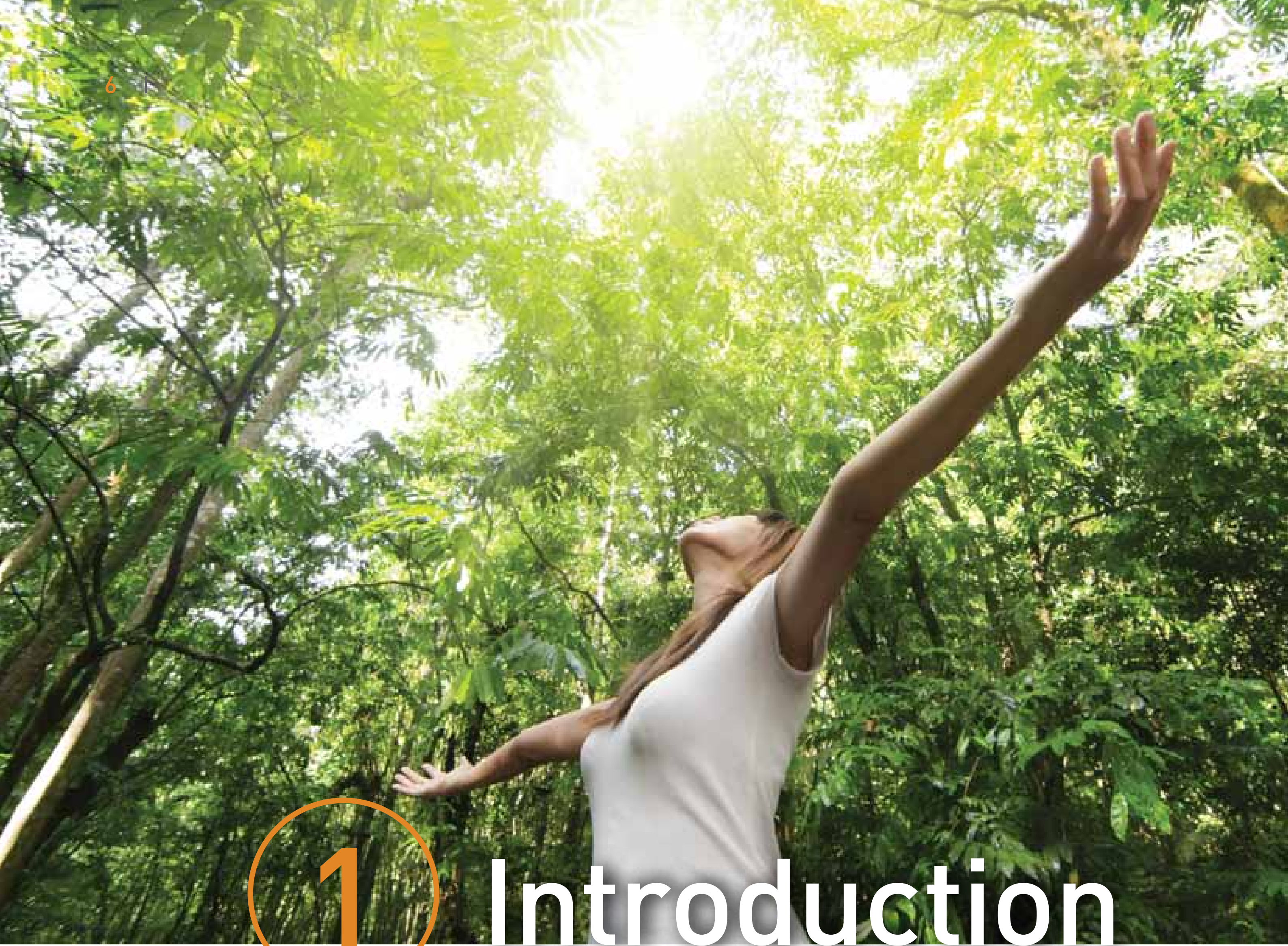
The objective of this document is to support European and national policymakers in defining research and development programmes. It presents the priorities of the District Heating and Cooling sector with a view to support European policies for the next few decades and to realise the Vision.

In line with EU political goals and policies, this Strategic Research Agenda (SRA) distinguishes between **short term**: towards 2020 and **medium term**: towards 2030, while taking into account that any of the developments described must remain sustainable and future-proof also in the **long term**: towards 2050. It takes into account the goals, thematic areas and research issues identified in a European-wide consultation amongst stakeholders and differentiates between **technical** and **socio-economic research topics**.



By 2020, the District Heating and Cooling sector must accelerate the **green transition**. This shall be achieved through **large-scale replication of best practice**: better valorisation of local resources, like renewable (incl. secondary biomass and waste) and surplus energy and by making District Heating and Cooling networks more efficient in relation to the use of new resources. In parallel, systems must evolve to provide even more **flexible solutions**. Important in this respect are the development of low-temperature networks, the integration of innovative thermal storage, and the interaction with other energy networks (electricity and gas). To enable significant expansion, **cost-effectiveness** must be enhanced by transitioning from handicraft to more industrialised solutions. Transfer of know-how and optimisation of policies are essential for facilitating market penetration.

Through these developments, District Heating and Cooling networks will function as the **backbone of smart cities by 2030**. The energy transformation relies on the involvement of communities. In order to give communities the possibility to choose the best energy mix, customers must be provided with the right tools and equipment. The District Heating and Cooling sector aims to **support communities** in their efforts to use energy more efficiently. Therefore, the sector needs to understand and anticipate energy demand developments in both the longer and shortest (from hour to hour) term. Furthermore, a wider range of sustainable applications should be developed in order to enable customers to meet thermal demands by thermally driven appliances and thereby replace more primary energy intense electricity production. These solutions must be tailor-made to suit customers' profiles and applicable to different scales from city wide networks to smaller neighbourhood solutions. Equipped with modern, future-proof District Heating and Cooling systems, **smart cities and communities** will be empowered **to optimally exploit the energy transformation** for the benefit of their citizens.



1 Introduction

1.1 Political background

The DHC+ Technology Platform published "**A Vision Towards 2020 - 2030 - 2050**", setting out in global terms how the District Heating and Cooling sector can participate to the EU energy objectives and how European District Heating and Cooling stakeholders see the future development of the sector up to 2050. The Vision represents the main basis for the present Strategic Research Agenda for District Heating and Cooling.

"The SRA is based on the DHC+ Vision and follows the EU ambitions for 2020 and beyond"

The District Heating and Cooling sector fully embraces the new growth strategy developed by the Commission for the coming decade, called **Europe 2020**, which was developed to ensure high competitiveness of the European market. It shares the principles of being sustainable, smart and inclusive that the District Heating and Cooling sector has been working towards for several decades.

By 2020, Europe committed itself to cutting greenhouse gas emissions by 20 %, producing 20 % of its energy from renewable sources and increasing energy efficiency by 20 %. In this context it should be noted that thermal energy plays the most important role in the European energy demand. Heating represents the largest energy end-use in Europe, being responsible for approximately 50 % of total final energy consumption. Cooling is critical for the correct functioning of computers and manufacturing equipment, and vital for industrial processes. Today, 40 % of commercial and institutional buildings in Europe have cooling systems and demand is set to grow substantially.

Today heating demands are mainly covered by fossil fuels, cooling demands by individual electric chillers. The high share of fossil fuels in the European heating market creates problems in terms of high import rates, lower security of supply, high carbon dioxide emissions and increasing heating costs. District Heating and Cooling provides a key infrastructure to remedy these problems by enabling the collection of recycled and renewable energy from distributed resources and thus the replacement of fossil fuels for heating. Therefore, and as recently confirmed in the following EU documents and legislative initiatives, the expansion of District Heating and Cooling is expected to play an important role in reaching the **2020 goals**:

- The **Energy Infrastructure Communication** recognizes that *"Thermal power generation often leads to conversion losses while at the same time natural resources are consumed nearby to produce heating or cooling in separate systems. This is both inefficient and costly. Similarly, natural sources, such as sea- or groundwater, are seldom used for cooling despite the cost savings involved. The development and modernization of District Heating and Cooling networks should therefore be promoted as a matter of priority in all larger agglomerations where local or regional conditions can justify it in terms of, notably heating or cooling needs, existing or planned infrastructures and generation mix etc."*[2]

- The proposal for a **Directive on Energy Efficiency** sees District Heating and Cooling as key elements in the *"promotion of efficiency in heating and cooling"* (chap. III, art. 10).[3]

- The **Energy Efficiency Action Plan** specifies that the *"Commission will therefore propose that, where there is a sufficient potential demand, for example where there is an appropriate concentration of buildings or industry nearby, authorisation for new thermal power generation should be conditional on its being combined with systems allowing the heat to be used"*. The related impact assessment specifies that District Heating and Cooling is *"particularly well placed to use the residual heat produced in industrial sources"* and *"could produce significant primary energy savings, and is a proven and cost-effective way to increase the comfort of EU citizens at a low cost"*.[4]

- **The Strategic Energy Technology (SET) Plan** sets out a medium-term strategy valid across different sectors. The **Smart Cities Initiative** *"will support cities and regions [...] to progress by 2020 towards a 40% reduction of greenhouse gas emissions through sustainable use and production of energy"*. District Heating and Cooling solutions fit perfectly with this objective.

- This trend is continued in the longer term, as reflected in the **Roadmap for moving to a low-carbon economy in 2050**[5] and the **Energy Roadmap 2050** developed by the European Commission, which both specifically refer to District Heating and Cooling systems as low carbon solutions and acknowledge that a *"cost-optimal policy choice between insulating buildings and systematically using waste-heat"* needs to be found.

1.2 Technical background

District Heating and Cooling systems increase the overall efficiency of the energy system by recycling heat losses from a variety of energy conversion processes. Heat which otherwise would be lost is recovered and commercially delivered 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, variable heating and cooling demands, District Heating and District Cooling provide the key to wide scale primary energy and carbon emission reductions in whole communities.

In terms of technology development, it is considered that **District Heating** is in its third generation.

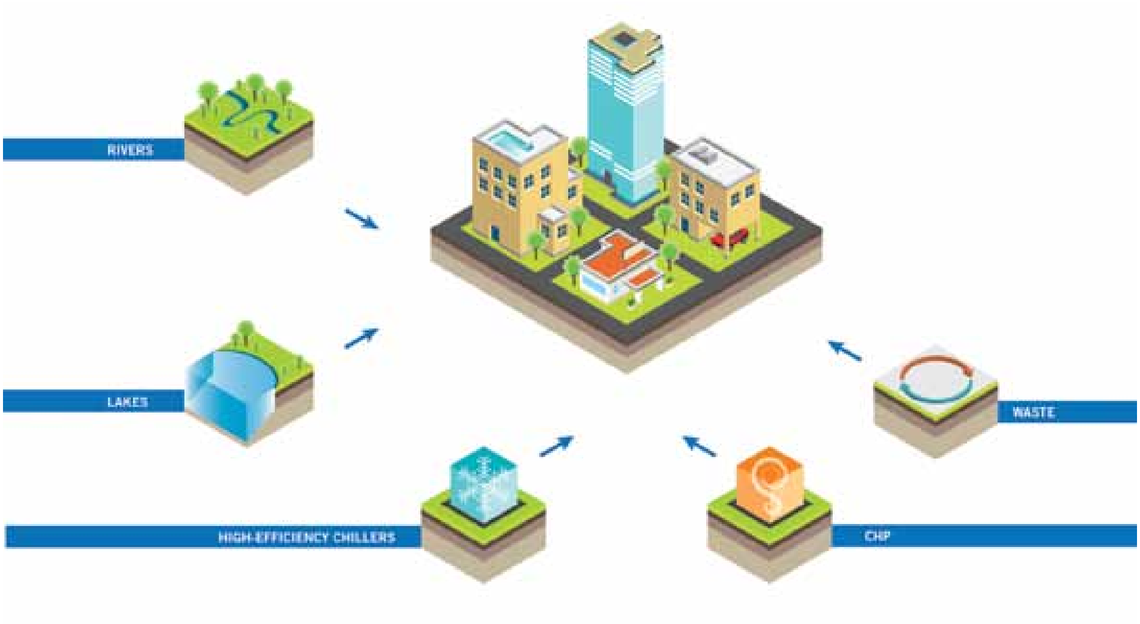
"4th generation means lower and/or more flexible temperatures, assembly oriented components and flexible materials"

The **first generation** of District Heating systems used steam as a heat carrier. These systems were first introduced in the USA in the 1880s. Almost all District Heating systems established until 1930 used this technology, both in the USA and Europe. The **second generation** of systems used pressurised hot water as a heat carrier, with temperatures mostly over 100°C. These systems emerged in the 1930s and dominated all new systems until the 1970s. The **third generation** of systems was introduced in the 1970s and took a major share of all extensions in the 1980s. Pressurised water is still the heat carrier, but the supply temperatures are often below 100°C.

The development directions during these three generations have been lower distribution temperatures, material lean components, and prefabrication giving lower manpower involvement at construction sites. Following these directions, a future **fourth generation** of District Heating technology should be based on **lower respectively more flexible distribution temperatures**, **assembly oriented components**, and more **flexible materials**. The final result will be a more environmentally friendly, customer-oriented solution.

District Cooling is an environmentally optimized cooling solution, using local, natural resources or absorption chillers using heat to produce cooling. As with District Heating, the customer is connected to the cooling production via a pipe network. Chilled water is distributed to the buildings where it loses its cold content, thus cooling down the building temperature.

District cooling can combine different cooling sources



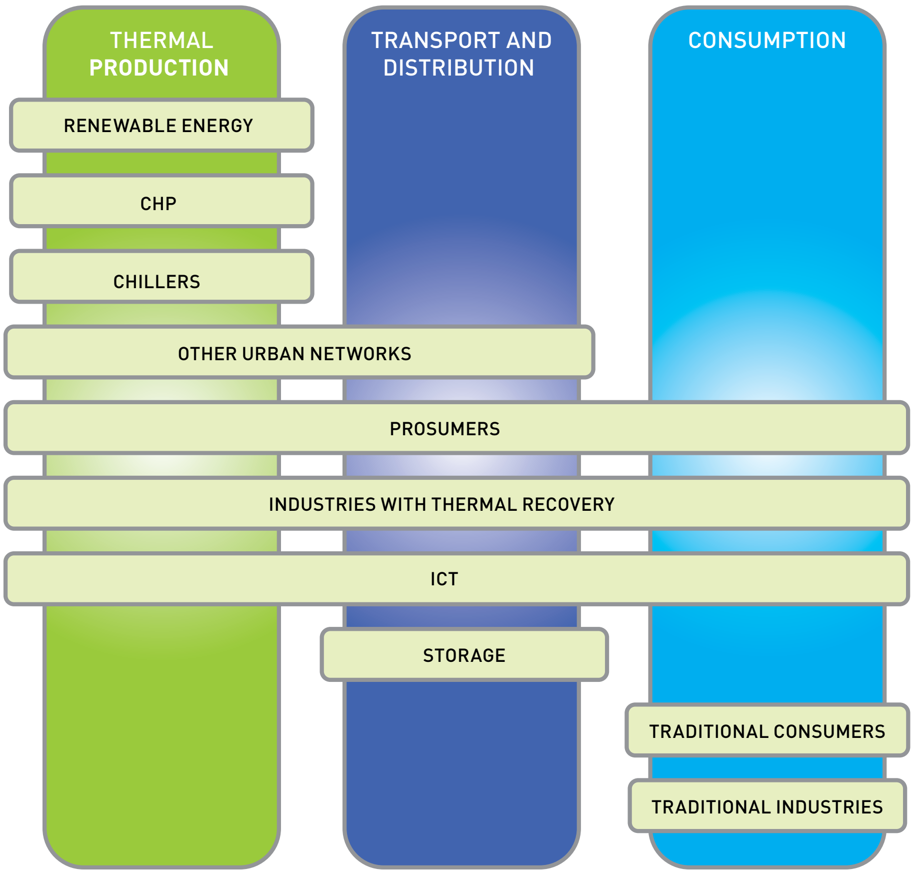
1.3 Nature of research priorities

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

For these reasons, the District Heating and Cooling industry constantly works in close relation with other stakeholders, like the renewable industry (solar, geothermal, biomass, incl. waste), building owners, operators and users, industrial facilities and the service sector, but also with urban planners and local authorities.
While parameter changes in any of the related sectors may pose challenges in terms of technical and operational adaptations in District Heating and Cooling 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.
As a consequence not only a wide range of technical issues (chapter 2), but also of socio-economic issues (chapter 3) need to be addressed.

"The cross-cutting nature of District Heating and Cooling involves a wide range of both technical and socio-economic research issues"

By its horizontal nature, DHC involves a large range of topics and stakeholders



SRA context and selected research and development topics

1.4 Time dimension

The cross-cutting nature of District Heating and Cooling also impacts on the time dimensions in research. On the one hand, changes in any of the aforementioned sectors, be they progressive or interruptive, require a highly adaptive and proactive approach based on contextual developments. On the other hand, as District Heating and Cooling systems are capital-intense, long term investments, it is important to highlight that all topics mentioned in this document need immediate attention.

However, to reflect the anticipated evolution of the energy system as depicted in various energy roadmaps, the **technical research priorities** have been categorized as:

- Short term demonstration projects for achieving 2020 EU energy and climate goals
- Preparation projects for achieving results in the medium term - 2030, while being future-proof for 2050 EU energy and climate goals

For the **socio-economic research 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 at regular intervals in order to cross-check against real developments. Similarly, business models need to evolve in line with new technical developments.)

1.5 Ranking of research priorities

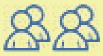
EU policies need to be supported by industries which propose competitive and environmental friendly solutions, for the benefit of the customers. The District Heating and Cooling sector is one of them. To reflect the three objectives, the research priorities have been weighted by their respective benefits.

 Impact on the environment;

 Impact on the citizens (social impact and benefit for the customers);

 Impact on the economy (local jobs, improved local spending, improved import-export balance, etc).

The following ranking is used:

Impact on...	*Good*	*Significant*	*Optimal*
Environment			
Social / customer			
Economy			

2 District Heating and Cooling as the Backbone of Smart Cities and Regions:

Technical research priorities

2.1 Towards 2020 The green transition

Already today, the District Heating and Cooling sector is a green industry. On average, 86 % of heat for District Heating in Europe derives from a combination of recycled and renewable heat. Many European communities demonstrate that District Heating and Cooling is a viable short term solution for a quick transition from fossil fuels to a combination of more efficient, renewable and competitive energy supplies[6]. Yet, there is room for further improvement, and in particular for expansion. With a 10 % market share, the potential is far from being achieved. European studies[7] have shown that by doubling and further improving District Heating and Cooling, it will be possible:

- to reach an average share of at least 25 % of renewable energies in District Heating;
- to decrease primary energy consumption with 2.14 EJ (51.1 Mtoe) per year, corresponding to 2.6 % of Europe's entire annual primary energy demand;
- to avoid an additional 400 million tons of CO_2 (corresponding to 9.3 % of all European CO_2 emissions).

As District Heating and Cooling development varies largely between EU Member States, studies distinguish between consolidation, expansion, modernization and emerging countries, with each of these categories having particular research possibilities and needs. Also, the transition to zero carbon energy solutions poses different challenges in countries where 2nd generation District Heating is still predominant than in countries with advanced 3rd generation systems or only very few existing systems. These aspects need to be taken into account when formulating new energy targets and/or research and development programmes.

2.1.1 *Optimising District Heating and Cooling fundamentals*

Due to the central role it will play in the development of Smart Cities and Communities, the District Heating and Cooling sector should evolve and improve itself in all parts, from thermal source production to consumption, including customer relations.

The higher the future market share, the more important it is for the sector to ensure that the energy is efficiently transformed, transported and delivered, with as low losses as possible. This will avoid oversized plants and reduce primary energy used. Thereby the competitiveness of District Heating and Cooling will be improved. Lower investment and operation costs will in the end benefit the citizens through a decrease in heat price and costs.

Many existing systems were first put into use several decades ago and now have old and aging parts with outdated technology which must be upgraded. Through the implementation of new technologies and/or through refurbishment of the existing systems, the District Heating and Cooling sector will continue to reduce its carbon footprint.

The European District Heating and Cooling industry is highly developed in operation and surveillance, but is still a handicraft industry in the expansion phase when it comes to the use of construction resources. Therefore, the District Heating and Cooling industry needs a higher degree of standardisation of working methods and system parts. Standardisation will allow the industry to lower its costs and to manufacture safer and more environmental friendly equipment for the benefit of the end-user.

Thermal production: Investor decisions are based on economic considerations. In the electricity sector, environmentally-friendly solutions such as cogeneration compete with condensing power plants. Large-scale cogeneration plants require relatively higher investments. Hence it is important to improve the electricity yield of such plants.

T.1 Cheaper high efficient CHP plants (in particular biomass and biogas)

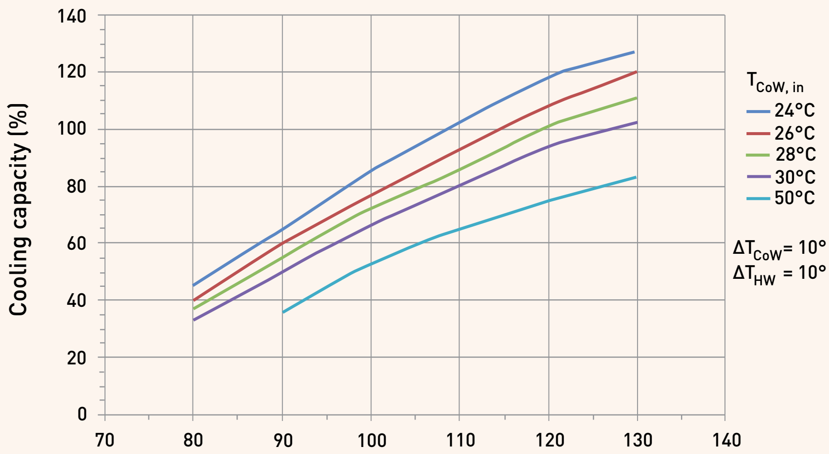
Objective: Minimise primary energy use for simultaneous power and heat production, improve return on investment / competitiveness as compared to condensing power plants.

Research priorities: Cheaper and more efficient CHP plants (improved power-to-heat ratio), enhanced heat recovery including through applications enhancing the summer load, flexible operation schemes, improved corrosion resistance.

< 2020

"DHC development varies largely between countries, thus having particular research possibilities and needs"

Sensitivity of absorption chiller to the inlet temperature



Hot water inlet temperature (C°)

Also for cooling, a more efficient and more flexible production is needed. As an example, the scheme below shows the sensitivity of an absorption chiller to the inlet temperature. For a temperature variation of 20°C, the efficiency of the chiller drops off 30%. The penetration on the market of cooling machines for District Cooling is low, resulting in small return on experience. As a direct consequence, the reliability of the machines is not optimal and must be improved.

Furthermore, demonstration and replication projects of both free cooling and hybrid cooling systems are needed in order to accelerate market penetration and prevent the undesirable growth of less efficient conventional solutions in the current dramatic growth of demand.

T.2 Improved cooling generation technologies and enhanced use of free cooling

Objective: More efficient and more flexible cooling generation technologies.

Research priorities: Improved chillers and heat pumps, free cooling demonstration projects, hybrid cooling demonstration projects.

< 2020

Transport, distribution and storage: In order to be as efficient as possible, the District Heating and Cooling sector must even further decrease thermal losses in transport and distribution. The connection of low-energy houses requires heat transport in smaller pipes which with current pipe technology would lead to proportionally higher heat losses. Constant improvement of pipe technology in accordance with contextual developments is a must.

Construction and/or maintenance of the networks usually give a bad image of the District Heating and Cooling sector to the population due to the disruptive work it implies. Future energy systems should be easy and quick to install, with as little inconvenience as possible for the population. The development of non-invasive solutions for the construction and maintenance of District Heating and Cooling networks, like improving trench-less technology, narrow trenches for DH, etc., should be stimulated. Also, the impact on the environment of these works must be reduced. The reduction of land space and refilling of trenches with recycled material responds to this need.

Today pipes are produced with a substantial degree of handicraft. For instance the production of bends is done separately according to every customers wish. In the same way, the use of distances and alarm threads is done by hand. The development of plug-and-play pipe systems could help to decrease the construction/maintenance time.

T.3 Reduction of thermal losses

Objective: To avoid oversized heat plants by increasing the efficiency of the networks. To adjust to energy demand developments by means of lower/flexible temperature levels, transport of low temperature (heat or cooling) over longer distances.

Research priorities: Better insulation solutions and/or material for thermal transport, improved joints, cost-effective methods for leakage detection and reduction.

< 2020

T.4 Less invasive works

Objective: Reduce impact of network construction and maintenance on urban life, reduce costs

Research priorities: Less invasive and cheaper solutions to build / maintain the networks, i.e. plug-and-play trench-less solutions.

< 2020

T.5 Integrated and standardised pipe solutions

Objective: Standardise the fabrication and the assembling of pipes to obtain safer and cheaper networks, using less handicraft.

Research priorities: Development of integrated and standardised pipe solutions.

< 2020

Customers are in the center of the cities-citizen-energy relation. To fully achieve the energy system transformation needed to reduce carbon emissions to almost zero, the consumer's role needs to be better taken into account. Any 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 taking responsibility for their energy use. The development of smart meters and controls will allow the systems to adapt even faster to the consumers' demand but also to inform the consumers about their consumption.

A number of white goods use electricity to produce thermal energy (heat or cooling). If the building is connected to the local thermal district energy network, it would be much more efficient and more environmental friendly to directly use thermal energy delivered by the network. Thermal district energy can provide thermal energy to a wide variety of in-house appliances that are actually producing heating or cooling with electricity. Studies show[8] that a saving of 62% of power can be achieved by using District Heating in a washing machine.

Like pipes, substations are mainly handicraft made. Standardisation should make it possible for manufacturers to have an industrial production in series with low handicraft parts, which is a necessary precondition for creating smarter, safer, more environmental friendly and cheaper substations for the European market.

Nowadays, the substations, namely the heat exchangers, are designed for temperatures above 70°C. With the introduction of low energy houses connected to low temperature District Heating (below 70°C), lower temperature makes the actual heat exchanger less efficient. With the development of highly efficient heat exchangers, heat costs for the customer will be reduced.

T.6 Develop and roll-out District Heating and Cooling driven white goods

Objective: Save primary energy by developing white goods able to use thermal energy directly from the district energy networks, instead of generating thermal energy from electricity. Reduce costs for these white goods by bringing them from demonstration to mass production.

Research priorities: Demonstration projects to show the feasibility of using in-house appliances which directly use thermal energy from the thermal district energy system.

< 2020

T.7 Improved, highly-efficient substations (for both today's and future lower/flexible temperature networks)

Objective: Enhance easy replication, reduce costs for substations and improve their eco-efficiency to adapt to new energy demand developments: smarter, softer, cheaper.

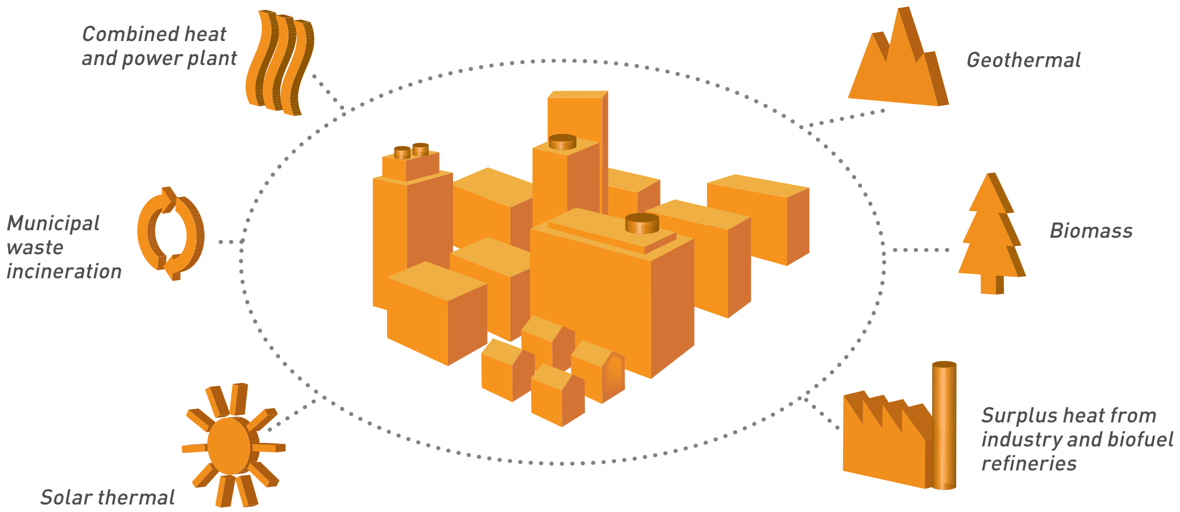
Research priorities: Harmonisation of requirements for substations, cheaper materials, more industrialised manufacturing methods, high-efficiency at temperatures below 70° C.

< 2020

2.1.2 *Better exploitation and integration of underused energy sources*

In cities, or nearby, a wide range of energy sources are available for heating, due to their location (renewable energies) and business activities (industry, agricultural waste) or in connection with essential urban functions (sewage, municipal waste). Although today these sources are underused, it is in the interest of the District Heating industry, but also of the local community, to exploit these resources as much as possible.

In addition to the valorisation of municipal waste, District Heating and Cooling offers a vast range of possibilities to valorise residual forest, agricultural and industrial waste as well as sewage through energy recovery which need to be considered from the planning phase. Demonstration projects showing the feasibility (and the necessity) of optimised waste management (including the final conversion of waste into thermal energy) are essential for future smart cities. These projects must also include a part on public acceptance of such solutions.



Waste-to-energy: After material recycling and composting, incineration of remaining waste is the main measure for waste destruction. Use of heat recovery in waste incineration plants combines the service for waste destruction with heat supply. Waste incineration plants often function as base suppliers of heat due to the negative operational costs of receiving the waste.

Due to the ban on landfill of both combustible and organic waste in EU countries, there has been an increase in waste incineration. In the countries were the waste incineration industry is well developed, the focus should be to use heat recovery in all waste incineration plants. In countries where waste incineration is still underdeveloped more waste incineration capacity is needed for reducing the landfill deposits.

T.8 Development of new waste-to-energy chains

Objective: To ensure that the continued transition from landfills to waste incineration integrates the use of waste as fuel for heating and cooling.

Research priorities: Establish waste-to-energy chains in communities switching from landfills to waste incineration.

< 2030

"Nothing needs to be wasted - we can always at least recover the energy"

T.9 Implementation of optimised waste management

Objective: Optimisation of waste management and energy recovery from creation (reduce amounts) to valorisation (boost recovery) at all levels: building, city, region.

Research priorities: Research and demonstration projects showing the feasibility (and the necessity) of optimised waste management (including the recovery of heat from waste incineration).

< 2020

"Renewables are decarbonising DHC - but full integration requires further research"

"Many communities have not yet discovered their potential to use surplus heat to replace fossil fuels"

Surplus heat from industry: Most industrial sites emit large amounts of surplus thermal energy which makes thermal energy recovery possible from a number of production processes as well as from supporting processes. This surplus thermal energy can be used in processes nearby or constitutes a potential source for District Heating. Replacing the direct use of fossil fuels contributes to reducing the bill for the end user and reducing local pollution for the community.

Plausible collaborations vary widely between different regions, between District Heating and Cooling grids and depending on which type of industry the collaboration involves. In order to promote and support District Heating and Cooling collaborations between industries and utilities, it is important to identify factors which promote and inhibit the collaborations.

Newer technologies must be designed based on an optimal use of heat recovery. At present, it is not always possible to recover the thermal energy in an efficient way. New developments must be made in this sense, allowing the District Heating and Cooling sector to capture and upgrade all available surplus thermal energy. The thermal energy delivered by the industry varies considerably, in terms of temperature levels, flow, quality and other factors. Currently District Heating and Cooling systems often work with homogeneous input. The connection to different types of industries, i.e. of thermal energy, requires an adaptation of the networks to the new circumstances. Further research activities are needed in order to allow District Heating and Cooling networks to efficiently integrate all type of surplus thermal energy, without jeopardising the quality of the service provided to the consumers.

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 renewable energies. District Heating and Cooling offer the possibility to use renewable sources which otherwise would be difficult to use, such as geothermal heat, secondary biomass, algae, heat from sewage, free cooling etc. For example, the use of natural cold resources in District Cooling systems reduces the primary energy supply and the corresponding carbon dioxide emissions substantially compared to individual cooling using electrical chillers.

The quality of the thermal energy delivered by different renewable sources differs widely in terms of temperature, flow, seasonal fluctuations, etc. Furthermore, the temperature levels and technological set-up of many existing systems pose limitations to the variety of renewables which can be cost-effectively integrated today (i.e. solar thermal in high-temperature systems). In order to overcome these limitations, further research is required.

The District Heating and Cooling sector works hand in hand with the European Renewable Research Community to perform joint research projects in order to increase the use of renewable thermal energy in European District Heating and Cooling systems.

T.10 Integration of various thermal energy sources in District Heating and Cooling systems

Objective: To use all available surplus and renewable thermal energy in the District Heating and Cooling systems despite differences in thermal energy quality and quantity within the industries and within the renewable energy sources.

Research priorities: Demonstration projects with integration of multiple types of surplus and/or renewable thermal energy in District Heating and Cooling; versatile District Heating and Cooling networks configurations and innovative system operation technology; innovative network connections / substations / heat exchangers, enhanced compatibility of network and user installations.

< 2020

2.2 Towards 2030 Flexible heat systems

The current district heat supplies and distribution networks are appropriate for the current level of heat demands, but with transition to more renewable sources and considerably lower final heat demands, the basic District Heating technology must be enhanced in order to maximise the benefits of these developments. A key change that will be brought in the future by an improved 4th generation of distribution technology is lower and/or more flexible temperatures in the distribution networks. This key change will deliver both lower distribution heat losses and higher utilisation of available renewable resources such as solar, biomass and geothermal energy. With the 4th generation of District Heating technology renewable energies will become more competitive compared to the current 3rd generation of networks.

4^{th} generation networks can be introduced in district heated areas with new buildings having lower heat demands and suitable heating

> **"Low temperature DH systems are essential to integrate low energy buildings and renewable energy sources"**

systems (e.g. floor heating). During a transition period, the District Heating systems will consist of a mixture of the 3rd and 4th generation technologies. When all other existing buildings have been refurbished to also have lower heat demands and handle the lower supply temperatures, the penetration of the 4th generation technology will reach 100%.

However, the availability of renewable energy sources is characterised by its variation in time. The heat should be produced when the sources are available, immediately consumed and/or stored to be used later on, when needed. Additionally the convertibility (e.g. heat pumps) and coupling (e.g. cogeneration) between different energy forms should be taken into account to optimize the integration of fluctuating energy resources

As a consequence, District Heating and Cooling is about creating smart cities by crossing system borders through cooperation and interaction within the sector, by integrating District Heating with District Cooling, and with other sectors/networks in the urban environment. This is a strong planning challenge when existing District Heating and Cooling systems are to be expanded/up-graded and new systems to be established.

2.2.1 Low temperature systems

In the future, citizens will need less primary energy for the same comfort. Thanks to the development of low temperature networks, District Heating and Cooling are able to provide the link between suppliers of heat with low primary energy content and the consumers in an efficient and environmental friendly way.

With the connection of an increasing number of low energy houses to 4th generation District Heating, the District Heating and Cooling sector will experience a transition phase during which both an "old" generation of District Heating and a "new" generation of District Heating will be mixed. The District Heating and Cooling networks have to demonstrate their ability to flexibly integrate these new types of buildings. It is expected that this situation will become increasingly prevalent over the next 20 years, when low energy buildings will represent the majority of the building stock. In this context, the preparation of domestic hot water in District Heating and Cooling networks should be given appropriate attention.

T.11 Integration of low temperature systems with existing systems

Objective: To integrate low energy buildings in existing District Heating and Cooling and smooth the transition to 4th generation networks.

Research priorities: Develop systems where 3rd and 4th generation technologies are integrated, and incorporate new and old building stock, demonstration of various types and sizes of low-temperature systems.

< 2020

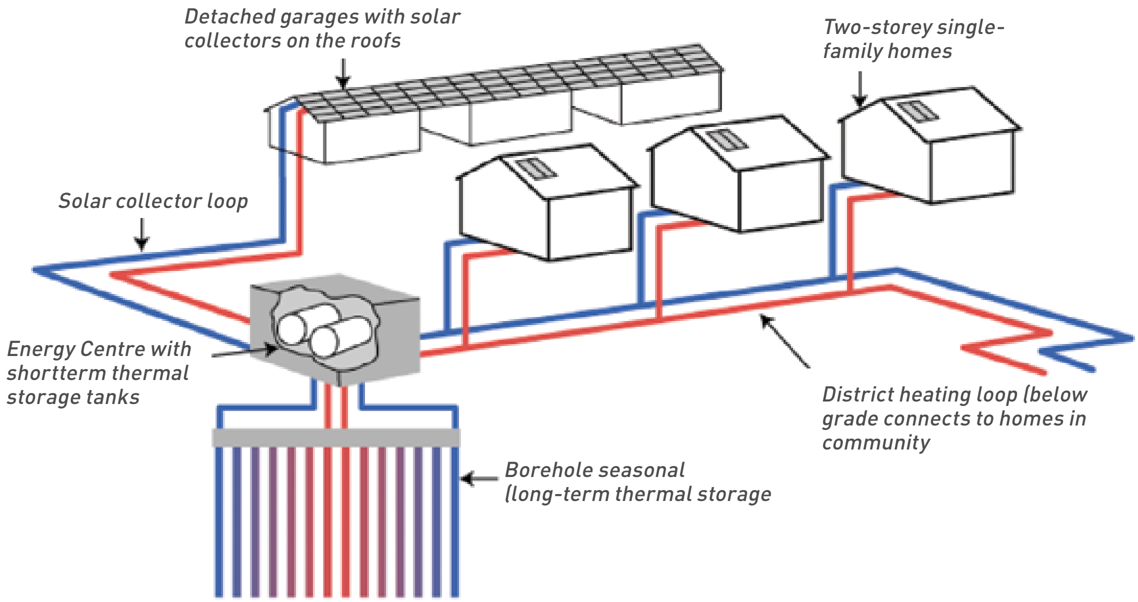
T.12 Develop appropriate solution for domestic hot water preparation

Objective: Develop appropriate solutions for domestic hot water preparation.
To develop customised solutions for the hygienic supply of domestic hot water (DHW) using low supply temperatures that are beneficial for the whole energy system.

Research priorities: Evaluation of different possibilities of DHW preparation (e.g. additional heating or direct heating without storage) considering the local energy systems framework.

< 2020

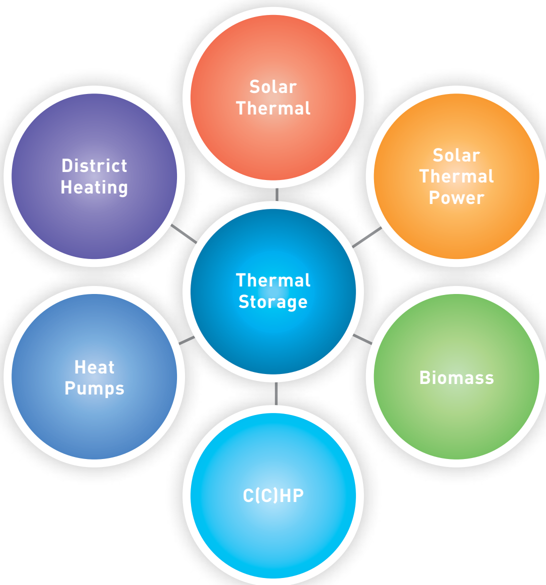
District Heating Schematic of the Drake Landing Solar Community, Alberta, Integrating Thermal Storage



2.2.2 *Thermal storage*

Energy storage is a central component in energy efficient systems. Storage will play a central role in the future energy market with the increase use of fluctuant resources such as wind and solar energy but also with the development of more integrated electrical and thermal networks. To respond to this challenge, thermal storage must be flexible and innovative in order to respond to different types of energy sources and needs.

Thermal energy storage is a central component of efficient energy systems



Aerial view of a district heating system working with solar panels, biomass, heat pumps and a seasonal storage

"With thermal storage solar and wind can reach their potential for supplying energy"

Short term thermal storage is already in use nowadays and is mainly used to cut heating peak hours. Short term storage can also be used to support the electricity grid. For example, in 2010, in Germany, due to network congestion, wind turbines needed to disconnect, resulting in a loss of up to 150 GWh, representing an energy loss increase of 69% compared to 2009 . In this typical case, the thermal network could have stored the electricity in the form of heat in order to use it when needed, allowing it to cut heat peak and making the wind farms more profitable.

In the same way, storage can be used to increase the use of solar thermal energy. Through the development of seasonal storage, it will be possible to store the energy from the sun during the summer period, and to use this thermal energy during winter time. This concept already exists in some places, but more research must be done, namely to reduce the heat losses, to increase economic feasibility especially for large scale applications and to increase awareness.

With the development of District Cooling, thermal storage facilities must be further developed to store heat but also cooling. These storage facilities should be able to be used on a short term and/or seasonal basis.

Innovative approaches to store heat should include the possibility of using heat storage in customer buildings, networks, etc. in addition to the actual central heat accumulators. The final objective is to make the thermal networks as flexible and reactive as possible.

T.13 Using District Heating and Cooling as buffer for excess electricity

Objective: To make use of all produced electricity by utilising the District Heating and Cooling systems.

Research priorities: Elaborate solutions to use District Heating and Cooling systems as short-term storage and/or sinks for excess electricity.

< 2030

T.14 Seasonal storage

Objective: To optimize integration of renewable energy sources and fully exploits the potential energy despite the fluctuation of thermal output.

Research priorities: To improve and develop the seasonal storage solutions for heat and/or cooling from renewable energy sources.

< 2030

T.15 Combined storage for heating and cooling

Objective: Reap synergies of storing heat and cold together.

Research priorities: Develop storage facilities able to store heat and/or cooling (short-term and seasonal storage).

< 2030

T.16 Smart and flexible storage solutions

Objective: New advanced storage technologies that offer smart and flexible solutions are to be developed to supplement the existing ones.

Research priorities: Develop storage solutions based on innovative technologies that can adapt to local conditions.

< 2030

2.2.3 District Heating and Cooling as an integrated solution

The idea behind the integration and the interaction of different facilities is to be able to provide a package of products, services and technologies that function more effectively as a whole than as the individual elements that comprise it. Nowadays, cities are composed of a number of networks – ICT, electricity, heat, cooling, transport, water, etc. – which are developed in parallel, with no real interaction sometimes or even on a competitive basis. However, in order to reach the common goals of decarbonizing the economy and securing the energy supply without negative influence on comfort level and growth, a new approach is needed.

Not only when planning a new area, but also when changing the (local) energy system (e.g. installing new energy generation units or refurbishing buildings), an integrated approach should be applied that allows for the best solutions and allocation of resources where and when they are needed. Planning should be done in order to combine saving businesses.

"Planning facilitates combining savings with businesses"

T.17 Smart tools for urban planners

Objective: Rational decision making and solutions when planning infrastructure in cities, which is currently not the case due to lack of knowledge about system-wide solutions.

Research priorities: Develop tools to help urban planners to evaluate and choose the most cost-efficient and environmentally friendly solutions, assessment of the systemic interrelations within urban energy structures and energy components for achieving integrated solutions for the urban energy supply.

< 2030

T.18 Assessing possibilities for local micro networks

Objective: To assess the possibilities and potentials of installing local micro networks next to larger-scale District Heating and Cooling structures.

Research priorities: To develop methods for evaluating the possibilities and potentials of thermal networks next to existing structures by connecting a few buildings or a neighbourhood with local sources and storage units for optimal efficiency. This should be applied to new development areas, existing buildings and the compound of both.

< 2030

The integration of the networks can take place at different levels: inside the District Heating and Cooling sector itself; and between the thermal networks and the other networks (electricity, ICT, water, etc.). Also, different network scales should be taken into account, in addition to traditional centralized structures, such as the installation of distributed micro-networks and connections to energy sources in surrounding regions which will contribute to achieve an overall optimum.

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

T.19 Better interaction between thermal production, storage, distribution and demand

Objective: Systematic communication between production, storage, distribution and consumption of District Heating and Cooling, through integration of smart ICT leading to increased efficiency of networks.

Research priorities: Development and demonstration of smart interaction and controlling in District Heating and Cooling, assessment, modelling and simulation of the dynamic behaviour of the related components.

< 2030

Thermal networks will increasingly integrate both District Heating and District Cooling. Currently, both networks are often designed and implemented separately. An integrated approach is needed when designing and implementing these networks. The results will be a more efficient service for the customers, lower operation costs and therefore lower thermal prices.

T.20 Integrated planning and management of District Heating with District Cooling

Objective: Combined planning of heating and cooling systems to future-proof infrastructure, and lower construction and planning costs.

Research priorities: Demonstration projects combining District Heating and Cooling in a single infrastructure development.

< 2030

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 electric 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 electric supply comes from intermittent power sources such as wind and solar power.

The composition of the building stock will have an important impact on the energy systems. More and more buildings will have the capacity to produce and store energy, both electrical (e.g. via e-mobility) 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 prosumers and consumers (buildings, industries, etc) must be further studied. This solution will allow transporting energy in smaller distance, reducing losses and making the overall energy system more efficient.

T.21 Improved interaction with and between prosumers and consumers

Objective: Better connectivity between net consumers and prosumers to ensure optimal exploitation of energy.

Research priorities: Research how to create and develop feasible links between thermal energy-contributing and consuming buildings/industries.

< 2030

T.22 Integrated energy networks to couple local supply with various energy demands

Objective: To achieve self-sufficient communities by coupling local energy sources (electricity, heat, cold, etc.) with the various energy demands.

Research priorities: Develop systems where District Heating and Cooling is used as infrastructure to provide effective exchange and redistribution of energy.

< 2030

3 Smart communities driving the energy transformation:

Socio-economic research priorities

3.1 Transfer of knowledge

> **"Thermal energy is a local matter - but available knowledge could easily be transferred within and between countries in the EU"**

Transfer of knowledge is crucial in the European environment. It is important to foster the synergy between different actions in order to obtain better and faster overall results at lower costs. District Heating and Cooling is a local business, but it is interesting to see that most District Heating and Cooling systems face the same issues and that easy, transferable solutions exist. The transfer of knowledge must be considered on two dimensions: at geographical level, i.e. between each District Heating and Cooling system or between National Associations; and at time level, i.e. between generations. Both dimension can (and should) be interrelated.

To ensure long term sustainability, it is important to teach younger generations about the District Heating and Cooling technologies. Nowadays, there is almost no specific academic formation on District Heating and Cooling. It is the responsibility of the District Heating and Cooling sector to ensure that relevant knowledge is passed on to a new generation of engineers, but also to architects, planners, etc. The new generation should be ready to develop smarter cities presenting integrated solutions. The development of a Master in District Heating and Cooling covering all of these topics is essential to ensure the long term vision of the European energy system.

S.1 Master degree in District Heating and Cooling

Objective: To improve and disseminate the scientific research and knowledge related to District Heating and Cooling.

Research priorities: Develop a master degree in District Heating and Cooling for students and researchers.

When comparing different thermal options, it is difficult for the consumer to make his choice because there are no intelligible tools allowing him/her to easily compare the different technologies. Even between the District Heating and Cooling systems, the comparison is sometimes difficult. The development of easy tools to compare the different thermal technology can represent an added value for the consumers / urban planners when making their choice. In addition, and in particular in countries where the population is less familiar with District Heating and Cooling technology, tools and programmes are required to improve knowledge, acceptance and planning.

S.2 Assessment tools for thermal systems

Objective: To provide customers and urban planners with reliable guidance for choosing thermal energy supply.

Research priorities: Development of consistent and intuitive assessment tools for thermal systems.

S.3 Improved public knowledge and acceptance

Objective: Develop knowledge and acceptance of District Heating and Cooling.

Research priorities: Dissemination/ education campaigns and projects.

3.2 Optimisation of European / National policies

There are many good examples of measures to support accelerated market penetration of smart thermal systems, including District Heating and Cooling, which lead to both economic benefits and reduced climate impacts. But all the measures are not implemented. Further analysis of how to get from potential measures to real implemented measures is necessary. Among other research topics, this will require more research about driving forces and barriers for implementation of District Heating and Cooling measures.

There is a great need to analyse how different policy instruments influence 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.

S.4 Enhance impact of EU and national legislation

Objective: Enhance impact of legislation, promoting the energy solutions that best fit the local circumstances and resources while being environmental friendly and cost-efficient.

Research priorities: Show-case and draw conclusions for future policies from best-practice in local level implementation of national and EU legislation.

S.5 Stimulate and support sustainable thermal systems

Objective: Comprehensive, multi-level country strategies addressing all relevant stakeholders are established.

Research priorities: 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.

3.3 Thermal energy demand

3.3.1 Cooling demand

Cooling is an increasingly popular topic in the energy sector. A cooling demand exists from industries and commercial businesses, which use cooling in their process, and by the citizens, in order to increase their living comfort during hot periods.

However, no reliable statistics are available on the actual overall energy demand for cooling on a European or national level. Building owners or tenants are in most cases not aware of the amounts of energy they use for cooling purposes, nor have an idea of how much money they spend on it. The main reason is that the energy used to run individual chiller systems, which cover approximately 98 % of the cooling demand in Europe, is embedded in the general electricity bill of a building or of the tenant. Generally no (sub-) metering is put in place and therefore no figures are available.

On a local or regional level, decision makers like mayors or city planners are often not aware of the vast amounts of energy used for cooling. As a consequence the negative environmental and economic implications of the rising electrical power demand due to cooling are underestimated.

S.6 Better analysis of cooling demand

Objective: To have an overview of the cooling demand, and raise awareness among consumers and policy makers about the cooling consumption. This will aid the development of efficient cooling solutions.

Research priorities: Develop method and carry out collection of facts and figures for further analysis on cooling demand in Europe.

3.3.2. Heat demand

Over the last few decades, the energy market has drastically changed, opening new horizons for energy consumers. Consumers are more aware of the importance of good energy management, from an 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.

To fit with the evolving demands of costumers, the energy sector must better understand the present and future customer demand levels (population developments, densification of cities vs. low-energy buildings, impact of new demands, own production).

Collection and efficient use of data is essential. More intelligent heat meters together with active data mining routines will allow having valuable information about the customer demands and flaws in customer thermal systems. On the one hand, this information will help the thermal network operator to manage the grid in the most efficient way. On the other hand, the consumer will be better informed about his/her consumption and about the possibilities to decrease his/her energy bills.

S.7 Anticipate the future energy demand

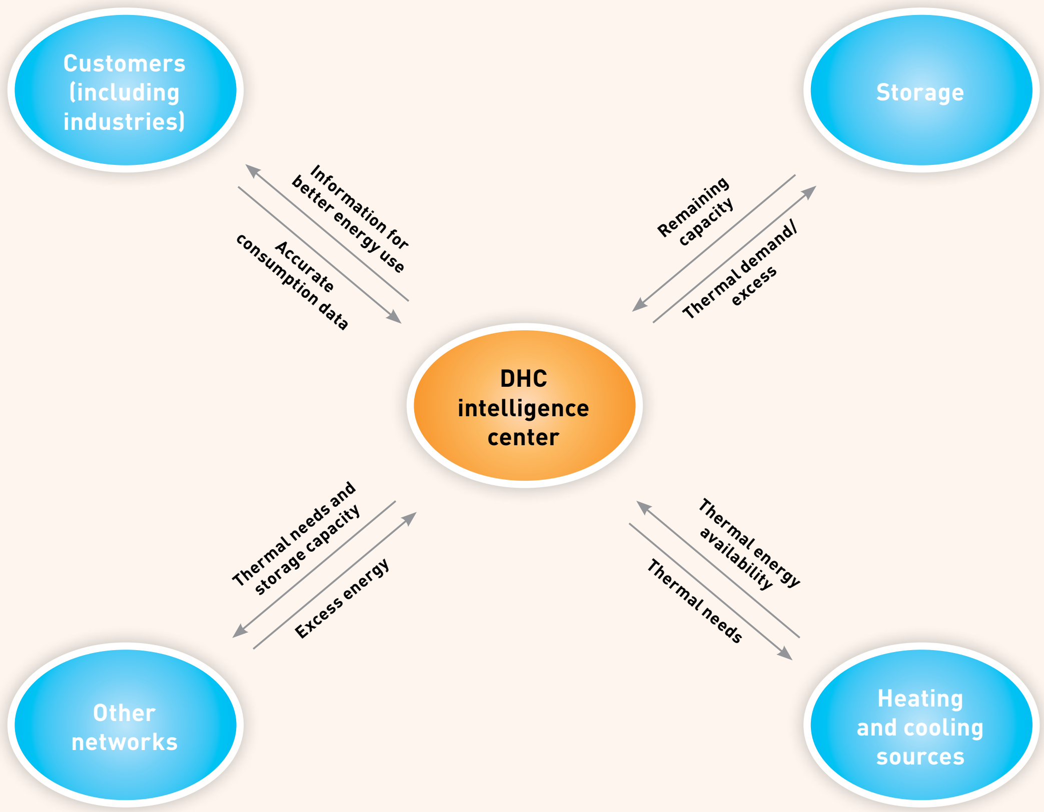
Objective: To fully understand the trends in energy and customer demands in the light of low energy building and rising awareness amongst customers and thus enable future proof energy supply.

Research priorities: Study and modelling the future thermal energy demand trends.

"No reliable statistics are available on the actual overall energy demand for cooling on a European or national level"

"Citizens have the right to choose how and what energy they consume based on relevant and sufficient information "

Information flow in modern DHC systems



Smarter meters will be at the center of the integrated 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 but this information should also serve to communicate with the consumer on his/her consumption and support his/her consumption choice.

Heat meters are now able to gather information more frequently, but the software to analyse these measurement streams in an efficient and cost effective way are not yet available.

S.8 Smart, integrated solutions

Objective: To obtain smart, integrated networks, collecting and interpreting data from different networks (heating, cooling, electricity, waste, water, etc.).

Research priorities: To develop new cross-network equipment allowing efficient collection, analysis and interpretation of collected data, Retrofitting strategies / priorities; City planning; Integrated energy-city-traffic planning.

Load management in customer substations and control units should also be developed in order to lower the customer capacity demands during peak periods. This system capacity interaction can lower the capacity demands for the total heat supply.

S.9 Load management and control units for substations

Objective: To lower the capacity demands for the total heat supply by integrating adapted load management and control units in customer substations.

Research priorities: To develop efficient load management and control units in customer substations.

3.4 More citizens using energy efficient solutions

To reach its 20-20-20 targets, the EU must put an emphasis on the energy efficiency component. Energy efficiency is one of the most cost effective ways to enhance security of energy supply, and to reduce emissions of greenhouse gases and other pollutants. Nonetheless, recent Commission estimates suggest that the EU is on course to achieve only around 9 % of the objective, half of the 20 % target[10].
District Heating and Cooling reduce primary energy demand. When taking into account that 86 % of heat for District Heating derives from a combination of recovered heat, renewable energy and waste resources, it is obvious that the District Heating and Cooling sector can play a major role to reach the 20-20-20 targets set by the EU. District Heating and Cooling represent the most suitable energy solutions for satisfying urban heat and cold demands.

As described in the Vision document[11], District Heating can double its share of the European heat market by 2020 and by the same time District Cooling can grow to satisfy 25% of cooling demands. Despite this huge potential, District Heating and Cooling is not always considered as a 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 European wide study, showing the benefit (or not) to build a District Heating and Cooling network in a city / region, from an economical and environmental point of view, is more than necessary. In this context, the future demand levels are also a very important condition, namely when developing the fourth generation of District Heating systems and smarter heat grids.

Apart from urban environments, energy demands from industry are suitable for District Heating and Cooling. Since the use of District Heating and Cooling in industries usually is low, knowledge of the potential for increased use of District Heating and Cooling in industries is limited. Consequently, the effects on the local district energy system, when the use of District Heating and Cooling in industries increases, have not been extensively studied.

More generally, the study of different demand levels for various customer groups, e.g. industrial, agriculture, residential and service sectors, as well as their interaction is most vital to achieve knowledge about possible future expansion of District Heating and Cooling systems. For example, the use of cascading temperature levels should be a further subject of study.

S.10 Synergies between different customer groups

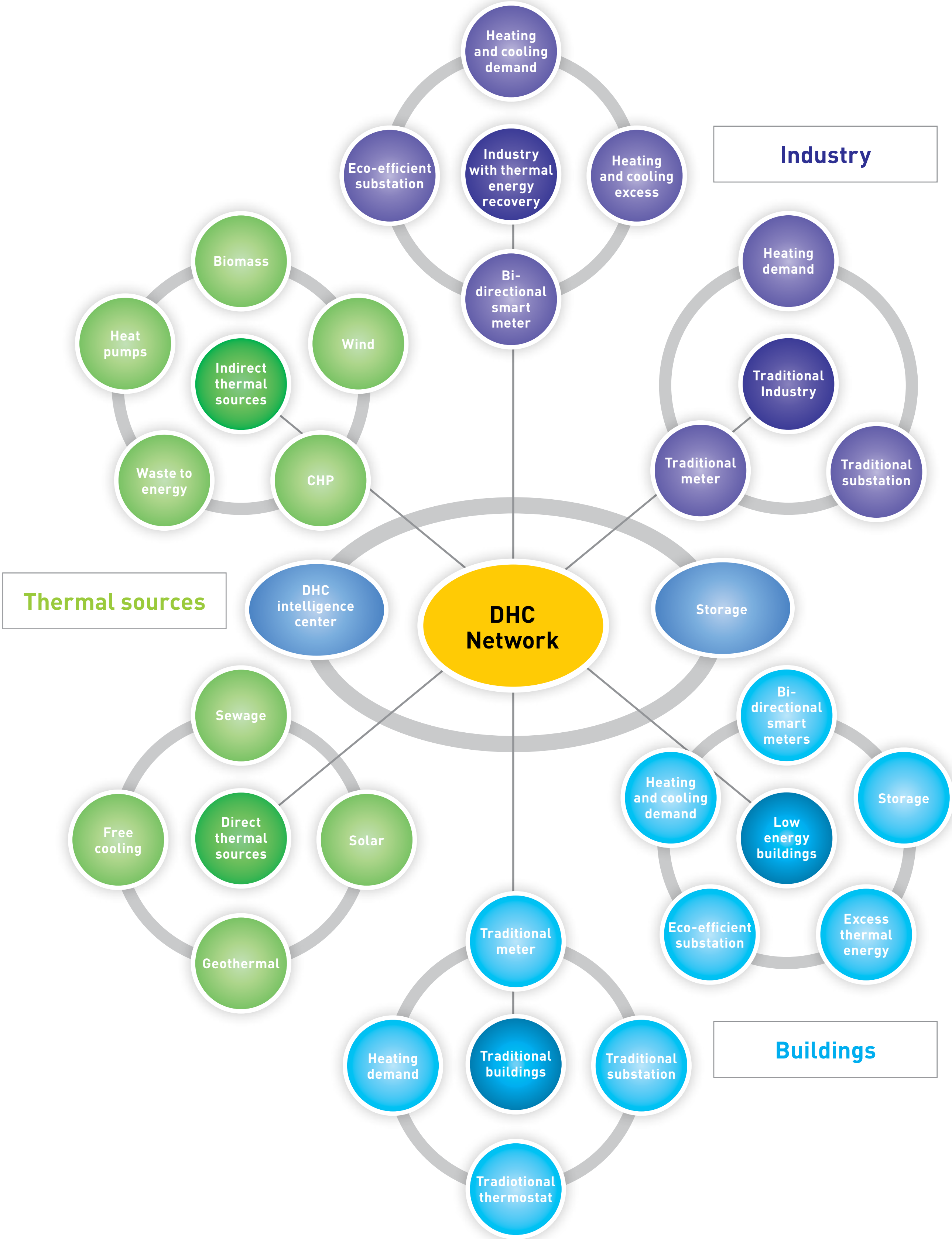
Objective: To be able to explore the possible synergies between various customer groups with different thermal needs.

Research priorities: To obtain knowledge about and showcase innovative and efficient thermal grids integrating multiple thermal energy needs.

3.5 Developing sustainable business models

To fully take part in the energy transformation, an effort must be made at a technical level, but also management level.

Regarding the District Heating and Cooling sector, today's business models are based on an increase in volume, which means an expansion in the District Heating and Cooling grid and consequently also more and more customers. Historically, the District Heating and Cooling business model was to produce, transport and deliver heat. This kind of business model does not take into consideration the new development that the energy market is facing.



Future business context

"Selling less should become a good business"

Nowadays, the District Heating and Cooling sector should not only deliver heat but it has to manage and make more efficient a very complex system, including storage, cooling, bi-directional relations with the costumers, interaction with other grids, etc. Also, whereas the District Heating company used to be a single player (from the thermal production to the consumption), it now has to deal with a multi-player market (prosumers, separation between the thermal production and transport and distribution, several thermal producers using different technologies, etc.).

With the development of low energy houses, it is expected that customers will use less heat. Also, some consumers will produce their own heat and will deliver their surplus to the thermal grids or directly to other buildings. The inclusion of storage in the system will allow for a decrease in peak load. 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 District Heating and Cooling system and the costumers. The final objective is to show that selling less could and should become a good business.

Therefore, more research is needed to design and evaluate new business models that support integration of strategic sustainability thinking in decision making processes in the energy sector, namely in the District Heating and Cooling sector (incentivising energy savings, delivering capacity and flexibility vs. delivering energy, etc.).

S.11 Development of sustainable business models

Objective: Development of flexible and sustainable business models in accordance with technological and societal developments.

Research priorities: Development of business models which allow the District Heating and Cooling sector to anticipate the evolutionary trends in energy demand and supply.

4 Towards 2050

Fully integrated energy exchange systems

With continuous development along the lines described in the previous chapters District Heating and Cooling systems built within the next twenty years are strong allies in the longer term decarbonisation of the energy system as a whole and future-proof in the longer term towards 2050. Together with further ICT developments and further integration with other networks and urban functions (waste management, transport, industry etc.) they will be even more flexible and allow smart communities to become "breathing energy exchange systems" in which the primary energy content of any fuel will be exploited to the maximum, the potentials of natural thermal sources and renewable energy fully reaped and no energy wasted - while ensuring a high quality of life to all citizens.

5 Annex I

Research items summary tables

5.1 Technical research priorities

ID	Research Topic	Scope	Environment	Customers	Economy
T.1	Cheaper high efficient CHP plants	< 2020	🌳🌳🌳	👥	💰💰💰
T.2	Improved cooling generation technologies	< 2020	🌳🌳🌳	👥	💰💰
T.3	Reduction of thermal losses	< 2020	🌳🌳🌳	👥👥	💰💰💰
T.4	Less invasive works	< 2020	🌳	👥👥	💰💰💰
T.5	Integrated and standardised pipe solutions	< 2020	🌳	👥👥	💰💰💰
T.6	Develop and roll-out District Heating driven white goods	< 2020	🌳🌳🌳	👥👥👥	💰💰
T.7	Improved, highly-efficient substations	< 2020	🌳🌳🌳	👥👥	💰💰
T.8	Development of new waste-to-energy chains	< 2030	🌳🌳🌳	👥	💰💰
T.9	Implementation of optimised waste management	< 2020	🌳🌳🌳	👥	💰💰
T.10	Integration of various thermal energy sources in District Heating and Cooling systems cooling demand	< 2020	🌳🌳	👥👥👥	💰💰
T.11	Integration of low temperature systems with existing systems	< 2020	🌳🌳	👥👥	💰
T.12	Develop appropriate solution for domestic hot water preparation	< 2020	🌳	👥👥👥	💰
T.13	Using District Heating and Cooling as a buffer for excess electricity	< 2030	🌳🌳🌳	👥	💰💰💰
T.14	Seasonal storage	< 2030	🌳🌳🌳	👥👥	💰💰
T.15	Combined storage for heating and cooling	< 2030	🌳🌳	👥	💰💰💰

ID	Research Topic	Scope	Environment	Customers	Economy
T.16	Smart and flexible storage solutions	< 2030	🌳🌳	👥👥👥	💰💰💰
T.17	Smart tools for urban planners	< 2030	🌳🌳	👥👥	💰💰
T.18	Assessing possibilities for local micro networks	< 2030	🌳🌳🌳	👥👥	💰💰💰
T.19	Better interaction between thermal production, distribution and demand	< 2030	🌳🌳	👥	💰💰💰
T.20	Integrated planning and management of District Heating with District Cooling	< 2030	🌳	👥👥	💰💰
T.21	Improved interaction with and between prosumers and consumers	< 2030	🌳🌳🌳	👥👥	💰💰
T 22	Integrated energy networks to couple local supply with various energy demand	< 2030	🌳🌳🌳	👥	💰💰💰

5.2 Socio-economic research priorities

ID	Research Topic	Environment	Customers	Economy
S.1	Master degree in District Heating and Cooling	🌳	👥👥	💰💰💰
S.2	Assessment tools for thermal systems	🌳🌳🌳	👥👥👥	💰💰
S.3	Improved public knowledge and acceptance	🌳🌳🌳	👥👥👥	💰💰
S.4	Enhance impact of EU and national legislation	🌳	👥👥	💰💰💰
S.5	Stimulate and support sustainable thermal systems	🌳🌳🌳	👥👥👥	💰💰
S.6	Better analysis of cooling demand	🌳	👥👥👥	💰💰💰
S.7	Anticipate the future energy demand	🌳	👥👥👥	💰💰💰
S.8	Smart, integrated solutions	🌳🌳	👥👥	💰💰
S.9	Load management and control units for substations	🌳🌳	👥👥	💰💰
S.10	Synergies between different customer groups	🌳	👥👥👥	💰💰
S.11	Development of sustainable business models	🌳🌳	👥👥👥	💰💰

Notes

1 www.dhcplus.eu

2 COM (2010) 677

3 COM (2011) 370

4 COM (2011) 109

5 COM (2011) 885/2

6 www.districtenergyaward.org

7 Ecoheatcool, Euroheat & Power 2006; Ecoheat4eu : www.ecoheat4.eu

8 "District heating distribution in areas with low heat demand density", Annex V I I I, 2008:8DHC-08-03, IEA

and www.carbonfootprint.com

9 Abschaltung von Windenergieanlagen um bis zu 69 Prozent gestiegen" - Bundesverband WindEnergie e.V. - 01 November 2011

10 Energy Efficiency Plan 2011, COM(2011) 109 final, European Commission

11 DHC+ Technology Platform, A Vision Towards 2020 - 2030 - 2050, 2009

- **Figure page 17:** Andrej Farazin, Energetika Ljubljana, Selection program of commercial absorption chiller.
- **Figure page 21:** (Top) Natural Resources Canada, Drake Landing Solar Community, Okotoks, Alberta, Canada; (Bottom) Marco Bakker, ECN.
- **Picture page 22:** Solites, Stuttgart, In the framework of the 7FP European Project "SUNSTORE4", the district heating grid in Marstal (DK) demonstrates the integration of a 100% renewable energy plant, based on solar energy and biomass energy (willow wood chips from energy crops), including a compressor heat pump using CO2 as refrigerant and electricity production from biomass through an ORC unit.

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