Integrated SET Plan

CETP

Clean Energy Transition Partnership

Input Paper to the Strategic Research and Innovation Agenda

Heating and Cooling

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1 Introduction of Heating and Cooling

Climate-neutral heating and cooling is essential for ambitious climate and energy targets of the European Union (EU). Heating and cooling accounts for about half of the total end energy demand in Europe. The annual consumption of thermal energy in Europe in 2017 amounted to about 5.600 TWh, against 2.700 TWh of electricity and 4.000 TWh used in the transport sector. However, in the same year only 19,5% of thermal energy was generated from renewable energy sources (RES) (EUROSTAT, 2019). The demand for cooling is limited on a European scale but is expected to increase. There is considerable scope for accelerating the use of RES and excess heat and cold to accelerate the path to a climate neutral energy system; an energy system that should also be fully adaptable to seasonal variations in heating and cooling demand.

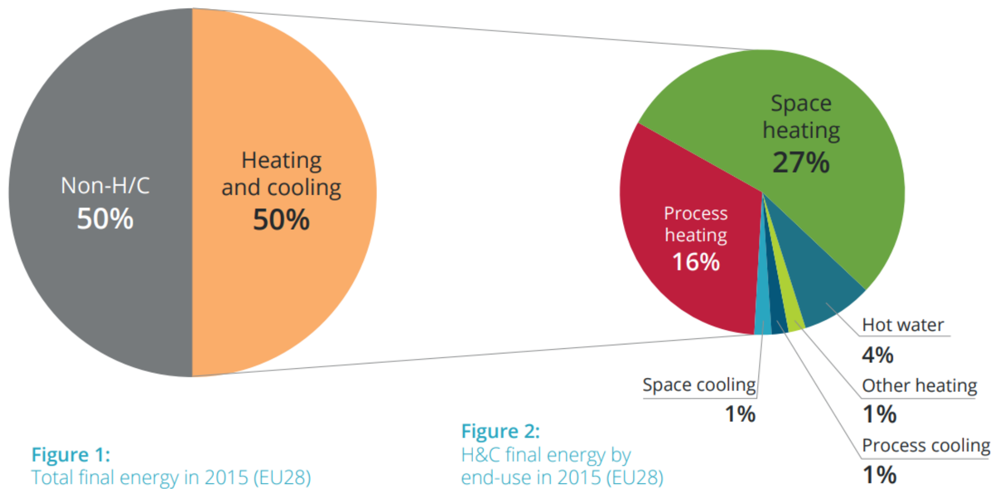

Figure 1: From Heats Roadmap Europe, Heating and Cooling Facts and Figures (2017), downloaded from https://heatroadmap.eu/wp-content/uploads/2019/03/Brochure_Heating-and-Cooling_web.pdf**.**

With the communication "an EU strategy on heating and cooling" (COM (2016) 51 final), in February 2016 the European Commission strongly emphasized the role of H&C in the decarbonisation process. This new attention led to the target of 1,3% annual average increase of RE in H&C, as mandated by the 2018 recast of the Renewable Energy Directive (Directive 2018/2001). The Renewable Energy Directive set the target of 32% RE by 2030; overall, about 40% of this share is projected to come from the H&C sectors.

RES for heating and cooling utilize solar irradiation (solar thermal, concentrated solar), ambient heat and cold, biomass in various technologies, and geothermal energy. Heat pumps and thermal storage technologies are an integral part of RES heating and cooling technologies. Climate-neutral heating and cooling technologies also include the use of excess heat and cold, e.g. from industrial processes and data centers. Heating and cooling demand for industrial processes covers the entire temperature range, with energy intensive industries having a large share of demand at high temperatures, where besides concentrated solar and renewable electricity also renewable fuels may become highly relevant as RES.

Heating and cooling applications usually require low exergy levels (except for some industrial processes), which can be easily matched with low-temperature thermal energy from RES and excess heat (e.g. by using low-temperature heat sources for low-temperature heating in residential and tertiary buildings). This leads to a more efficient energy use, allowing to use high-exergy energy carriers, such as electricity, for applications which need high-quality energy, e.g. mobility or high- temperature industrial demand.

Energy flexibility is crucial at a system level and thermal energy storage (TES), the thermal inertia of buildings, and piping networks can compensate the temporal mismatches between energy demand and source availability; allowing to cover demand on different size scales (building to city level or load profiles of industrial processes) and overcome temporal mismatches on different time scales (hourly to seasonal). Moreover, the benefits of TES go beyond the H&C sectors as such, since through sector coupling it can contribute to balance the electricity grid when high levels of RES are introduced.

Below we introduce an overview of heating & cooling data for households, tertiary and industrial sectors.

Households

Households are considered separately in EU statistics at least since 2007. According to EUROSTAT, in 2018, households accounted for 26.1% of final energy consumption in the European Union (EU), most of which is consumed as thermal energy. More specifically, 63.6% of the final energy consumption in the residential sector was space heating, while 14.8% was devoted to water heating. Space cooling still represents a minor fraction of energy consumption, 0.6%, whilst the rest is used mainly as electricity for lighting and powering most electrical appliances plus cooking.

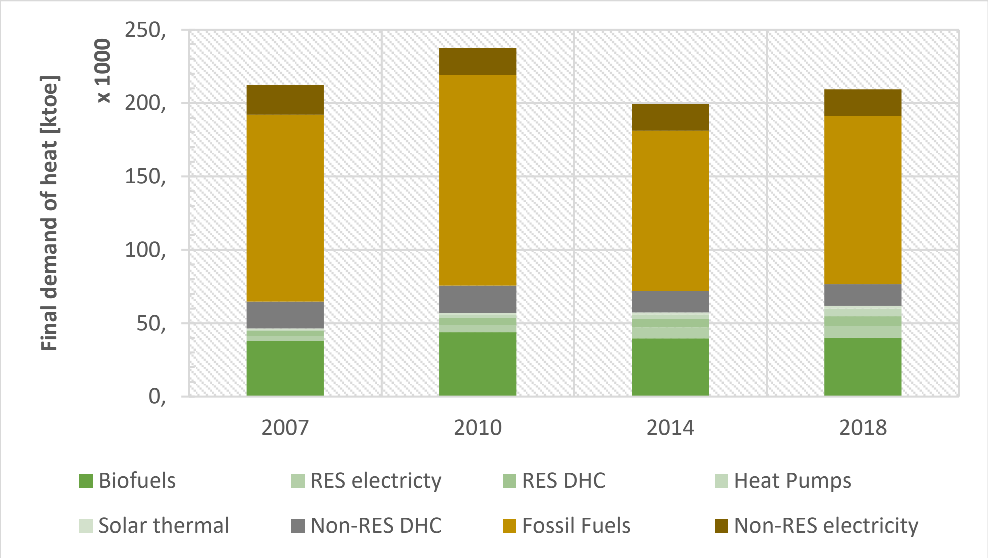

Figure 2: Final Energy Demand of Heating in the Household Sector (derived from Eurostat)

Figure 2 shows the evolution of the final thermal energy consumption in households in the period between 2007 – 2018 and the overall composition of the energy balance. These results were obtained from available data taking into consideration the following assumptions:

1. The fraction of energy for thermal use was calculated from the total final energy demand as an aggregate of the concepts reflected as "space heating", "space cooling" and "cooking". This fraction amounts for approximately 85% of the energy use of households.

2. The energy sources were grouped according to their renewable/non-renewable character. This separation is more complex in the case of heating from derived heat (basically district heating networks) in which the renewable fraction was calculated according the general EUROSTAT "Derived Heat Statistics", in which it is possible to deduce the general energy balance for derived heat in the whole EU. According to this, in 2018 about 31% of DH network heat was from renewable sources. Renewables are shown in different greenish colours for a better visual identification.

The overall thermal energy consumption of households is above 200 Mtoe showing a stabilization, but not a clear tendency in the observed period. One important remark is that the overall share of renewables in the thermal household sector has been steadily increasing from about 22% to about 30% during the period shown. This higher penetration of renewables is mainly explained by the combination of the contribution of heat pumps, and the parallel decarbonization of the electricity and district heating contribution. In contrast, the predominant fraction of renewables, solid biomass-based bioenergy, does not show a marked increase in the considered time span.

Energy Demand in the Non-Residential Building Sector

In EU statistics, the energy demand of non-residential buildings is considered within the "commercial/tertiary sector" statistics. This aggregate includes thermal uses of buildings, as well as many other activities which cannot be disaggregated easily, however, the thermal use of buildings is an important part of it. In a 2008 survey[1] based on 2004 data, the authors concluded, after examination of different sources, that the share of the non-residential buildings in the final energy use in the EU is of about 11%. Moreover, it could be reasonable to assume that the renewable/non-renewable share in tertiary/commercial buildings could be approximately the same as in households.

In summary, the overall share of buildings in the final energy demand of the EU27 is of about 37% of the final overall energy demand. The share of renewables in 2018 was about 30% being bioenergy the largest contributor, although heat pumps and decarbonized electricity are progressively getting more important showing quite substantial growth rates

Heating/Cooling Demand in the Industrial Sector

Due to its large contribution (25 %) to the final energy consumption (FEC) in EU28 countries, important changes to the current energy supply in the industry are needed to achieve the European ambition of net-zero GHG emissions by 2050.

The majority (69%) of current industrial energy use is for process heating & cooling purposes, meaning that sustainable supply and efficient use of heat should be a priority for the industry. The heating and cooling of new processes (needed to process alternative secondary resources) has to be designed to avoid GHG emissions.

At the same time, the emergence of large-scale, cost-effective renewable electricity paves the way for electrification of heating and cooling and systems that directly use renewable energy (for example solar radiation) to produce heat are being developed and combined to achieve higher end-to-end energy efficiency. However, this comes with the need to deal with increasing fluctuations in the supply of electricity using new solutions, including demand side management and integration of local energy storage at process industry sites. Heat storage & renewable hydrogen are key developments to add flexibility for industrial heating and cooling.

Thermal energy demand can be provided by various alternative energy sources. For higher temperatures electricity can be used by developing electrical furnaces/kilns (which in some cases also generate process efficiency gains), and for lower temperatures heat pumps (again leading to efficiency gains) or flexible hybrid boilers (operating on renewable electricity when this is abundantly available) can be used. Bioenergy, waste, synthetic fuels, solar and/or geothermal energy can also be used to provide heat. The best energy source will be selected depending on regional circumstances, with high potentials of hybrid systems synergetically combining different sources.

Research and Innovation in industrial heating and cooling is therefore key for a climate neutral European industry. The challenge for research and innovation for industrial heating and cooling is to develop and demonstrate the next generation heating and cooling technologies, which will lead to 100% climate-neutral industrial heating and cooling systems in 2050.

70% of industrial emissions result from the heating processes related to furnaces (50%) as well as steam and hot water (20%) (Figure 2). The direct emissions in industry are given per end use and subsector in Figure 3.

[1] Perez Lambart et al. Energy and Buildings 40 (2008), 394-398

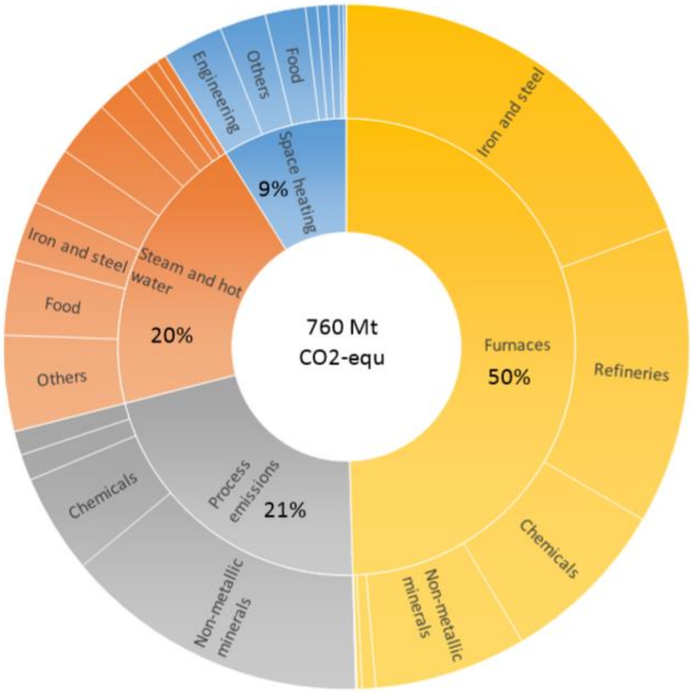

Figure 3: EU 28 Industrial Direct Emissions by End Use and Sub-Sector (source LTS, FORECAST modelling)

The industrial heat needs can be categorised in low temperature (<100°C), medium temperature (100 – 500°C) and high temperature (>500°C), as depicted in Figure 4

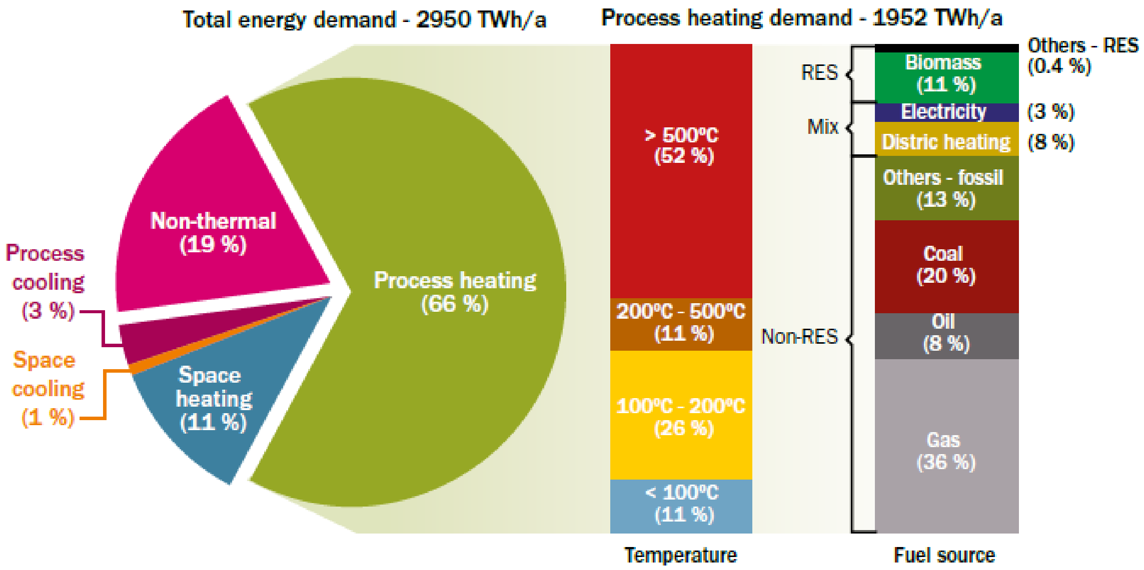

Figure 4: Breakdown of the Final energy Demand in European Industry by Broad Application (left) and Process Heating Demand by Temperature Kevel (centre) and Energy Source (right) (RES = Renewable Energy Sources) (data sources for compiling the image [2,3])

Climate neutral heat supply can be realised using different technologies such as biomass/biogas/geothermal and solar heating. Integration of cost-efficient thermal storage ensures demand-oriented supply, mitigating fluctuations renewable energy resource. Solar heat in industrial

[2] Eurostat. Energy Balances. 2019, Fleiter T, Elsland R, Rehfeldt M, Steinbach J, Reiter U, Catenazzi G, et al.
[3] Heat Roadmap Europe. Deliverable 3.1: Profile of heating and cooling demand in 2015.

processes (SHIP), can be integrated in particular in the low to medium temperature range, up to 1000 ºC in regions with high solar irradiance.

2 Overview of Challenges

100% climate-neutral heating and cooling in 2050 will be supported by development of the following sub challenges:

2.1 Challenge 1: Towards 100% Renewable Heating and Cooling of Individual Buildings

- One of the main challenges is the **development of collective retrofit** strategies for large sets of buildings, and simulations and modelling through the entire building stock in the region. Enlarging the scale of renovations to collective scale (streets/districts…) can greatly enhance its cost effectivity.
- Secondly, smart building management systems can increase the building heating efficiency. **Smart decision tools** are needed to evaluate the optimal technology choices where the building energy management is integrated in the context of a smart energy districts, as described more in the subchapter 2.1.2. These smart decision tools should be able to investigate the wishes and decisions of different type of local stakeholders such as project developers, municipalities, prosumer organizations etc.
- A third aspect is the more **seamless integration of renewable energy technologies** in the urban environment, such as building integrated PV, or several types of storage solutions. CHP technologies on fossil-free gaseous fuels such as hydrogen or synthetic gases need to be further optimized to improve the integration of historic districts or hard-to-retrofit buildings in the energy system.

2.2 Challenge 2: Heating/Cooling in Climate-Neutral Energy Districts and Cities

This challenge addresses the dual target of creating climate-neutral Energy Districts that generate integrated electric and thermal energy systems, with increased use of local renewables, as well as generate local support among citizens and professional stakeholders to make the districts sustainable in the long term. Climate-neutral Energy Districts, increasingly independent from greenhouse gas emission during fuel combustion, will contribute to increased uptake of renewables and the decarbonisation of the local energy system[4]. The districts will form part of integrated local energy systems and will span across energy vectors, leading to positive impact on the wider energy infrastructure, such as increased flexibility and reduced peak loads.

The target of achieving climate-neutral Energy Districts requires solving of a distinct set of innovation challenges[5]:

- **Active management of energy consumption and production** in the buildings within a neighbourhood (new, retrofitted or a combination of both) as well as active management of the energy flows between the buildings and the regional/wider energy system.
- Define and calculate the energy balance of the district, the geospatial potential for renewable energy technologies and the boundary conditions, including technological, spatial, social, economic, regulatory and other innovation perspectives. **Flexible energy planning tools need** to

[4] With climate-neutral energy districts it is meant that the districts are compatible with a climate neutral society, independent of fossil fuel combustion, however it is not a strict requirement that climate-neutral energy districts are self-sufficient in terms of energy generation.

[5] https://ec.europa.eu/inea/sites/inea/files/02_20171024_-_bartholmes_-scc1_info_day_-_jb.pdf

be developed to support cities and municipalities pursuing the appropriate energy choices taking into account all abovementioned local factors.

- Create **standardized packages** of energy efficiency, flexibility and generation measures (materials, equipment, demand response, storage, smart grids, e-mobility, distributed ledger technologies etc) that can be customized according to local conditions (demographics, building stock, heritage and other societal value, local availability of RES etc). The main challenge is the combination of the scale advantage of the standardized approach while still accounting for the diversity of the local societal and geographical situation in European cities. This links to the challenge mentioned in 2.1.1.
- Organise **experimental facilities** such as regulatory sandboxes, testbeds, and living labs to develop, text, implement and monitor innovative solutions faster. Low-regulation zones can be an important enabler to test new tariff schemes, social acceptance and market design.

2.3 Challenge 3: Next Generation of District Heating and Cooling Networks

District heating and cooling systems will play a crucial role in densely populated areas and also in specific other applications such as greenhouse farming. The next generation of district heating systems includes many different sources of waste and renewable heating and cooling energy, it includes connections to thermal storage systems, and delivers heating and cooling to the end-user at maximum efficiency. The road to 100% climate-neutral district heating and cooling systems requires innovations and demonstrations in all constituent parts of the collective systems:

- Including **less conventional low temperature sources** (e.g. sewers, cooling facilities, water treatment plants, metro lines, data centers…) can greatly enhance the efficiency of the system.
- To a certain extent, a well-insulated building stock, the district heating network itself and the decentralized storage tanks in buildings can be used as a storage system providing thermal flexibility and to balance the heating demand with renewable sources. Other local **chemical or man-made underground thermal storage solutions** can contribute to more long-term heat storage options.
- **Digitalisation in district heating and cooling networks** will play an important role: (1) large scale collection of data located throughout the DHC production, transport, distribution and users chain, (2) using state-of-the-art machine learning algorithms to further process the data for optimal to control of the network and to support the analytics (real-time monitoring, analysis, fault detection and visualisation).
- This aspect includes system design and innovative business models where the **heating/cooling sector is integrated with other sectors**. These business support tools and strategies can enable the maximal use of RES and residual heat, support other energy networks and reduce the operational costs of the system.

2.4 Challenge 4: Towards 100% Renewable Industrial Heating & Cooling

The majority (69%) of current industrial energy use is for process heating & cooling purposes, meaning that sustainable supply and efficient use of heat should be a priority for the industry. Research and Innovation in industrial heating and cooling is therefore key for the reducing the greenhouse gas emissions of the European industry.

The challenge for research and innovation for industrial heating and cooling is to develop and demonstrate the next generation heating and cooling technologies, which will lead to 100% climate-neutral industrial heating and cooling systems in 2050. The road towards climate-neutral industrial heating and cooling requires innovations and demonstrations in the different topics:

- For widespread **adoption of heat pumps for industrial heating,** the challenges are to reduce the capital investment cost, development of cost-effective systems in the megawatt scale and cost-effective integration of heat pumps in industrial processes.
- For robust and efficient industrial electrical heating, the objective is to demonstrate (TRL9) **industrial electrical heating at high temperatures** and using advanced heating technologies before 2040, with emphasis on reducing CAPEX and energy efficiency.
- To deliver **highly reliable and automised solar thermal heating in industrial applications**, especially in the 60-300°C temperature range and at smaller, industrial scale plant sizes, further research and digitalisation of concentrating solar thermal plants is needed. Other challenges are further cost reductions of SHIP systems, materials and receivers for high temperature CST, heat transfer fluids and storage.
- Demonstration projects are needed to advance the **integration of renewable heat** (such as solar heat, and geothermal) and renewable fuels (renewable hydrogen, bioenergy, waste and other new renewable fuels) in the industrial environment at different scales and temperature ranges.

For heat storage, there is a specific focus on technologies that allow heat storage for both one day and longer term, e.g. over a week, to increase the flexibility of the process industries. The objective is to develop materials for **compact, large capacity high-temperature heat energy storage** and to integrate these technologies in the process industries.

Aside from research and innovation challenges in the industrial sector, other challenges and barriers exist. For instance, one of the major barriers for improving the energy efficiency of the system and integrating the urban and industrial environment is the lack of bottom up data on industrial excess heat. Top-down studies which assess the technical potential are often not replicable using a bottom-up method, where reliable data are not publicly available or in practice exporting the excess heat from the industrial site might require significant investments.

3 Detailed Description of Challenges

3.1 Challenge 1: Buildings

3.1.1 Description of the Challenge: A Modelling Outlook to the coming 10 years

The most relevant outlook about the future of the energy sector in Europe is based in the projections that, based on the PRIMES[6] model, the COM performs in the context of the planning of future policy and social developments (see Figure 5). Especially important are the documents known as EUCO policy scenarios[7], that include a detailed projection of the energy balances in the EU and its member states, based on foreseen rates of growth in the various aggregates. The EUCO policy document contains different scenarios, termed EUCO27, EUCO30, EUCO+30, EUCO+35 and EUCO+40 figuring out how different measures in the energy sector can contribute to the fulfilment of the long term overall decarbonization targets of the EU. These projections have been the basis for a number of impact assessments and the negotiations of the legislative acts proposed under the EU 2030 energy and climate policies (Effort Sharing Regulation, Staff Working Document, low-emission mobility strategy, recast of the Directive on RES and revised Energy Efficiency Directive, electricity markets revised rules, etc..).

In addition to the previous scenarios, more recently a new EUCO3232.5 scenario was released to support the new EU energy and climate policy developments and designed to achieve a 32% share of renewable energy in gross final energy consumption and a 32.5% energy efficiency target in the EU. The energy

[6] The PRIMES model is an EU energy system model which simulates energy consumption and the energy supply system. It is a partial equilibrium modelling system that simulates an energy market equilibrium in the European Union and each of its Member States. It includes consistent EU carbon price trajectories.
[7] Technical report on Member State results of the EUCO policy scenarios. By E3MLab & IIASA, December 2016.

efficiency target is referring to the total primary and final energy consumption in 2030 as compared to the 2007 baseline scenario (i.e. a 32.5% reduction from a primary energy consumption of 1887 Mtoe in 2030 and a final energy consumption of 1416 Mtoe projected for 2030 in the 2007 baseline).

The EUCO scenarios forecast a substantial reduction in the thermal energy demand of buildings along the 20-30 decade to below 200 Mtoe (compared to 240 Mtoe in 2010). The rate of decrease in household energy consumption between the most conservative (EUCO27) and ambitious (EUCO+40) scenarios ranges from an average of -1,1% to -5,6% due to the combination of more stringent and ample market measures and incentives for the energy renovation of buildings and ecolabeling of appliances.

Regarding the RHC sector, the only policy measures explicitly mentioned along the EUCO scenarios is an increase in the heat pump sector, in parallel with a decrease in the overall demand of the "renewable energy forms" (from -0,5% to –3,6%). Yet, heat from "heat pumps" is not explicitly considered in the EUCO detailed energy balance sheets[8] and it is henceforth difficult to see how this decrease is distributed amongst the different sources of renewables. A further reduction in the DHC and CHP sector is foreseen of up to -4,8% in the most drastic EUCO+40 scenario.

Overall, the share of renewables would increase according to the different scenarios, as the decrease in fossil fuels is foreseen to be much higher than the decrease in the demand of electricity or renewable energy forms.

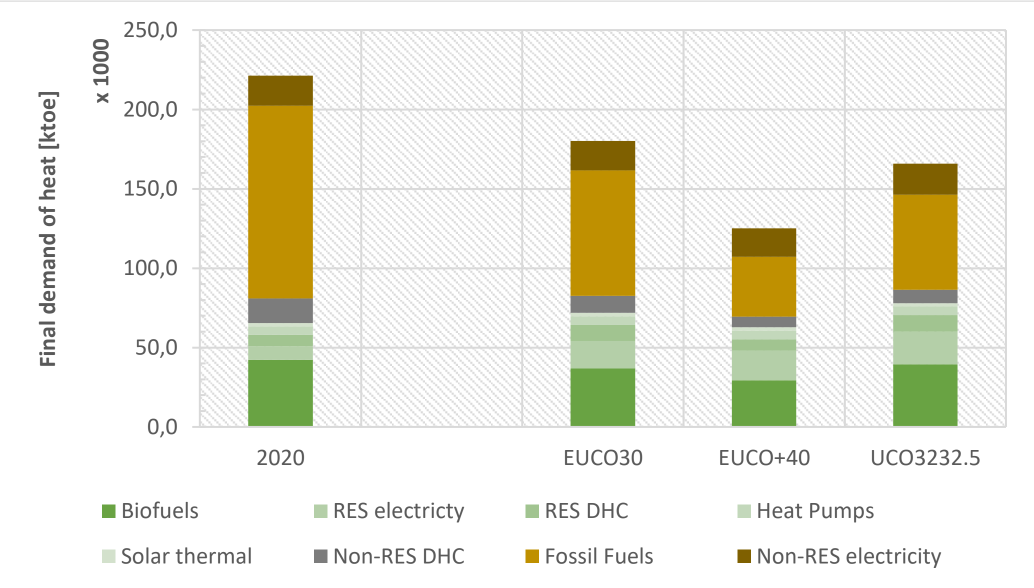

Figure 5: Final Heating Demand in the Building Sector as calculated with the PRIMES Model

In the most ambitious EUCO+40 scenario (highest demand reduction), this share would be of around 50% in 2030.

With respect to the former, the EUCO3232.5, more in line with the nowadays policy lies in between the base EUCO30 and highly ambitious EUCO+40 scenarios. The increased share of RES is obtained by adjusting the total share of renewables in the production of electricity to 55,5% in 2030 (compared to 48,7% in EUCO30) and, significantly, reducing the foreseen decrease in the demand of "other renewables" and DHC.

Since, to streamline the EU policy scenarios towards the desired political targets, it is critical to consider RHC contribution and its dynamics. However, in the EUCO scenarios these dynamics are only a result of market forces considering technologies and policies in their in their current form as EUCO modelling is *"based on cost-effective achievement of targets and often simplified or aggregated representation of*

[8] At least not in the publicly available documents to the authors knowledge.

national and European policies and circumstances. National results should be read in this context and they do not prejudge the national plans to be developed in the governance process" [9] moreover*, "models outputs can only be claimed to represent the real world developments if respective, simplifying assumptions are held and all other conditions are unchanged".*

For this reason, it would be important to highlight that:

- EUCO projections rely extremely on a steady and ambitious reduction in the energy demand of households/buildings. From Figure 5, however, one may observe that the decrease in building energy consumption, at least to 2018, is not steady and the foreseen decreases in the EUCO scenarios are within the annual fluctuations – related to the economic activity - observed in the EU statistics.

- In relationship with the RHC sector it is important to note that there is not a consistent treatment of the different RES sources and their potential in the different scenarios. In particular, the projections of a policy support for measures like "heat pumps" or in general "RES", does not reflect in an increase in the demand of these.

- EUCO projections do not take into consideration the change in market equilibrium conditions deriving from the cost reductions that R&D policies can cause in the different energy sectors.

In summary, a substantial, consistent and ambitious R&D policy for the RHC at EU and national level is needed to ensure that the building stock is decarbonized, irrespective of the fact the foreseen decrease in the energy demand in buildings is accomplished or not, ensuring an increased share of the RES energy demand in buildings.

To reach that goal, certification may be a key enabler for increasing interest of RE between installers and consumers. Furthermore, a better integration of the components of the value chain in the design and construction of buildings is essential to enhance competitiveness and technical skills of fossil technologies installers, as well as create solid background to installers for optimum RE technology selection related to buildings' needs. In this are several activities are needed which include but are not restricted to the following:

- New tools for developers, building owners and stakeholders (public and private) to allow a ready and simple resource assessment of RES availability.

- Developing an EU information strategy aimed at informing the installers, architects, end users, manufacturers, suppliers etc. of the benefits of working with RES technology

- Identifying the key success factors are for training systems to make them attractive to installers (online, modular approach etc.) and where the need for training is and which competences are missing.

- Enabling markets to actively participate in development of training information in alliance and synergy with already existing certification schemes (e.g. LEEDS, BREAM).

In view of the foreseen more favourable market conditions that will exist in the next decade it is critical that technologies and resources are available and that the right planning and administrative conditions are in place at all levels of policy action: EU, member states

[9] Technical report on Member State results of the EUCO policy scenarios. By E3MLab & IIASA, December 2016. Page 2 and 3.

3.1.2 Research & Innovation Priorities for Buildings

RHC Area 1: Cost-Effective Retrofitting of Old, Historical, and Special Buildings

Developing affordable, compact, highly efficient, easy to install, and intelligent renovation kits for replacement of traditional fossil oil- and gas-fired heaters, allowing ease of control, operation and maintenance. Renovation kits should include innovative storage concepts. Pushing developments for achieving the economic breakeven point for serial renovation of buildings earlier, through efficient prefabrication of elements and advanced HVAC capabilities. Optimising the system architecture for combination with new RE-sources allowing tri-generation of low temperature heat, cold and electricity, while considering the multi-level cost of electricity, heat and cold and the overall renovation cost rather cost, rather than just cost for the refurbishment of the HC equipment. Exploring and demonstrating new RES, which can act as heat source for more efficient ground-based heat pumps. Digital tools and models need to be developed to be able to select the optimal technologies for collective renovation and integration of RES for fossil-free heating and cooling, taking into account local opportunities and the consumers wishes.

Due to serial renovation of buildings, the renovation time shall be reduced from months to days or a few weeks. Highly automated production of e.g. façade elements and HVAC-modules shall diminish renovation costs substantially. Highly efficient HP systems with new refrigerants with low GWP for heating and cooling are also an issue, including the critical need for high temperature heat pumps that are compatible with existing internal heat distribution systems/radiators.

A further priority is the mapping of the historic buildings (one fourth of major cities' building stock[10]) and characterisation of their energy needs for HC in order to find possible classifications that allows to develop plug & play solutions for integration of RES. Special care should be addressed to these buildings to guarantee comfort conditions to users without impairing their aesthetic value. For historic and special buildings solutions shall not compromise the value of the building, in terms of aesthetics and lifetime, especially when some of the components of the RE HC systems need to use the building façade to capture the energy.

It is necessary to evaluate available spaces and possibilities for energy storage systems, as well as possible energy efficiency measures to reduce energy demand. Furthermore, the development and application of easy to use methods that allow evaluation of aesthetical impact of solutions with integration of RE in the façade in order that it can be accepted by stakeholders is key. Based on the existing European standard EN 16883:2017[11], further develop its application to include also the integration of RE for HC.

RHC Area 2: RHC Sources, Fuels Technologies and Systems for new Buildings; Integration and External Connectivity

This research area aims to provide a wide range of sustainable RHC technologies and combinations for energy-efficient buildings, i.e. buildings built according to modern building standards. Technologies such as those mentioned in the following list will contribute to a make RES generally available and cost efficient for the future carbon neutral buildings:

- Integrated solar RHC systems (solar thermal and PV/PVT) in the building envelope (Façade), and new system architectures for utilisation of the intrinsic advantage of PVT collectors for tri-generation of electricity, heat and cold

[10] According to Task 59 of Solar and Heating TCP – IEA.
[11] Conservation of cultural heritage — Guidelines for improving the energy performance of historic buildings

- New solutions for HP and their integration with RES and the building thermal envelope, including its integration with geothermal heat sources like e.g. thermally activated geostructural elements.
- Development of new biomass fuels (solid, liquid, gas) and new biomass heating technologies adapted to the needs of new buildings.
- Optimised integration with grid RE electricity, from and to the grid, considering alternative electricity production and storage solutions (e.g. fuel cells, vehicle-to-grid) and smart grid integration for demand response, peak shaving and increased share of RE own-use. Development of compact, affordable and easy to install HC kits, e.g. (HP + TS + control software).
- Increase of building automation through BMS (monitoring sensors, controls, actuators) and decision-making tools for optimum use of buildings/systems in terms of energy efficiency. This includes smart control of heating and cooling systems.
- A particular challenge are historical or other hard-to-retrofit buildings. These buildings can benefit from CHP technologies powered by synthetic gases or biogases. CHP technologies can provide full integration with other RE technologies, they can use storable RES (biomass, biogas, underground storage, renewable hydrogen etc.) to produce on-demand electricity and storable heat and cold. Particular challenges are the reduction of manufacturing and maintenance costs, increasing efficiency, and flexible connection to the electricity grid (power factor correction, grid code compliance etc.)

Expected key results are a 100% RE coverage of HC in new individual buildings, a complete independence of fossil fuels' use in the buildings when they are built, and from external gas supply (i.e. only electricity grid connection), adapted to local possibilities and regulations, high efficiency, cost-effective and sustainable RE systems.

3.2 Challenge 2: Climate-Neutral Districts & Cities

3.2.1 Description of the Challenge

The target of creating 100 Positive Energy Districts by 2025 (SET-Plan Action 3.2, 2018) requires integrated energy systems with sector coupling (heating, cooling, storage, smart grids, buildings, e-mobility etc) rather than stand-alone systems and individual technologies installed in buildings or connected to the local grid[12]. Renewable energy will not only need to be integrated with conventional energy networks, but also with sustainable land use and mobility planning, and an energy efficient urban fabric and built environment.

One of the key challenges in districts is the assessment of potential sources and the prioritization of fossil-free technologies. Models for case-by-case selection of the optimal resources and infrastructure need to be developed. E.g. in historic city centers retrofit potential or geospatial energy generation potential will be limited, and different technologies will need to be combined.

Making integrated solutions available, reliable and affordable for all, will require massive capital investments, updated regulations, and innovative business and risk sharing models. It will also require transition arena and urban living labs in which solutions can be co-created, tested, implemented and monitored with local energy utilities, municipalities, citizens, knowledge organisations and other stakeholders.

[12] In this chapter we use the term climate-neutral cities and districts to avoid confusion with self-sufficient cities (i.e. Positive-Energy-Districts do not have to be able to provide for their entire energy consumption at all time)

3.2.2 Research & Innovation Priorities for Climate-Neutral Districts & Cities

(1) Planning Tools for Defining and Implementing the Energy Ambitions within the District

- How to account for the embodied energy of the entire life cycle of the district, its building stock and thermal and electric energy systems? How to include circular economy perspectives?
- Develop models and tools to prioritize the technologies which will be integrated in the urban environment. The choice needs to include local factors such as geospatial potential for renewable technologies, local market design, social factors etc.
- Quantify the impact that Decentralised Energy Sources (DER) offer for working at district level and across energy vectors, not only as a technical solution for locally generated electricity/heat, but extended to include technological, spatial, social, economic, regulatory and other innovation perspectives, with quantitative and qualitative Key Performance Indicators that support advancements in Technology Readiness Levels as well as Societal Readiness Levels
- Ensuring that energy efficiency, savings and flexibility are included; avoiding to simply have larger energy supply than demand, without performance criteria for energy efficiency and energy savings

(2) Active Management of Energy Consumption and Production, and Energy Flows

- Between buildings in a neighbourhood, taking into account whether they are new or retrofits, and their functionality, use profiles and energy consumption patterns, and diversity of energy systems with various parameters, centralised/decentralised, district heating and cooling networks, aggregators (specialized, end-user focus, etc.), shaving/shifting peaks, practical issues related to hot water consumption and heat pumps, etc.
- Tools and technologies to enable seamless integration of local energy systems and vectors, both within the district and between the district and the regional/wider energy system
- Coordinated geospatial planning of decarbonized energy networks, heat technology plans by zone. For the planning of district heating grid architecture advanced models need to be developed which can take into account the physical limitations of the district heating grid while providing a futureproof design for the heating demand in cities and large areas.
- Identifying new potential for system innovations due to improved ICT services, such as the role of smart services/technologies as enablers, machine learning, multi-agent systems, agent-based modelling, security
- Roles and responsibilities of prosumers, incl citizens, local businesses, building managers etc, and taking into account human perspectives such as behaviour, acceptability, diversity, added value, accessibility (physical, economic, cultural…)

(3) Create Standardized Packages that can be Customized according to Local Conditions

- In order to avoid every district/city to reinvent the wheel[13], create standardised packages of successful cross-vector solutions (materials, equipment, demand response, storage, smart grids, e-mobility, distributed ledger technologies, energy cascading, location of buildings/infrastructures etc), corresponding planning instruments, data, KPIs, and investment and business models that can be used in specific types of districts (according to demographics,

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[13] Vandevyvere, H., 2018. *Why may replication (not) be happening? Recommendations on EU R&I and Regulatory policies.* [online] EU Smart Cities Information System D32.3A. Available at: https://www.smartcities-infosystem.eu/sites/www.smartcities-infosystem.eu/files/scis_library/scis_-_why_replication_may_not_be_happening.pdf

building stock, availability of RES, predominant typology such as heritage, residential, industrial or commercial districts, or mixed-use etc)

- Guidelines on how to customize these according to local conditions (demographics, building stock, heritage and other societal value, local availability of RES, local stakeholder ecosystems etc)
- Replicability towards international markets. Scaling up, replicating and transferring solutions on a global scale, adjusted to various lifestyles, working cultures, traditions, building styles, etc., enabling Europe to gain a higher global market share with export of packaged solutions, processes and expertise

(4) Organise Regulatory Sandboxes, Testbeds, Living Labs and other Experimental Facilities to Develop, Text, Implement and Monitor Innovative Solutions Faster

- Creating a suite of experimental facilities that acknowledge the multi-level, multi-sectoral, multi-functional, and multi-type nature of thermal and electric energy system planning and operation required for Climate Neutral Energy Districts, and that can help develop a better understanding of the relationality and interdependencies in governing energy and district/urban planning.
- enabled by public-private partnerships in which businesses, researchers, authorities, and citizens work together for the creation, validation, and testing of new services, business ideas, and technologies.
- Support is required to enable districts/cities to organise the necessary resources or settings for testing, and to organise the pilots in such a manner that they can be scaled up and replicated

3.3 Challenge 3: Next Generation of District Heating and Cooling Networks

3.3.1 Description of the Challenge

One of the challenges for district heating and cooling systems is to integrate more RES and excess heat and cold sources at suitable temperature levels and integrate locally available RES and low-carbon energy sources effectively. They should also provide flexibility and interoperability for short (hours to days) and long term (seasonal) variability of supply and demand through integration of heat and cold storage technologies. Retrofitting existing districts and modernising existing collective heating and cooling systems are part of the challenge. A suite of concepts for various conditions (climate, availability of sources, geology) could be imagined. The focus is on district heating, but the scope is broader and includes all collective heating and cooling systems.

The next generation of collective heating and cooling systems will be key for urban areas. Local governments, local and regional utilities, consumers, technology suppliers, greenhouse farmers, infrastructure suppliers are all market stakeholders. The actual set of stakeholders will vary by country, as there are significant national differences in market structures. The required developments to enable next generation collective/DHC systems throughout Europe are two-fold:

- Development and demonstration of the next generation integrated solutions for collective/ DHC networks using various sources of renewables, waste heat and thermal storage,
- Retrofitting conventional DHC systems to allow for lowered temperature and increased uptake of renewable thermal sources

Towards implementation, access to local data sources is a key requirement for assessing the economic viability of district heating/cooling projects. High-level studies may identify potential for connecting heating/cooling sources with demand. However, the actual cost of a district heating infrastructure in a certain trajectory can be highly dependent on roads, waterways, existing underground infrastructure, planned interventions smart control systems, alignment opportunities, etc. The investment cost for valorisation of industrial excess heat, as well heat from datacentres, offices and supermarkets or heat from aqua thermal sources, is very dependent on the site/sector in question. In addition, regulatory hurdles still exist. For instance, smaller cities or municipalities are main contact point for citizens, however they often lack the technical knowledge for facilitating a complex process such as implementation of a district heating grid. The roles, benefits and responsibilities of the different actors for production, retail and maintenance of the district heating infrastructure are is some regions still unclear, hindering an efficient process towards implementation.

3.3.2 Description of the Transition Challenges

Collective heating and cooling systems need heating and cooling sources, storage solutions, distribution networks, and all this needs to be integrated efficiently. The subchallenges are defined around these constituent technologies and the integration needs.

Robust and Efficient Local Heating and Cooling Sources

Climate neutral sources for heating and cooling are essential constituents of any next-generation collective HC system. These sources should be local, because transportation of heating and cooling over large distances is expensive. Also, low-exergy sources should be preferred. One way to address this challenge is by improving the efficiency, flexibility and robustness of existing sources and sinks of renewable heating and cooling, such as geothermal, solar thermal, ambient heat (air, surface water, sea water) and seasonal stores. Another way is to develop other sources, such as industrial excess heat and cold, waste heat from data centres, abandoned mines, sewer heat, and also power-to-heat or power-to-cooling can contribute here. Heat pumps play an essential role to match available temperatures to required temperature levels. Absorption and adsorption heat pumps, which are heat-driven, can complement such systems. Smart cascades of sources can be part of this challenge. For industrial waste heat which has great potentials, business and contractual models need to be developed, as well as incentives and support schemes for waste heat owners.

The objective is to progress renewable heating and cooling technologies (See ‘enabling technologies’ input papers) and develop solutions to access other sources of heating and cooling efficiently, including heat pumping technologies, in order to develop and demonstrate solutions for local heating and cooling sources for a suite of typical locations throughout Europe.

The impact of this development will be that many European locations will have sufficient choice of cost-effective heating and cooling sources to establish a 100% climate neutral heating and cooling system, with low-exergy sources.

Technical, cost-effective solutions and new business plan should be addressed to district energy transition considering the gradual retrofitting process of existing buildings and providing efficient integration with different HVAC systems.

Robust and Efficient Storage Systems

Robust and efficient storage systems are essential constituents of collective heating and cooling systems, because space heating demand peaks in winter, while space cooling demand peaks in summer. Many heating and cooling sources have a flat or reverse year-round profile. Such stores should be affordable, robust and efficient. Underground thermal energy storage and man-made constructions for thermal storage such as pit storage systems and their integration into collective heating and cooling systems need further improvement and broader applicability to get to affordable solutions for all Europeans. This is also addressed in the input paper on storage and fuels. Heat pumps play an important role to match supply and demand temperatures. For shorter timescales, sector coupling solutions and the use of storage options in the system (buildings, pipelines) are of interest. Such technologies smooth the interaction of P2H with the fluctuating electricity prices and overcome the mismatch between the variable renewable electricity production and consumption.

The objective is to develop and demonstrate affordable and robust heat and cold storage solutions in various sizes and temperature ranges for application in collective heating and cooling systems.

Such improved storage technologies will contribute greatly to the affordability of the heat transition. With storage technologies available, the capacity of the available sources can be used year-round, and stored GJs will address the peak demands.

Robust and Efficient Distribution Networks

Robust and efficient distribution networks couple end-users, sources, sinks and stores. Both hardware and software need to be developed further to allow the cost-effective growth of collective heating and cooling systems and retrofit of existing systems. Low and ultra-low temperature networks allow the inclusion of many heating sources, but need solutions for health and safety, in particular legionella, see the challenge on indoor distribution systems. In the distribution networks, smart realisation and control are key. This means connecting to the various RES and waste sources and stores, and realising the network cost-effectively and without major disturbance, both for new systems in existing densely populated areas, or for retrofitting existing networks. In order to accelerate the market uptake and roll-out of modern district heating networks, technology developments that accelerate the deployment are needed: network design, component production (e.g. digital printing of spare parts), innovative pipe infrastructure e.g. via horizontal drilling etc.

The objective is to further optimise the networks and develop and demonstrate hardware and software that contributes to that goal. This challenge is closely related to the next challenge, integration into the energy system.

Integrated Solutions for the Next Generation Collective Heating and Cooling

The smart integration of end-user demand, available sources, available storage options and the infrastructure and the integration the collective heating and cooling system in the energy system is essential to realise the full benefit. Demonstration initiatives, integrating innovative solutions, are needed to demonstrate the technical and economic viability of advanced district heating and cooling solutions. Research and demonstration of advanced substations capable of coping with needs of both heating and cooling and also able to enable bidirectional energy flow is needed.

Digital technologies offer a wide range of possibilities, from the design processes to operational procedures to increase operating efficiency of the district heating and cooling infrastructure and sector coupling as well as closing the gap with the users. An example is fault detection and remote control allowing to increase energy efficiency and the flexibility of the system with minimal investment costs. The next generation of control systems could bring together users/consumers with production and distribution systems. Enabling data aggregation, and data sharing is instrumental to unlock this next generation control, to create new user-centric business models and to enhance city energy planning tools. In addition, new business models, not solely relying on selling GJs of heating have to be developed by involving consumers and developing concepts of “heat as a service” and “cooling as a service”.

Developing overarching control procedures and processes and dedicated digital solutions to effectively explore, enable and use energy flexibility services integrating various sources and sinks of low-temperature heat, P2H solutions, storages, building demand side management procedures , is needed to enhance the efficiency of the district heating and cooling infrastructure and the sector coupling capability.

Control methods using big data functionalities and advanced predictive control (such as digital twins, predictive model-based engineering solutions), capable of interacting with different energy markets and flexibility solutions and of optimizing the energy flow between the generation, storage and consumption side, shall be developed and tested in real environments. Digital integration spanning other energy carriers (e.g. electricity for price signals when to operate HPs) are as well needed.

Next to these technologies for integration other areas of interest need to be explored.

One of these areas is to explore new cross sectoral business models based on revenues streams from different energy markets (DRM- demand response market and DSM – demand side management), which create tangible profits also for consumers (especially for the ones engaged in demand side management activities), and optimise the efficient integration of various RES supplying thermal and electrical energy into the energy system of the district.

Another area is about societal embeddedness of these technologies. For a successful implementation of these technologies the right conditions should be there. It is not only about implementing one new technology, but it is as well related to functioning in the district system and upscaling in other districts or cities. This is about alignment with city planning and vision, public acceptance of smart grids, effective regulations and legislation. Governance of district heating, citizen ownership, cooperative organisation influences the roll-out of district heating and cooling systems.

3.4 Challenge 4: Industrial Heating and Cooling

3.4.1 Description of the Challenge

An overview of the research and innovation areas for industrial zero-emission thermal processes are given in the P4P roadmap 2050 (Figure 6). Next to that heat re-use is important to increase the energy efficiency in industry.

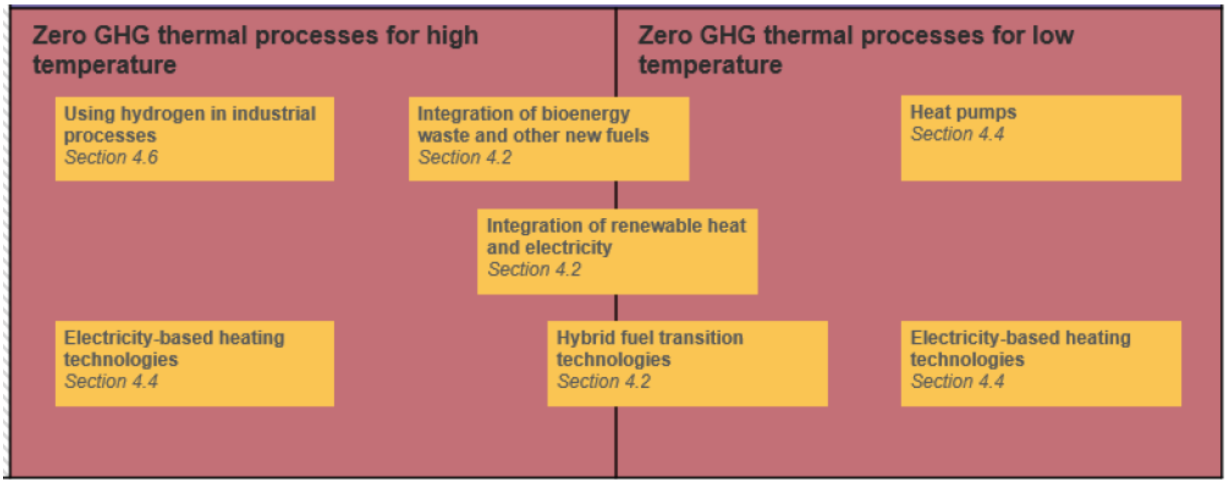

Figure 6: Research and Innovation Areas P4P Roadmap 2050

Efficient Systems for Heat Re-Use

Heat is currently used in many industrial processes to drive material transformations. Although optimisation of heat management in process industries is not new, large flows of heat are still discarded and there is potential for advanced heat reuse technologies. Within the EU industrial sectors, up to 1/3 of energy for EU industrial thermal processes is lost through waste heat, yet could be re-used, there is a waste heat potential of 300-350 TWh/yr compared to the total industrial energy consumption of 3217 TWh in 2016 (Agathokleous et al. 2019). Waste heat utilization is established as an early efficiency measure for low cost emission reductions within the industry sectors in many long-term strategy scenarios for decarbonization of the industry. Therefore, waste heat utilisation is to be maximised by 2030.

The objective is to develop technological innovations that enhance the business case for heat reuse by increasing the applicability of heat exchangers so more heat can be recovered. Recovered heat can be used to heat other process flows directly or the heat can be increased by heat pumps..

Electrification of Thermal Processes

Around 52% of the European process industries' own emissions originate from the use of fossil fuels for heating purposes. As temperatures grow to around 150 °C, this heat can now be delivered by heat pumps (which produce about three units of energy in the form of useful heat for each unit of electricity input, using available waste heat as input). Innovation, and the resulting increased production volumes, will decrease heat pump costs and make them more attractive. Another innovation objective is to increase the temperature that these heat pumps can deliver to 250 °C in 2030 and above in 2035, increasing the range of processes in which heat pumps can be used significantly, enabling savings of 15 MtCO2. Because heat pumps deliver a multiple of the amount of electricity consumed in the form of heat, their application also increases the energy efficiency of processes significantly—and the available renewable electricity is used well.

The innovation challenges for heat pumps differ by temperature levels:

- For temperatures up to 150 °C the technology is already available, but too expensive to compete with fossil fuels.
- For higher temperatures, the technology is not developed and there are various technical challenges that need to be solved. Technologies with the potential to reach temperatures up to 250 °C are in the early stages of development. This is needed because a large share of heat demand in energy intensive industries is at higher temperatures (de Smidt & Marina, 2017).
- It might be possible to use heat pumps for even higher temperatures, but these technologies are at a lower TRL.

The innovation objectives for heat pumps include the following:

- Reduce CAPEX of heat pumps up to 150 °C to 200 EUR/kW (thermal) in 2025 and 150 EUR/kW (thermal) in 2025 – Because of their high efficiency, heat pumps can compete with fossil fuels on fuel costs even if the electricity price is much higher than the price of fossil fuels. Operating at a coefficient-of-performance of 3, for example, a heat pump will be competitive on energy cost even if the cost electricity is 3 times as high as the cost of the fossil fuel. However, the high upfront investment cost of current heat pumps leads to unattractive payback times. The large-scale deployment of heat pumps requires a reduction of the CAPEX. The 2030 target will trigger the first wave of heat pump deployment; afterwards, the standardisation and supply chain optimisation will decrease costs to meet the 2050 target;
- Developing heat pumps and MVR up to 250 °C to TRL9 in 2030 – Innovation is necessary to extend the temperature operating range of compression heat pumps are:
    - Refrigerants must be available with good thermophysical properties and low global warming potential (e.g. HFOs);
    - Lubricants must ensure the correct operation of the lubricant-refrigerant mixture within the operating temperatures, compressor technology, and suitable vapour compression cycle;
    - Components must be able to withstand high temperatures, and novel concepts and cycles.
- Developing heat pumps and MVR higher than 250 °C to TRL9 in 2040 – It may be possible to push heat pumps to even higher temperatures. This will be researched, and at a later stage it will be determined whether it is worth pursuing further.
- Cost-effective integration of heat pumps in processes – Much of the heat used in industry is supplied by generic utility systems. In fossil-fuelled systems, the heat temperature does not

impact the efficiency of heat production. For heat pumps, the efficiency depends on waste heat temperature levels and the temperature of produced heat. As a result, highly process-integrated solutions offer better opportunities to increase efficiency and reduce investment cost. To capitalise on the opportunities, it is necessary to involve process and equipment suppliers in the development of process integrated heat pump systems. Engineering firms are not well-informed enough about the potential and possibilities for heat pumps integration because the market is not asking for it. Therefore, projects aimed at knowledge transfer to the engineering sector and technology providers and demonstration projects are required. Heat pump integration should be coordinated with innovation programs such as Digital process development and engineering (for advanced process modelling), Heat reuse (for innovative heat exchangers), and Circular regions (for the optimisation over multiple plants).

- Knowledge and awareness about heat pumps – A major barrier to heat pump implementation is the lack of knowledge about integrating medium and high temperature heat pumps in industrial processes. There is also a low level of awareness of the technical possibilities and the economically feasible application potential among users, consultants, investors, plant designers, producers and installers. Knowledge sharing and creating awareness are key to the success of this programme.

When GHG emission-free electricity is used in electricity-based heating technologies to replace natural gas, coal, waste or biomass, the fuel-related emissions are eliminated also for high temperature applications like reactors, furnaces or kilns. This deeply reduces the emissions of steam cracking furnaces (the start of the hydrocarbon value chain of the chemical industries) and eliminates (almost) all heat related emissions of both the ceramics industry and highly flexible electrically heated reactors with further potential in refineries. Electric kilns reduce the emissions of the cement and lime sector by around one-third (the heat related part of the emissions). In some applications, just the heating will be done differently, while in other applications switching to electrically heated furnaces or kilns offers the potential to also deliver efficiency gains in the process (for example for ceramics drying/sintering). The aim is to have electric heating technology fully developed for application in 2030 (ceramics and steam crackers) until 2035/2036. More specifically for applications with limited efficiency gains the objective is to develop and demonstrate these technologies with an emphasis on reducing CAPEX, and for the other applications to develop the technologies in such a manner that the energy efficiency gains are realised. The price of renewable electricity needs to be sufficiently low to make these investments attractive. The total emission reduction enabled by this development is 106 MtCO2.

Heat Storage

Add flexibility by means of storage – In some cases, onsite storage can be more cost-effective than centralised storage in the energy system. For example, industrial sites with integrated renewables can use more of the generated electricity or waste heat can be used later in batch processes to bridge the time between batches. This storage can be in the form of electricity, heat, or other energy vectors. For heat storage, there is a specific focus on technologies that allow heat storage for over a week. The projects will aim at integrating existing technologies in the process industries.

Using Hydrogen in Industrial Processes

Hard-to-electrify processes can require retrofitting or complete changing the different processes of the industry where the low carbon hydrogen could be used.

For instances, the combustion in furnaces can be improved in by using hydrogen rather than fossil fuels: When hydrogen is produced without GHG emissions, replacing fossil fuels (such as natural gas or coal) with hydrogen eliminates the GHG emissions. Currently used furnaces are often not equipped to use hydrogen, as:

- Different burners would be needed

- The higher flame temperature and different radiation of hydrogen combustion causes a need to adjust (retrofit) the combustion system and the conductive zone of the furnace
- Hydrogen-based combustion leads to higher volumetric gas flows
- The higher amount of water generated creates the need to adjust the off-gas system (increase water separation capacity and for potential corrosion when a mixture with a sulphur-containing fossil fuel is used)

Integration of renewable heat such as solar heat, and geothermal will require changes to the industrial processes due to different temperatures, supply profile, process control, storage and more. To explore the extent of changes required and potential synergies, demonstration projects of various sizes are programmed before 2030, reducing fossil fuel emissions by an estimated 10 MtCO2 (e.g. PV powering a ceramics kiln, or solar heat used for drying).

Integration of bioenergy, waste and other new fuels requires adaptation of processes to different fuel characteristics (making the process biomass-tolerant) or pre-treatment of biomass to the requirements of industrial processes. These technologies are already under development and to be demonstrated before 2025, with more development to decrease costs afterwards.

Solar Heat in Industrial Processes

Solar Heat in Industrial Processes (SHIP) has a large potential to substitute fossile heat supply and thus significantly contribute to the decarbonisation of the industrial sector. Currently, most applications are in the lower temperature range (< 100°C) e.g. in the food and beverage sector (dairies, breweries). Solar heat currently is mostly integrated on the supply level e.g. in hot water or steam networks and in combination with thermal energy storage TES to mitigate fluctuations of the solar resource and ensure supply adapted to a given demand profile. Direct process integration is often more challenging and industry is more reluctant to implement direct process integration for many reasons. At lower temperatures (< 100°C), solar radiation is converted to heat using mostly stationary collector technologies (flat plate collectors FPC, evacuated tube collectors ETC). With these mature collector technologies, challenges remain on integration aspects, further system cost reductions or automated control systems. General challenges to a wider application of SHIP are integration and hybridisation with other sources of heat supply (waste heat, heat pumps, biomass, …) or power generation (CHP), thermal storage integration at required temperature levels (up to high temperature thermal storage), direct process integration, automated control and simplified operation and maintenance, materials, receivers and technological advances for high temperature SHIP. Supply of solar heat at medium and high temperatures (100°C-1000°C) is using concentrating solar thermal (CST) technologies. For medium temperature applications up to approx. 400°C, linear focusing, single axis tracked collectors are used (parabolic trough collectors PTC, linear Fresnel collectors LFC). In large installations, such concentrating collectors may provide economic solutions also in lower T applications. For high temperature applications, point focusing collector technologies are available (dual axis tracked, parabolic dish, central receiver (tower) systems) which can generate heat up to 1000°C. In particular, energy intensive industry sectors have the largest share of heat demand in this high temperature range, to be addressed using CST technologies in combination with high temperature TES.

About 40% of the thermal energy consumption in the industrial sector is within the range 60–300ºC. These systems are often relatively small, which result in the demand for a robust and highly automated systems to reduce O&M cost and to increase the efficiency of the solar system for industrial processes. However, the sector still needs the development of highly autonomous solar fields to further reduce maintenance requirements and to increase the amount of thermal energy delivered to the industrial process. Also, significant cost reductions may be additionally achieved by the use of direct steam generation, which has many advantages over the use of thermal oil or pressurized liquid water as working fluid in line-focus solar fields. For high temperature industrial heat applications with temperatures up to 1000°C the development of suited receiver materials, technologies and autonomous solar fields promises to provide low-cost thermal energy and such reduce significantly the release of CO_2 to the atmosphere.

Specific Challenges to Achieve Targeted Impact

- Autonomous and smart solar fields e.g. fail detection software, active & predictive management of solar plant.
- Suitable high temperature (600-1000°C) receivers adapted to industrial processes
- Materials for increased robustness and durability
- More reliable and cost-effective receiver tubes (even non evacuated)
- Low melting point heat transfer fluids to reduce operating costs
- Solutions to satisfy 24h operation
- Development of software tools for predictive design and test a solar plant in industrial environment
- Materials and functional materials for increased robustness, efficiency and durability
- Hybridization by integrating power generation from the produced industrial heat or from waste heat
- Hybridisation with other (renewable, conventional) heat sources and TES at all temperature levels