The Future of High-Temperature Heat Pumps

Why High-Temperature Heat Pumps?

Heat pumps, as we know them today, are mainly used for **space heating** and **domestic hot water**. The required temperature levels are modest—usually below **70°C**. For heating above **100°C**, industry has until now relied on **fossil fuels**, or in some cases **biofuels**.

Globally, there is increasing pressure to reduce fossil-fuel use to limit **CO_2 emissions**. This will also increase competition for biofuels. At the same time, awareness is growing that the fastest way to decrease atmospheric CO_2 is to **increase global biomass**, for example by planting more trees. Increasing bioenergy harvesting risks doing the opposite—**reducing** the amount of carbon stored in biological material.

This raises an urgent question:
How will we supply high-temperature heat for industrial processes in the future?

The natural answer is **high-temperature heat pumps** powered by **fossil-free electricity** (wind, solar, hydro).

Future scenarios show strong expected growth in heat pump deployment. A notable market analysis in the field of **Waste Heat Recovery (WHR)** predicts that the value of sold WHR units, including heat pumps, will increase by **50% between 2018 and 2025**.[1]

According to an **IEA** report[2], the total number of heat pumps installed globally per month will rise from today's **1.5 million**, to **5 million in 2030**, and **10 million in 2050**. The report also anticipates rapid development of industrial heat pumps for the **100–400°C** temperature range.

The **U.S. Energy Information Administration (EIA)** estimates that global energy use will grow by **50% between 2018 and 2050**[3]—significantly increasing the risk of higher greenhouse gas emissions. This threatens the Paris Agreement target of limiting temperature rise to **no more than 2°C**.

In this article, we describe the **current state of research** and the **remaining challenges** before high-temperature heat pumps can become a widely commercial product.

Industrial processes require heat for **drying**, **evaporation**, **dehumidification**, **pasteurization**, and more.

For example, the Swedish wood and pulp industry uses around **20 TWh of energy per year**[4]. Today, biofuel is widely used for drying, but if the value of biofuels increases, large-scale use of heat pumps may become highly attractive.

Classification of Heat Pumps

Heat pumps can be classified according to the **temperature levels** they can reach.

Figure 1. Classification of heat pumps according to temperature level.

According to this system, nearly all heat pumps in use today are **low-temperature** units. But **medium-temperature** heat pumps have been commercial for decades, installed for example in district-heating systems already in the 1980s. They can also be used for industrial drying, distillation, and sterilization.

For every heat pump, the **temperature difference** between the cold and hot sides is crucial for efficiency. The theoretical maximum COP is given by the **Carnot equation**:

$$COP_{\text{Carnot}} = \frac{T_1}{T_1 - T_2}$$

where T_1 and T_2 are the hot and cold temperatures in Kelvin.

As the equation shows, doubling the temperature lift halves the theoretical COP. Therefore, high-temperature heat pumps benefit greatly from having a high-temperature waste-heat source.

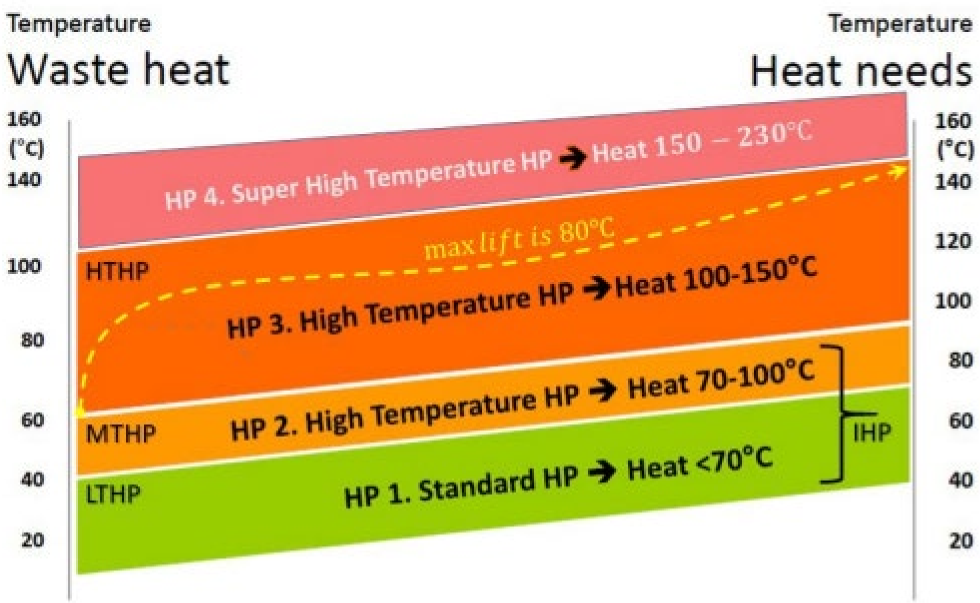

Figure 1. Classification of the heat pumps based on the temperature levels

Substantial R&D efforts focus on heat pumps delivering **100–150°C**, and commercial units already exist. The development goal is **beyond 150°C**, ideally **200°C** or even **300°C**.

However, Carnot limitations must be kept in mind. A heat pump operating between **20°C and 300°C** will have a theoretical COP of only about **2**, and in practice lower than that. The advantage over direct electric heating is therefore modest in such extreme cases.

If **100°C waste heat** is available as a source, the theoretical maximum COP approaches **3**, and between 100°C and 200°C it rises to **4.7**.

Technical Challenges for High-Temperature Heat Pumps

As with all applications, the refrigerant must be selected based on the desired temperature levels.

One must aim for **reasonable pressure levels**:

- **Very low pressures** require large pipes and large compressor swept volumes.
- **Very high pressures** impose stricter mechanical strength requirements.

Another key property is the **critical temperature** of the refrigerant.

In earlier articles, we have explained that COP tends to drop if the **condensing temperature approaches the critical temperature**. Many traditional refrigerants have critical temperatures near **100°C**, making them unsuitable for high-temperature heat pumps.

Because pressures rise strongly with temperature, it is natural to look for **low-pressure refrigerants** with **high critical temperatures** for this application.

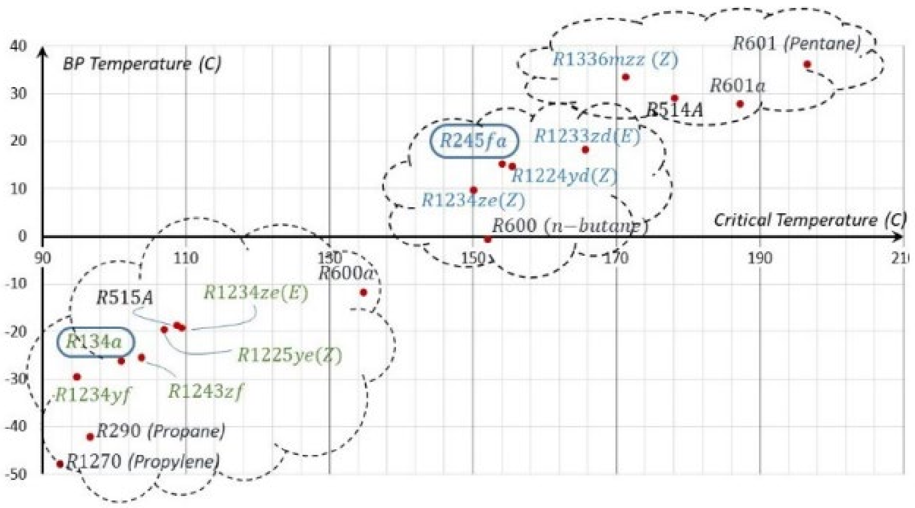

Figure 2. Relationship between boiling point at 1 bar and critical temperature for a selection of refrigerants.

As Figure 2 shows, there are HFCs, HFOs, and natural refrigerants that may be suitable. Transcritical cycles (e.g., CO_2) may also be relevant.

At KTH, a new project is currently exploring **high-temperature heat pumps and refrigerants**. Besides refrigerant selection, **compressor oil** selection is another major challenge.

A **radical solution** for high-temperature heat pumps is to use **water** as the refrigerant.

Advantages include:

- Safe, non-toxic, environmentally benign
- Very high critical temperature
- In processes where heating water is the objective, the same fluid acts as **refrigerant and heat carrier**
- Recent work from Trondheim shows water can even act as a **lubricant in a compressor**[5] (with special compressor design)

Several universities are now focusing on high-temperature heat pumps, and a detailed report on ongoing projects and completed installations has recently been published[6].

Industrial Need and the Coming Expansion

As noted above, industry needs heat at **higher temperatures** than today's heat pumps can normally supply. As fossil fuels are phased out and competition for biofuels increases, the market for high-temperature heat pumps is expected to **expand dramatically**. We are at the very beginning of this development.

A Side Note…

Earlier, we wrote about **TFA (trifluoroacetic acid)**—a degradation product of many HFO and HFC refrigerants, with long environmental lifetimes and suspected impacts on health and ecosystems.

In summer, it was announced that five EU countries, including Sweden, intend to propose **stricter legislation** on **PFAS substances**. Because TFA belongs to the PFAS group, this may eventually impact **refrigerant use** as well.

We will surely return to this topic.[7]

References

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