APPLICATION OF INDUSTRIAL HEAT PUMPS

Rainer Jakobs[1], Laurent Levacher[2], Hans-Jürgen Laue[1]
[1] Information Centre on Heat Pump and Refrigeration e.V.
Karlsruhe + Breuberg Germany, Jakobs@izw-online.de Laue.IZW@t-online.de
[2] Energy Efficiency Research for Industry
EDF - R&D, ECLEER, laurent.levacher@edf.fr

Abstract: Markets for heat pumps have been expanding at a healthy rate over recent years. Two major drivers have been uncertainty over energy prices and growing environmental and climate concerns, which have highlighted the need to save energy and optimize renewable energy sources.
Heat pump markets in many countries have focused chiefly on residential heat pump applications. Turning to heat pumps for high capacity in commercial and industrial applications has been much less of a natural reflex. Increased energy cost and awareness of the need for reduction of CO_2 - emissions are drivers for large heat pumps. The main market barriers are expected to be lack of experience and thus lack of acceptance in market.
This paper summarizes the objective of a new started IEA Annex to reduce the use of energy and greenhouse gas emissions by the increased implementation of large heat pumps. This paper will also highlight some successful applications.

Key Words: Industrial Heat Pumps, Definition, Application Potential

1. INTRODUCTION

Following the first two rounds of oil price increases in 1973 and 1982, the world got used to relatively inexpensive energy which was often wasted and not sufficiently recycled. The recent price increases, raising awareness of its inexorable depletion and the impact of global warming again underscore the need to control the consumption of energy. This raising awareness is almost worldwide, resulting in international agreements (Kyoto and Montreal protocols), political action (white papers, parliamentary debates), laws and regulations.

Europe has adopted a particularly pro-active position in the world and has, in particular, issued standards and directives to encourage increased energy efficiency in all the member states (Directives: 2006 Energy End-Use Efficiency and Energy Services, 2002 energy performance of buildings, 2003 tradable CO_2 emission permits). Most member states have transcribed theses directives into national legislation.

Industry, given its primarily economic motives, has been the "good boy" in terms of energy efficiency and significant results have been achieved over the last thirty years. Nevertheless, there remains a great potential for energy efficiency in this sector, which uses 1/3 of the energy in Europe. Indeed, whilst energy intensity in industry decreased by 2 to 3 % per annum before 1990, it then settled to a more moderate level of 1 % per annum. Potential energy savings with the best available technologies, i.e. excluding technological failures, has been estimated to be between 15 and 20 % of consumption by industry in Europe.

The evolution of the context and the will to find more extensive energy savings require a review of all acquisitions and develop more ambitious analyses, particularly in terms of the boundaries of analysis. This new approach analyses processes from raw materials (or halffinished products) to end products, including not only the products themselves, but also co-products, waste, gas and liquid effluent for all sectors.

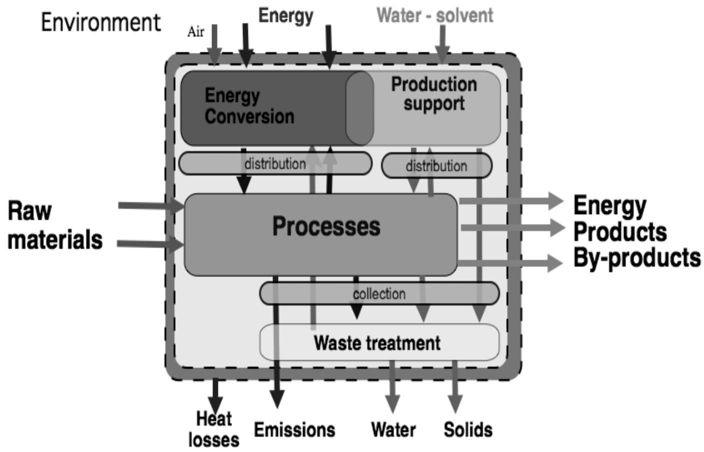

Figure 1: Final representation of a production process

The systemic view of a production site given in figure 1 defines the system concerned by energy efficiency. In this system, the process or processes transform raw materials into products and reusable by-products. Processing is carried out using various production methods, depending on the sector. The vector for such processing is energy. For this, it is necessary to convert the energy purchased and distribute it in the most appropriate form to meet the requirements of the process. Since processing raw materials into products and by-products is not perfect, the process produces waste which is then treated and/or recycled and degraded energy.

Energy and exergy analyses include all the components of processing. The approach should be implemented to the level of detail required to compare the process studied with competitive processes and include the limitation of emissions of pollutants of all kinds. The field of analysis is that of the processing of materials to achieve a finished product, energy optimization concerns the best available processing path.

The heat pump (HP) markets are currently growing at a steady pace. The prices for energy and environmental concern set focus on energy conservation and use of renewable energy sources. Heat pump markets and policy in many countries have focused mainly on residential heat pumps for space heating and domestic hot water.

While the residential market may be satisfied with standardized products and installations, most industrial heat pump applications need to be adapted to unique conditions. In addition a high level of expertise is crucial. Industrial heat pumps within this annex are defined as heat pumps in the medium and high power ranges which can be used for industrial processes and in industrial, commercial and multi-family residential buildings as well as district heating. Their potential for energy conservation and reduction of CO_2 - emissions is enormous.

Heat pumps for high temperature applications and industrial use have often been neglected. The share of energy cost has been low for companies and thus investments to improve production normally have a much higher priority than investments in energy efficiency. Increased use of energy has, to some extent, been an indication of economic growth. The industrial sector is of course a large energy consumer. Figure 2 shows, as an example, how close in size industry's share of total energy consumption is to that of households and services in the European Union.

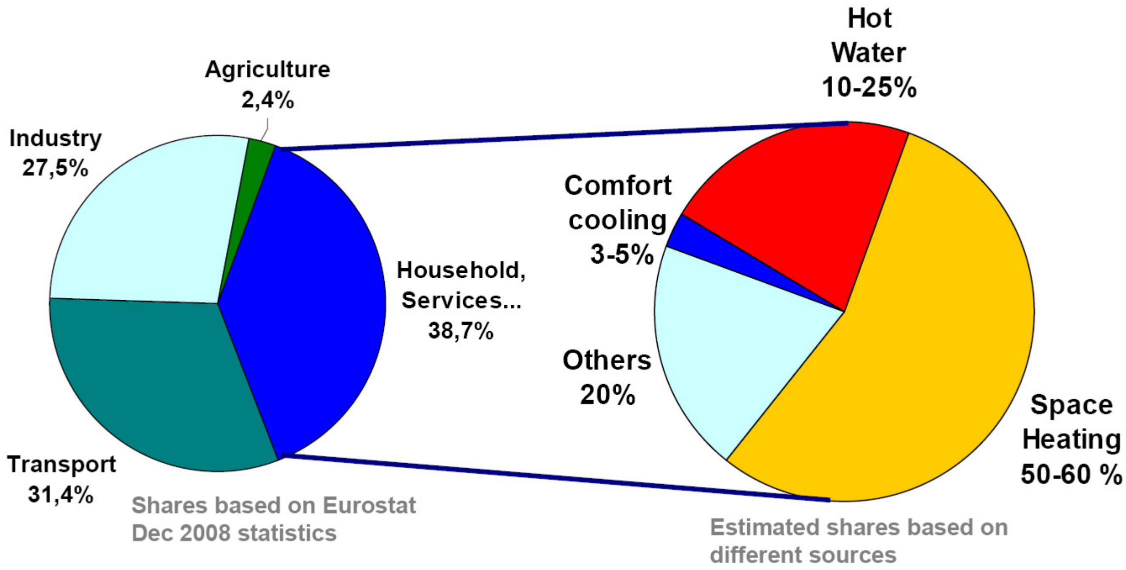

Figure 2: Final Energy Consumption -EU 27- by Sector (2006)

Under the IEA Implementing Agreement on Heat Pumping Technologies already two annexes dealing with industrial heat pumps were executed:

HPP Annex 9: High Temperature Industrial Heat Pumps (1990)
HPP Annex 21: Global Environmental Benefits of Industrial Heat Pumps (1992 -96)

HPP Annex 21 generated an overview of potential industrial heat pump applications and also developed an "Industrial Heat Pump Screening Program" to determine how industrial heat pumps could be used in different applications. Since the final report on Annex 21 there are new possibilities and new developments:

Better and further developed software
Newly available compact components
Higher energy costs and expected further rise
More stringent government legislation (reduction of Carbon dioxide emissions)
New refrigerants considerations

A strong motivation for launching this initiative is the enormous potential for energy conservation and reduction of CO_2 - emissions that industrial heat pumps offer, a potential that policy papers do not currently take into account.

2. WASTE HEAT IN INDUSTRY

Energy losses in industry are partly due to the lack of motivation in rehabilitating some installations near the end of their life, often built at a time when energy performance was not a priority. They can also be explained by the difficulty in improving the energy efficiency of existing installations that cannot be modified in depth. This improvement requires an exhaustive knowledge of available technologies to recover and use lost energy, frequently at low temperature (usually less than 150°C, see some examples in the following table). It also requires the use of sophisticated scientific approaches to identify heat flows and the best way of using them as a function of their quality and field constraints.

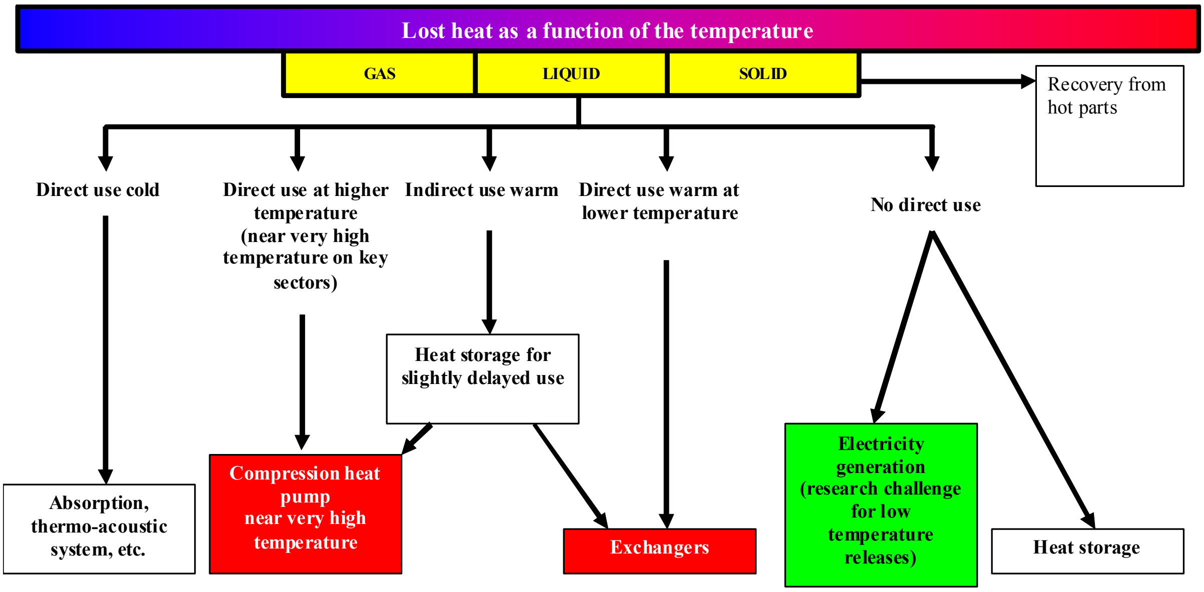

Figure 3: Lost energy way

It is possible to give priority to:
better energy management in the long term and in different places due to the use of heat exchangers, and storage and distribution systems;
an increase in fluid temperatures using the heat pump technologies;
electricity generation using electricity generating cycles (e. g. organic Rankine cycles) or the use of thermal electricity;
chemical or biological conversion, for example for the production of bio fuels;
production of cold; etc. …

Therefore, improving the energy efficiency of existing installations requires:
a large quantity of data about industrial processes and the technologies to be used; and knowledge and know how of specialists to select and size better energy paths based on economic and environmental criteria, etc.

A heat source can be exploited when its energy can be transported or transformed so that it can be sold to a third party, or if it can be used to reduce energy purchases. We can already define a minimum temperature threshold at which a heat source can be included in the «exploitable» category: 40 °C would appear to be a minimum because the ambient temperature is very close to this threshold in summer. The following table indicates sources and temperatures applicable to some industrial fluids or solids.

Table 1: Example of waste heat to be reused

Type	Temperature	Place	Advantages/Disadvantages
Exhaust gases	120-600 °C	Chimney stacks	+ High volume flow - High temperature - Content of corrosive products
Steam	100-400 °C (1-40 bars)	Flares in the chemical industry	+ High enthalpy Pressure constraints - Discontinuity
Condensates (liquid water)	60-90 °C	Condensate returns	+ Compact air/water exchangers – Low temperature Acidity
Solids	60-400 °C	Ash from solid fuels	+ High density - High temperature – Heat exchanges difficult
Hot air	40-90 °C	Cooling towers	+ High volume flow- Large air/air exchanger Low temperature

Therefore, there are four major sources of energy that can be recovered, transformed and exploited:
Hot products: for example, a product at 1.000 °C in an annealing line (steelworks) can «restore» up to 84% of the energy that it received when it cools (energy representing 75% of the energy used by the process).

Hot liquid effluents: for example when manufacturing cheese, there are several washing and rinsing operations (cleaning tanks and cleaning in place of the circuit, mould tunnel washing cycle and tray washing cycle) use water on hot objects (between 50 °C and 75 °C), from which the energy is not recovered.

Hot exhaust gases: for example during heat treatment of boiler tubes, with precise temperature control to +/-5 °C at a temperature of 700 °C, a furnace consuming 1.872 MJ/t can reject up to 1.123 MJ/t in its exhaust gases.

Effluents and by-products sometimes have a high energy value:

● either because they are composed of elements that can be exploited directly (combustion) or after a drying or concentration type treatment, for example

• burnt straw, wood, or black liquor; • air containing solvents from paint booths; • oil-based effluents from mechanical industry;

● or because they can be transformed by a chemical or biological method into a usable product (at variable times in the future):

• dry wood residue type by-products (gasification to produce heat and electricity, hydrolysis and fermentation to produce ethanol, pyrolysis to produce biogas); • wet sludge type by-products (methanisation and biogas to generate electricity and heat, biogas that could be injected into the network) • starch or oil type by-products (fermentation to produce ethanol, trituration or esterification to produce biodiesel)

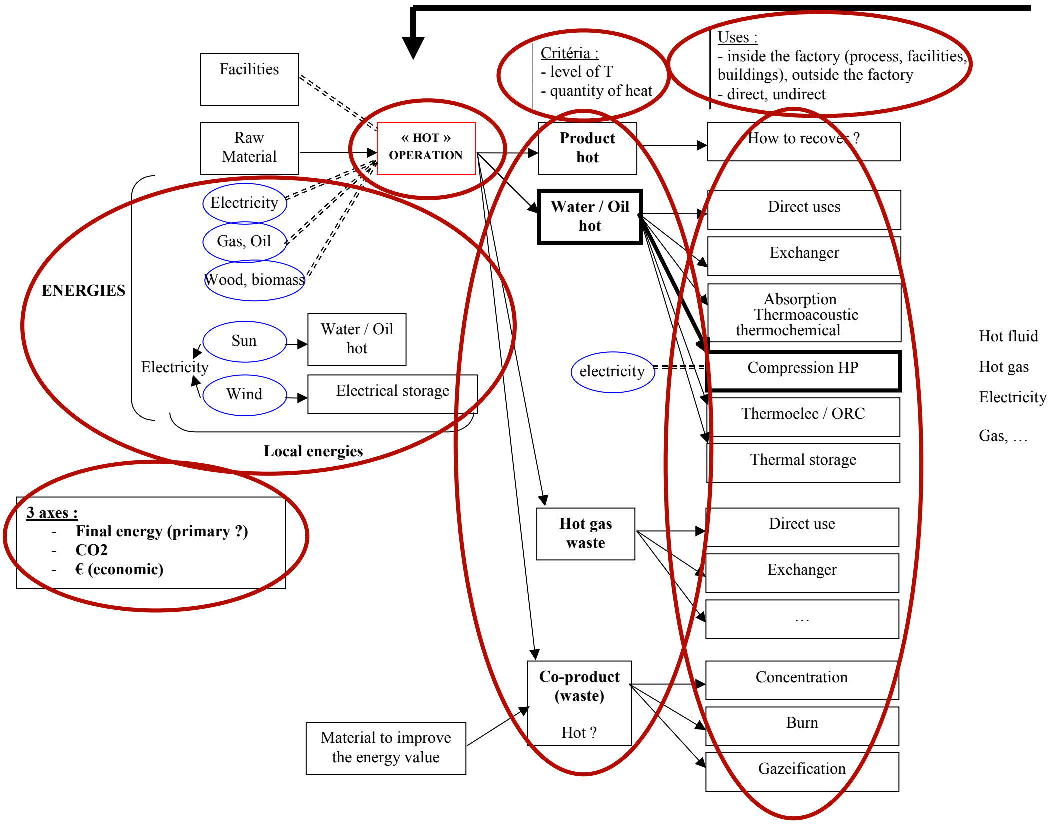

Figure 4: Energy recovery, recovery and conversion technologies

3. MAIN BARRIERS

The main market barriers are expected to be lack of experience and thus lack of acceptance in market with operators, industrial partners and its supply and consulting chains. These barriers can be broken down into several focal points for work to be undertaken under the Annex. There are at the start of the Annex four different directions:

● Introduction of heat pumps in process industry such as chemical industry with its distillation columns, the pulp and paper and steel industry. Advanced software models are used by large specialized engineering companies. Process intensification and standardized and proven concepts are applied.
● Introduction of heat pumps in industrial processes on a smaller scale, especially in food industry (breweries and dairies), where both heating and cooling are used. Specialized suppliers are active in this field of standardized machinery and concepts up to complete turn-key built factories. Some of these are aware of the possibilities to increase efficiency of their products by integrating heat pump technology in their concepts and products.
● Expansion of cooling processes towards the use of condenser heat and heat wasted in cooling towers, as this is one of the new developments among suppliers of refrigeration and cooling concepts.
● Introduction of heat pumps in small manufacturing companies, often located at a common area, where heating of offices is the main use of heat and the other energy need is power to drive machinery.

The temperature level of the waste heat is determined by process fundamentals and process equipment design, and is thus, for an existing plant, set. However the temperature level which the waste heat appears and can be used is determined by the design of the utility systems, i.e. cooling water and air. This essential difference is often overlooked when discussing waste heat utilization.

The amount and temperature level of the waste heat can be determined by process integration methods, e.g. pinch analyses. These methods are powerful tools and give a total picture of the situation at the plant including the possibilities for internal use of the heat. There are several competing alternatives to utilize waste heat and it is normally not obvious which the most favorable one is. The heat can internally be better used for heating purposes and in new or modified process parts. Heat pumping is one of the alternatives which are today already common practice in some branches and with a large potential to grow in other industries. Another option is to use the heat for heating demands outside the plant in a district heating system.

To be able to increase the awareness of possibilities and to select between the alternatives, a high level of expertise for system design, process integration and planning is crucial. Design software on process integration and design plays an important role at this stage. However, this seemingly being a complex approach needing a lot of high level expertise, simple straight forward solutions on a small scale should not be overseen.

There seems to be a lot of barriers to apply heat pumps. On the other hand it is also noticed that in several sectors there are successful heat pump applications.

4. TECHNICAL ASPECTS

While there is enormous potential and scope to exploit, the work of the new Annex must be tailored to resources available and aim at realistic targets that are smart in terms of economic efficiency. We shall therefore start with an overview of technologies and applications, and analysis of technical barriers affecting the decision-taking process in existing and new applications.

● Overview of the development of components and heat pumps from medium sizes upwards and the need to develop new technology
● Develop technology to reduce energy costs, fossil energy consumption and CO_2 -emissions
● Find possibilities to integrate heat pump technology into standard process machinery
● Develop ways to avoid the constraints related to medium and high temperature refrigerants and adapt compressors for high temperature and capacity control

4.1 Definition

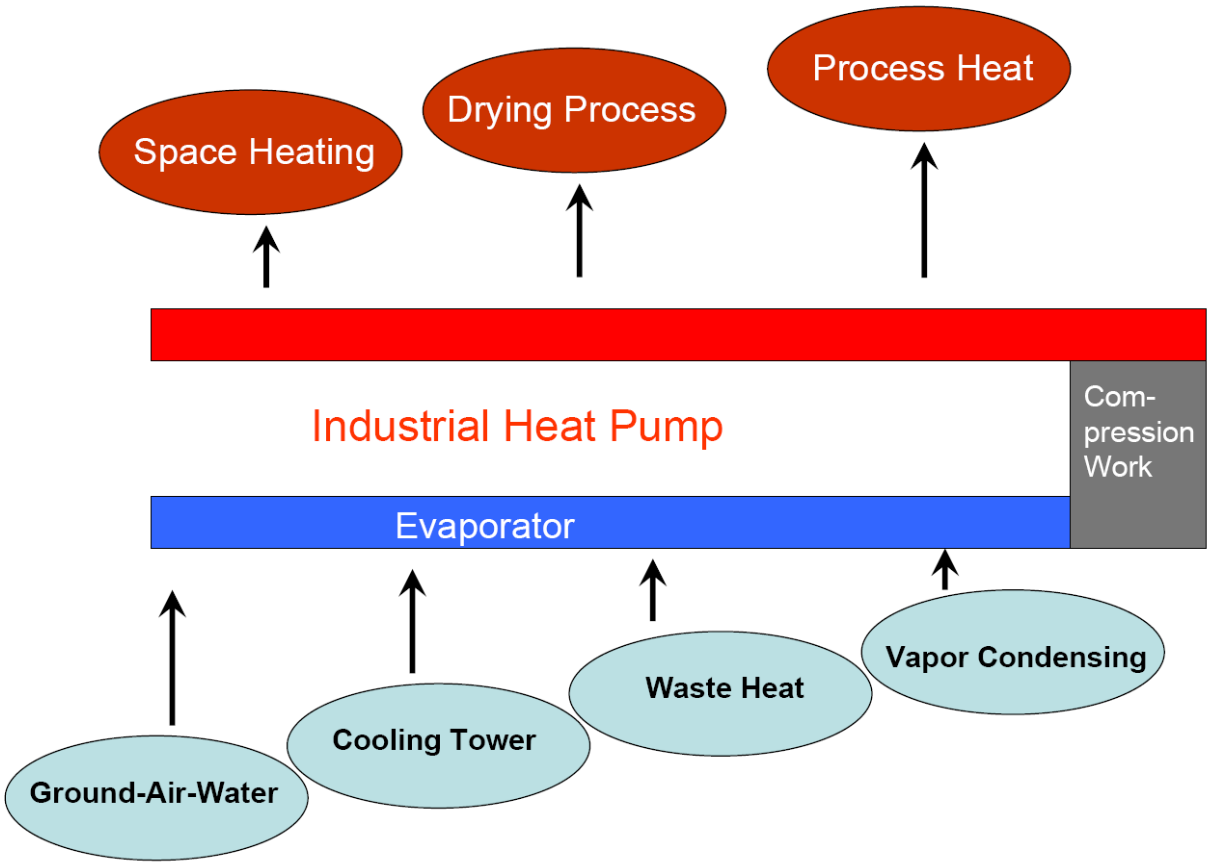

Figure 5: Heat pump with combination of cooling and heating (heat source and heat sink in industrial processes)

"Industrial heat pumps" IHP within this annex are defined as heat pumps in the higher temperature and medium and high power ranges that can be used for heat recovery and heat upgrading in industrial processes, but also for heating, cooling, air-conditioning in industrial, commercial and multi-family residential buildings, also for district heating:

● Space heating: Heat pumps can utilize conventional heat sources for heating, cooling and air-conditioning in industrial, commercial and multi-family residential buildings as well as district heating. They can recover industrial waste heat that could not be used directly, and provide a low- to medium temperature heat that can be utilized internally or externally for space and greenhouse heating.

● Process water heating and cooling: Many industries need warm process water in the temperature range from 40-90 ºC, and often have a significant hot water demand in the same temperature range for washing, sanitation and cleaning purposes. This can be met by heat pumps. Heat pumps can also be a part of an integrated system that provides both cooling and heating.
● Steam production: Industry consumes vast amounts of low-, medium- and high-pressure steam in the temperature range from 100-200 ºC. Steam is used directly in industrial processes, and for heat distribution. Current high temperature heat pumps can produce steam up to 150 ºC.
● Drying process: Heat pumps are used extensively in industrial dehumidification and drying processes at low and moderate temperatures (maximum 100 ºC). The main applications are drying of pulp and paper, various food products, wood and lumber. Drying of temperature-sensitive products is also interesting. Heat pump dryers generally have high performance, and often improve the quality of the dried products as compared with traditional drying methods. Because the drying is executed in a closed system, odors from the drying of food products etc. are reduced.
● Evaporation and distillation processes: Evaporation and distillation are energy-intensive processes, and most heat pumps are installed in these processes in the chemical and food industries. In evaporation processes the residue is the main product, while the vapour (distillate) is the main product in distillation processes.

4.2 HP Type and Application Range

Type of industrial heat pumps

- closed compression cycle, electric motor-driven or motor-driven
- mechanical vapour recompression (MVR) and thermal vapour recompression (TVR)
- absorption – compression cycle; absorption cycle; adsorption cycle

Temperature range

- To 100 °C and more
- Heat sink temperature: > 70 °C
- Heat source: < ~60 °C
- Heat recovery from ~50 – 60 °C, upgraded to ~90 – 100 °C

Power Range

- Medium power: 50 – 150 kW
- High power: 150 kW to several MW

Refrigerant Limits

Limit of present, most common HFC: ~ 80 °C

- > 80 °C: NH_3 –H_2O; NH_3; CO_2 ; R290(Propane); R600 Butane and
- some HFCs: Pentafluorpropan (R245fa); Pentafluorbutan (R365mfc)

Research and development high temperature e.g.:

- R718 (H_2O); R744 (CO_2); R717 (NH_3); Mixtures R717-R718

5. FOCUS

Focus will be on medium to small size process industries and industrial areas with small manufacturing processes:

- Specialized suppliers of standardized machinery, concepts and turn-key factories not aware of the possibilities to increase the energy efficiency of their products by integrating HP technology in their concepts and products.
- Development and application of high temperature heat pumps.
- Standardisation in cooling processes towards the use of condenser heat and heat wasted in cooling towers.
- Small manufacturing companies, often located at a common area, where offices are the main use of heat and the other energy need is power to drive machinery.

The work will also focusing on analysing the status of heat pumps in models and the system aspects requiring technological knowledge as input in the models, see (Lambauer et al. 2008 a) and (Becker et al. 2009).

Reliable data are important for design of the heat pump systems for industry with each unique installation. To have reliable tools for design is of utmost importance for the installers of the systems. Adequate integration of heat pumping technology in process design methodologies and manufacturing process technologies is important.

6. POTENTIAL ANALYSIS FOR LARGE SCALE HEAT PUMPS IN GERMANY

As shown in figure 2 27.5% of the final energy consumption in Europe is used in the industry. Figure 6 shows the energy consumption of the main industries in selected European countries. Only one third of the energy is electricity. Oil, gas and coal dominate the final energy use in the industry.

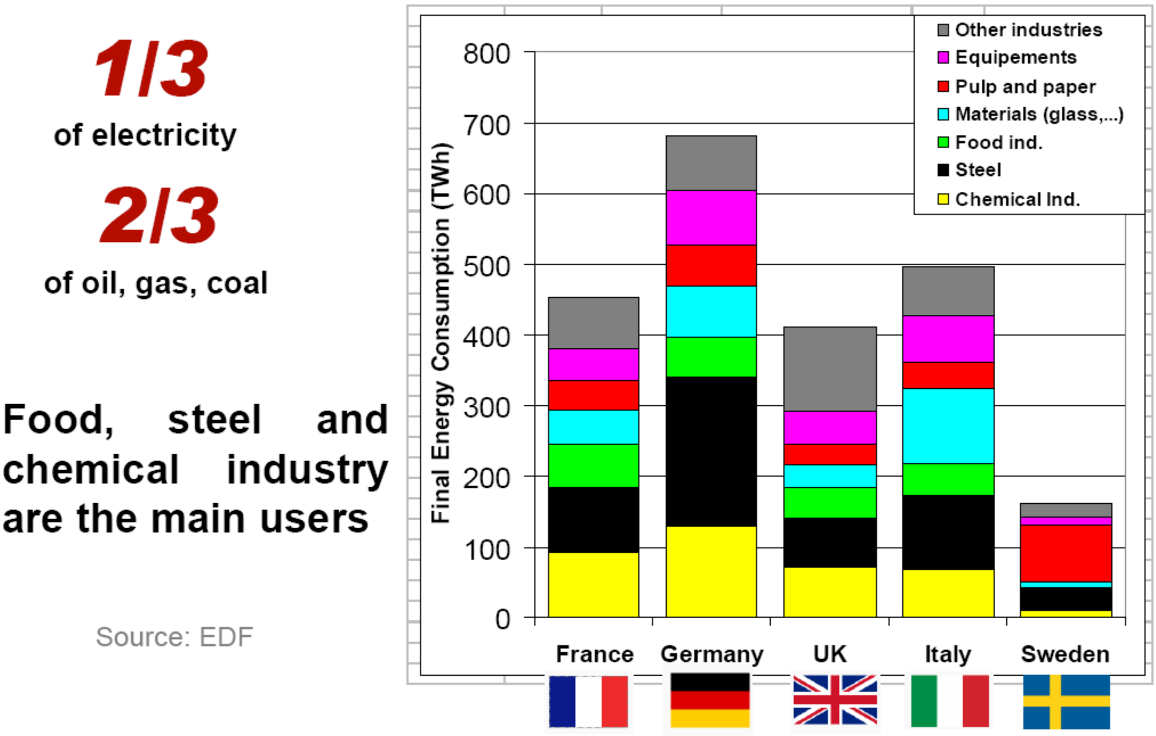

Figure 6: Energy consumption in the industries (700 TWh = 2,520 PJ)

According to (Heidelck et al. 2000), (IZW-DKV 2000), and (IZW-DKV 2001) the use of IHPs in Germany is relatively low compared to other countries.

To estimate the technical potential that can be made available by the use of HP technology in the German industry sector, calculations in regard to the usable temperature level and the identified applications based on the energy consumption of different branches of industry are conducted by (Lambauer et al. 2008 a,b) The possible reductions in primary energy consumption as well as CO_2 - emissions are calculated. This analysis is done for different sizes of enterprises within the same branch of industry to consider for example differences in energy cost and production structure.

The conducted analysis shows for Germany that for hot water supply in industry around 14.6 PJ per year could be provided by heat pumps. For low temperature process heat and for heating three different steps are calculated in regard to the possible output temperature of heat pumps (70 °C, 80 °C and 100 °C). At current technological level (70 °C) heat pumps could supply around 161.4 PJ for heating and 55.1 PJ process heat per year. Altogether HPs with their current technology have the potential to supply 231.1 PJ per year. By raising the temperature to 80 °C this number increases of about 10.6 PJ per year supplied by HPs. To raise the possible temperature level up to 100 °C would result in an increase of possible heat supply of additional 147.9 PJ per annum. Figure 7 illustrates the potential of heat supply for HPs for selected industry branches. This graph shows the importance of raising the possible output temperature of industrial heat pumps from currently around 70 up to 100 °C.

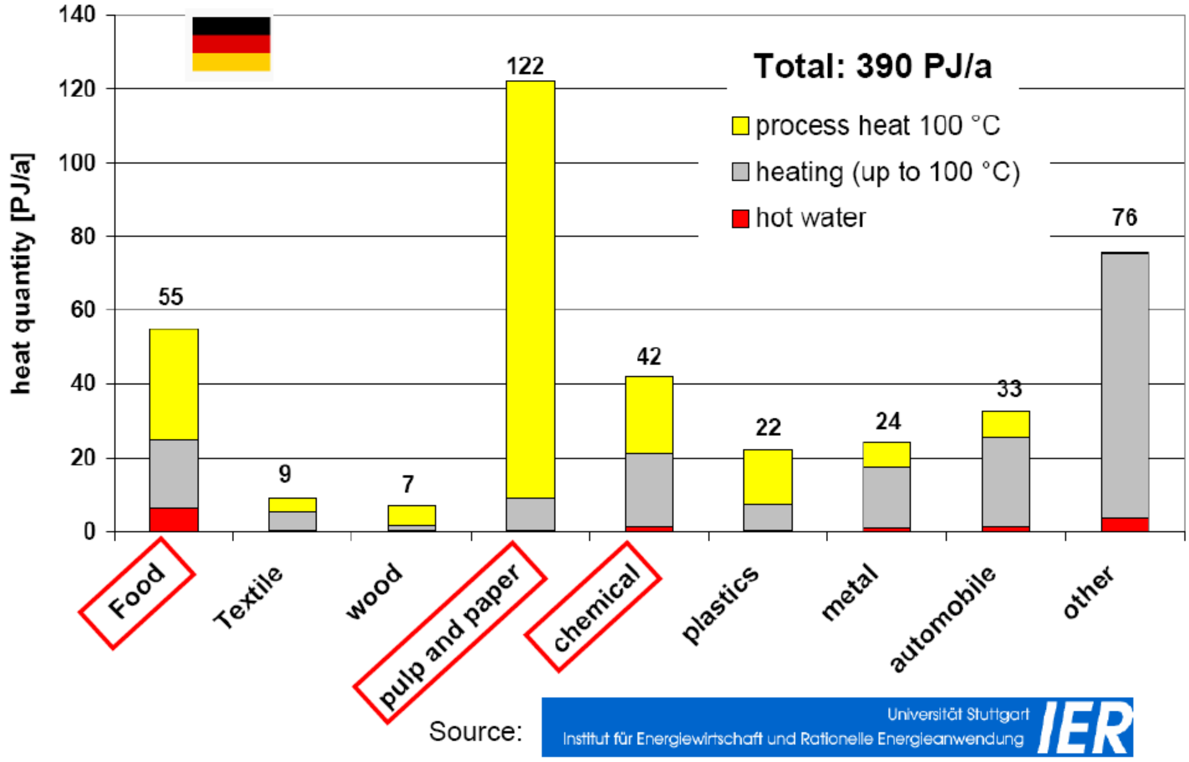

Figure 7: Potential Analysis for large scale heat pumps in Germany

Heat pumps (output temperature 100 °C) have the possibility to provide around 390 PJ per year which is equal to around 16 % of the total energy consumption of German industry in 2005. But up to now just a very small number of this potential is used by IHPs.

7. HEAT PUMP APPLICATIONS

Värtan Ropsten, Sweden, the largest sea water heat pump, successful in operation since 1985, district heating 180 MW; 80°C

Nimrod in Stockholm City is a district cooling and heating plant operating since 2001. The cooling capacity is 48 MW and the district heating capacity is 36 MW. Sea water is heat sink and heat source.

SYSAV Malmö – waste incineration plant with heating capacity of 19 MW running since 2002

Sandvika, Oslo, Waste heat recovery from sewage water, Heating capacity 14 MW, water temperature for district heating 78°C,

Skoyen Vest, Oslo, Waste heat recovery from sewage water, Heating capacity 12 MW Hot water production temperature 90°C, operating since 2005

Katri Vala, Helsinki, District heating and cooling production, heating 90 MW and cooling 84 MW, operating since 2006

EnergieAG Powertower Linz, First Austrian High-Rise Passive Building, Ground source HP, 780 KW, 35°C, First Austrian High-Rise Passive Building

Basel, Waste water plant since 20 years, heating capacity 800 kW

Winterthur**,** Waste water plant, heating capacity 820 kW

Modernization Luxushotel 5* Carlton in St. Moritz, Domestic hot water production, 150 kW, since 2006

Further information see: http://www.heatpumpcentre.org/ http://www.ehpa.org/ http://www.hp-summit.de/en/ http://www.hptcj.or.jp/e/index.html http://www.ecleer.com

8. TARGET AND BENEFITS

Reliable data are important for estimation of the potential energy savings and emissions reduction with the technology for a sustainable society. This is mainly addressed to policy makers for input to directives and legislation, and as input to statistics. Correct design is essential for the long-term reputation of the technology. This is mainly addressed to installers, manufacturers and consulting engineers.

Finally, it is important to have a fair comparison between different heat pump systems in order to contribute to a sustainable society and also to support state-of-the-art technology. Reliable data for marketing will simplify the selection procedure for the end users and stimulate the manufacturers to develop new generations of competitive and efficient heat pumps. In order to contribute to a sustainable society, it is of importance that the heat pump systems eventually installed are selected among the best heat pump systems on the market.

9. CONCLUSIONS

HP markets in many countries presently focused on residential application. HPs for industrial and commercial applications have on many markets been neglected due to the payback period. As energy cost are growing, industrial payback period values are more easily attainable. Need for research & development for high temperature use IHP`s potential for energy conservation and reduction of CO_2 - emissions is enormous. The objective of the new HPP Annex **Application of Industrial Heat Pumps** is to reduce the use of energy and emissions of greenhouse gases by the increased implementation of large scale HPs in industrial and commercial application.

● Developing information for key stake holders in industry and its supply and consulting chain.

● According to the current analysis of potential applications and the best-practice examples it can be concluded that the main applications are hot water supply and space heating.
● For most industrial processes the possible temperature level of current heat pumps is not sufficient. But the use of waste heat offers in addition to the result of the potential analysis another huge potential for heat pumps in industry.
● Furthermore the contact with manufacturers, potential users, planers, associations and information centre shows that the knowledge about large scale heat pumps is rather low.
● For the application of heat pumps specific conditions must be adhered in order to get satisfying results.

10. REFERENCES

IEA 1995, IEA Heat Pump Centre. Industrial Heat Pumps, Final Report from Annex 21 of the Heat Pump Programme. April 1995.

Heidelck R., Kruse H., Laue H.-J. (IZW) 2000. Wärmepumpen in Gewerbe und Industrie – Ein Überblick. In: **IZW-DKV 2000,** Deutscher Kälte- und Klimatechnischer Verein (DKV): IZW-DKV Wärmepumpenstatusbericht Nr. 2: Wärmepumpen in gewerblichen und industriellen Anwendungen. Stuttgart, DKV Dezember 2000.

IZW-DKV 2001, Deutscher Kälte- und Klimatechnischer Verein (DKV): IZW-DKV Wärmepumpenstatusbericht Nr. 4: Wärmerückgewinnung durch Wärmepumpen, Stuttgart, DKV Dezember 2001.

DOE 2003, U.S. Department of Energy, Industrial heat pumps for steam and fuel savings, Industrial technologies programm, DOE/GO-102003-1735, June 2003, 17p.

Lambauer J., Fahl U., Ohl M., Blesl M., Voß A. **2008a**. Industrielle Großwärmepumpen-Potenziale, Hemmnisse und Best-Practice Beispiele, Forschungsbericht, Institut für Energiewirtschaft und Rationelle Energieanwendung, Stuttgart, Germany 81p.

Lambauer J., Fahl U., Ohl M., Blesl M., Voß A. **2008b**. Large scale industrial heat pumps market analysis, potentials, barriers and best practice examples, Proc. 9th International IEA Heat Pump Conference, 20 – 22 May 2008, Zürich, Switzerland.

Becker H., Maréchal F., Vuillermoz A. **2009**. Process integration and opportunity for heat pumps in industrial processes, Proc. 22nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems August 2009, Foz do Iguaçu, Paraná, Brazil