NATURAL REFRIGERANTS IN HEAT PUMPS - A STUDY OF MARKET, TECHNOLOGY AND POLICY TRENDS IN NORTH AMERICA, EUROPE, CHINA & JAPAN

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Abstract: Today, a growing number of suppliers offer low GWP, natural refrigerant (NR) heat pump technologies ready to help satisfy demands for zero-energy buildings, high COP, and higher comfort often demanding mutual heating and cooling. However, while worldwide four million CO_2 refrigerant hot water heat pumps have been produced, the technology has been largely confined to Japan where such systems have reached highest market penetration levels thanks to strong governmental support and a well-established supply industry. This paper serves as a summary of market, technology and policy developments affecting the uptake of NR heat pumps. It integrates data from two studies conducted by shecco among the European and North American HVAC&R industry, as well as information obtained during leading conferences and trade shows 2011-2014.

Key Words: heat pumps, natural refrigerants, ammonia, carbon dioxide, hydrocarbons, market trends, technology update, policy, Europe, Japan, USA, China

1 INTRODUCTION

Market trajectories for heat pumps (HP) using ammonia, carbon dioxide or hydrocarbons have shown distinct differences for selected world regions. This paper aims to provide a brief market overview with examples of successful products commercialised, give an insight into recent technology trends, and outline which policies have already or could influence the further uptake of NR-based HP technology. Special emphasis for Europe and North America is put on two studies conducted by shecco in 2012 and 2013, to investigate overall prospects for the NR industry, the share of NR products being developed, their importance for R&D activities, as well as specific expectations regarding NR heat pump technology by 2020.

2 JAPAN

2.1 Market Overview

In Japan, the “Eco Cute” hot water heat pump (HWHP) using CO_2 refrigerant has been a run-away success over the past decade. It is estimated that four million units have been installed so far. Annual sales are now at 400-500,000 units per year, to reach a market share of 98% of all new residential HWHPs (Kimura, 2014). This number is likely to reach 10 million units by 2020. After first introducing CO_2 units in 2001, Panasonic announced in early 2014 one million units of cumulative sales (Shimada, 2014). Manufacturer Sanden stated that it would increase production of its hermetic CO_2 compressor, used in heat pumps and commercial refrigeration, from 300,000 units to 600,000-800,000 units a year (Ichikawa, 2014).

2.2 Technology Trends & Examples

In the country that has led the global uptake of CO_2-based HWHPs, innovation within the Eco Cute sector continues. In the residential sector, Sanden developed CO_2 space heaters with water output temperatures of 40-70°C and a COP of 4.0, made available in 2012 (Campy, 2012). Denso Corporation, which has a series of CO_2 heat pump units ranging in capacity from 4.5kW to 7.0kW, has developed a multi-functional CO_2 heat pump that also supports space heating, and a solar hybrid model, developed in conjunction with Sharp (Kimura 2014). The latter features a “Solar power assist” function that enables operation of Eco Cute with stored energy prior to solar power generation in the morning; and a “Summer mode” function, which allows for daytime savings without the concern of running out of hot water.

In the commercial sector, Mitsubishi Heavy Industries (MHI) developed a CO_2 heat pump with a rated heating capacity of 30kW, which is maintained in ambient air temperatures as low as -7°C. The air source heat pump is probably the first to use a two-stage CO_2 compressor, avoiding the significant heating capacity reduction occurring in low ambient temperatures. The HP’s average COP is 3.04. Field-testing in severe winter conditions in Hokkaido with temperatures as low as -20°C has shown reduced energy costs to 43-54% compared to conventional boilers (Takigawa, 2014). Mayekawa’s ‘Unimo’, an air and water source CO_2 heat pump suitable for hospitals, hotels and other facilities, achieved a 62% CO_2 emissions reduction compared to conventional hot water boilers (Komatsu, 2014). Designed to provide a constant supply of hot water, the output temperatures reach up to 90˚C. For material drying and heating, paint drying and similar applications, Mayekawa has also commercialised a CO_2 hot air heat pump, the ‘Eco Sirocco,’ which can achieve close to 50% emissions reduction compared to conventional systems.

2.3 Policy Trends

High-level government support has been a major factor in the success of Eco Cute CO_2 heat pumps. To draw lessons from Japan’s rapid market adoption of NR-based technology, a short overview of the country’s effective support scheme from 2002 until today is provided:

The government’s role in raising awareness with market players has been instrumental in early market adoption stages. The “Energy-Saving Grand Prize”, an annual government-affiliated award for excellent products and technology developed by Japanese institutions, was awarded to Eco Cute technology in 2001. It exerted a positive impact on the product’s introduction, as a guarantee of its effectiveness and reliability. In 2005, the government announced a target of 5.2 million Eco Cute units to be installed by 2010 under its “Kyoto Protocol Target Achievement Plan”. The Plan also required local governments to take initiative in introducing CO_2 HPWHs in line with the “Law on Promoting Green Purchasing”.

Whereas manufacturers are eligible to receive grants for R&D activities, a governmental subsidy scheme for buyers established in 2002 aimed to halve the price difference between Eco Cute and conventional boilers. Additional cost for consumers was reduced by about US$1,500. Each year, the amount of subsidy decreased in proportion to the price decrease of Eco Cute. After 2006, the scheme was changed to a fixed-amount support of about US$500, decreasing gradually thereafter (Sumi, Fukushi and Hiramatsu, 2010). In 2010, subsidies for households and commercial entities buying Eco Cute became available under the ‘Eco-Point Programme’ introduced as a time-limited measure for energy-efficient appliances. Eco Cute in residential use was subsidised with up to 40,000 Yen (~ 320€) while Eco Cute in commercial use could benefit from up to 830,000 Yen (~ 6,700€). Whilst the 2011 earthquake had a negative impact on CO_2 HP sales, the inclusion of HPWH in the Japanese Top Runner Approach in 2013 was expected to reverse this trend (Kimura 2013).

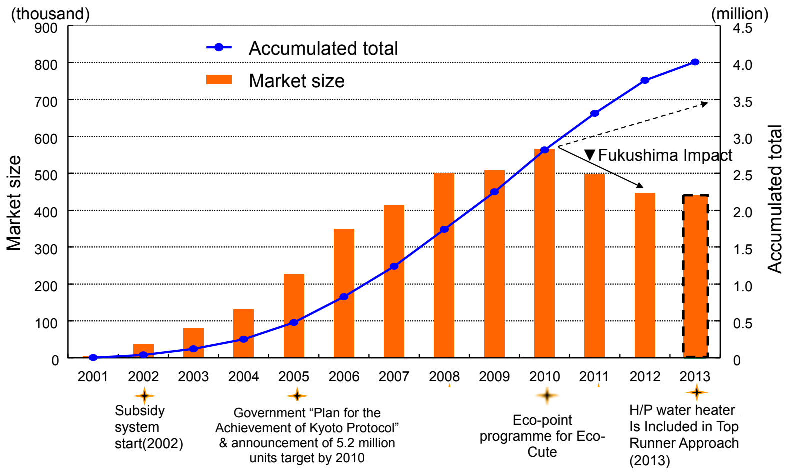

Figure 1: Market development of Eco Cute and Support Measures in Japan 2001-2013

It can be noted that the variety of support schemes and high-level support have led to a rapid market uptake of NR-based technology, in addition to broadening the range of products. Experience gained from developing CO_2 transcritical HPs has been used by Japanese suppliers to transfer results to other sectors, such as refrigeration and air conditioning, and to enter new markets outside Japan. Similar schemes to the Eco Cute support scheme by the Japanese government provide currently incentives for natural refrigerants in other sectors, such as in investment grants for end users investing in NR commercial refrigeration.

3 EUROPE

3.1 Market Overview

Market prospects for natural refrigerants are overall favourable, a growing number of HVAC&R industry professionals estimated in 2012. 16 manufacturers produced CO_2 HP systems for a variety of industry sectors and applications in Europe, a 2012 shecco study showed (Burhenne et al. 2012). In Denmark alone there are over 1,000 natural refrigerant heat pump units in operation (Van de Hoff, 2012). However, as compared to Japan and China currently advancing the use of CO_2 HPs, Europe has not yet caught up on driving the commercialisation of such models. The market share is at a low estimated 3% in the residential heating sector (shecco, 2012).

3.1.1 Natural Refrigerant Industry Distribution & Development Trends in Europe

A shecco study conducted in 2013 investigated the availability of European-based suppliers providing products and services for natural refrigerants (NR) - a prerequisite for any effective market uptake across the integrated European Union market and beyond. As a first indicative figure, a minimum of 400 European companies are active in the field of natural refrigerants. The resulting "suppliers map" provides evidence of three major trends: 1) The number of companies experienced in NR technology has increased steadily across Europe. Southern or Central European countries, where regulatory frame-works driving the adoption of HFC-free technologies have not been as stringent, would clearly benefit from more ambitious support for entities investing in NR refrigerant solutions. This could range from taxation and charge limits for f-gases, to bans in applications where HFC-free solutions have become mainstream, and/or incentive schemes for producers and end-users of natural working fluids. 2) Higher competition levels and growing R&D into NR technology can be found, driving down cost for HFC-free solutions. Various technologies have already reached similar or even lower capital and life cycle costs - a trend that is likely to increase with rising direct (cost of substance) and indirect (taxes, use restrictions, additional obligations, etc.) costs of f-gases. 3) As a result of greater activity in the NR industry, technology is becoming increasingly available. While sectors such as domestic and industrial refrigeration have already switched to HFC-free solutions, others are expected to do so in the foreseeable future, including commercial refrigeration and heat pump applications, to name just two.

3.1.2 Potential Commercial Availability of NR Heat Pump Technology in Europe

To further verify above-mentioned trends especially for the NR heat pump industry in Europe, shecco carried out an analysis of the potential commercial availability of such technology across the EU, for the period 2013 to 2025. The analysis was performed in close cooperation with technology providers. Table 1 indicates the potential commercial availability of air-conditioning sub-sectors, including heat pump water heaters (HPWHs) and heat pumps for combined space and water heating. NR-based HWHPs products are currently available in low volume production. The study concludes that by 2016 full commercial availability for HWHPs could be reached with sufficient production capacity. For NR-based HPs combining space and water heating, semi commercial availability will continue until 2018 before potentially reaching sufficient production capacity across Europe. However, the analysis concludes that while several national HVAC&R markets are already moving in the direction of limiting f-gas use even without regulatory measures, clear sector-specific f-gas bans would provide further certainty and impetus to a growing European NR industry with elevated innovation potential. Hence, the projected commercial availability assumes clear political signals to drive investment in NR-based solutions.

Table 1: Potential Commercial Availability of Natural Refrigerant Technology, Air-Conditioning Sub-Sectors in the European Union, 2013-2025

AIR-CONDITIONING	TODAY	2015-2020	2020-2025	2025
Movable room A/C				
Split A/C		2018		
Multisplit / VRF A/C				
Rooftop A/C				
Displacement chillers				
Centrifugal chillers		2018		
Heat pump water heaters		2016		
Heat pumps for space and water heating		2018		
A/C in cargo ships				

To investigate further general market, technology and policy trends in Europe, as well as specific trends for HP technology using non-fluorinated gases, a research project was conducted by shecco between March and November 2013. As the survey attracted more respondents familiar with or interested in natural refrigerant technology, this led to a clear overrepresentation of the “NR Group”. 76.0% of respondents hence already offered, used or dealt with NR. The large majority of the 365 respondents came from Germany and the UK (15.9% each), followed by Italy (8.5%) and Spain (7.9%). In total, responses from 30 different European countries were collected. 36.1% of responding organisations represented the system manufacturing sector, followed by the engineering & contracting business (31.7%), and component & refrigerant suppliers (29.5%). Training & Research, as well as Consultancy & Marketing institutions were less represented. A large majority of 71.9% indicated to be active in light-commercial or commercial refrigeration. 52.3% were active in commercial & industrial heating; another 38.8% in residential heating (multiple responses).

3.1.3 Current and Future Natural Refrigerant Use in Europe's Heating Sector

Out of the 248 respondents already using or offering NR-based solutions ("NR Group"), the highest use of f-gas free refrigerants by mid-2013 was indicated for CO_2 in commercial refrigeration (25.7%), followed by CO_2 in industrial & commercial heating (24.6%). Overall, it was evident that for companies with NR-related offerings the HFC share was still dominant. For residential heating, respondents indicated the use of CO_2 (19.9%) or hydrocarbons (14.2%) to be predominant among the non-fluorinated solutions.

Regarding the expected use of natural refrigerants in future products and services for the heating sector, among all respondents to this question (220) - including companies using and not yet using natural refrigerants – CO_2 (33.2%) and ammonia (24.3%) showed the best prospects in Industrial & Commercial Heating. For Residential Heating, CO_2 (33.6%) and hydrocarbons (HC) (32.8%) would be primarily used within the next 7 years (Fig. 2).

Results were also confirmed by respondents' expectations regarding the total market share of NR products in the heating sector by 2020. For Residential Heating, 22% of respondents believed the market for CO_2-based HPs could reach a 11-20% market share, while another combined 21% estimated it to be at a minimum 21% market share. For HCs, 17% believed the share could reach 11-20%, while another 31% state it could go up to a minimum 21% market share by then. For Commercial & Industrial Heating, the market was expected to be split between different NR solutions. An absolute majority of 55% stated that at least a market share of 11% would be possible for CO_2, including 9% of respondents forecasting a more than 50% market share in Europe. Hydrocarbons and ammonia reached agreement rates of 41% and 40%, respectively, for the same range of 11+% market share. 8% were of the opinion, HC could take a 50+% market share by 2020.

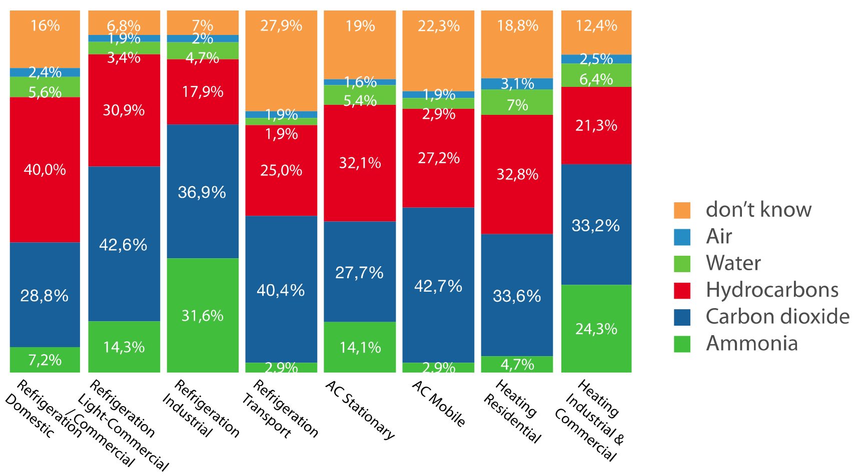

Figure 2: Use of Natural Refrigerant Products & Services in Europe 2020

3.1.4 R&D Activities for Natural Refrigerants in Europe

For those organisations experienced with natural refrigerant (NR) use that had R&D activities related to refrigerants, 28.0% had rather low R&D activities dedicated to NR (between 1-10% from total refrigerant-related activities), while a high 44.4% dedicated between 11-50% to HFC-free R&D activities. Another 26.7% could be considered proactive innovators for NR solutions, with a share of 71-100% of refrigerant R&D activities dedicated to natural working fluids. For this "NR Group" with R&D activities (185 respondents), a high 70.6% believed that NR-focused initiatives would experience a "moderate" or even "strong increase". 6.3% were not sure yet which direction their R&D activities would take (Fig. 3).

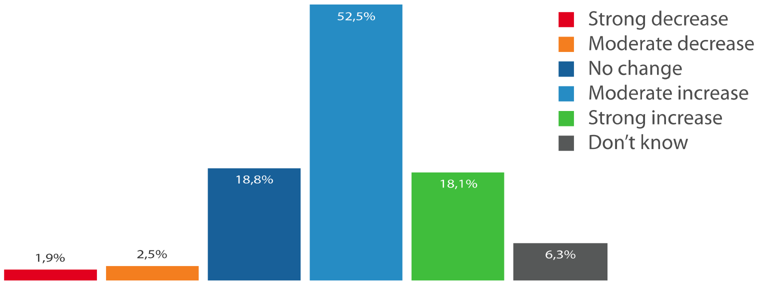

Figure 3: R&D Activities dedicated to Natural Refrigerants, Change until 2020

3.2 Technology Trends & Examples

The adoption of smaller NR heat pumps is expected to benefit from an increasing number of European-based providers making such solutions commercially available. For example, a high temperature CO_2 air/water HP with a new cascade and control is targeting space-heating applications. The unit supplies hot water of up to 80°C, the temperature required by heating systems in older buildings (shecco, 2012). The patented technology is based on the upper stage recovery of excess heat through an intermediate heat exchanger. A heating capacity of 8.6kW with a COP of 2.6 is reached. According to laboratory tests, in combined mode of space and water heating, the R744 solution would be more efficient than HFC.

As one example, Sanden's CO_2 heat pumps for residential hot water and large capacity water production have been available in Europe since 2011. Based on Japanese technology, the product was re-engineered to suit European conditions for hot water temperature, water storage volume, control logic and installation. In 2013, Sanden also launched the first combi-type CO_2 HP for residential space and hot water heating, with a COP of 3.64 (Campy, 2013).

More solutions for non-HFC systems in Europe's heating sector exist for commercial and industrial-size applications, including district heating: 1) In Denmark, CO_2 heat pumps were installed in Frederikshavn and Marstal for district heating. At Frederikshavn, 1 MWth CO_2 heat pumps (16 units) at the town's wastewater treatment plant use 2 GWh a year to extract 4 GWh of heat. 6 GWh of heat for the district heating supply are produced. 2) The German municipality Lauterecken installed a district heating system working with a high temperature CO_2 HP. The CO_2 heat pump covers 77% of the heating needs and saves 53 tonnes of carbon emissions per year. The project is eligible to subsidies from the German government stimulus package II. 3) In Sweden, a CO_2 transcritical HP project in Lund provides domestic hot water and heating for 24 apartment buildings with more than 400 flats. A 54 kW and 68 kW HPs were developed. Total annual energy savings for this project are calculated at about €1.1 million, and the payback period is expected to be around 5 years (Christensen, 2014). 4) Around 130 CO_2 units were installed at a pioneering housing project in Dublin, Ireland, to provide heating and hot water for social housing apartments. The use of CO_2 HPs allows the project to meet the building regulation requirements for the use of energy (R744.com, 2011). 5) The Tveita housing cooperative in Norway installed 100 kW heat pumps in three 13-storey buildings for domestic hot water, capable of raising the temperature from around 8°C to 70°C in a single stage. The company won the Varmepumpeprisen 2013 (heat pump prize) for its use of eco-friendly CO_2 units. 6) As a last example, Schlachtbetrieb Zürich AG installed the largest CO_2 heat pump system with 800 kW in Switzerland. The three units are used to produce hot water (90°C) for the slaughterhouse based on waste heat from refrigeration systems. About 260,000 m^3 of natural gas has been saved per year and the annual CO_2 emissions have been reduced by around 30%, or 510 tonnes per year (Masson et al, 2014).

As regards the use of ammonia (NH_3) HPs, several hundred units have been installed in Europe since the early 1990s, mostly in larger buildings (200 kW to 2 MW) and in district heating and cooling systems (700 kW to 8 MW): 1) In the world's largest district-wide natural HP system in Drammen Fjord near Oslo, an NH_3 unit is used to provide over 13 MW of heat for a community of 60,000 people (Gaved, 2014). 2) A 900 kW ammonia heat pump system for space heating, space cooling and hot water heating was installed at the StatoilHydro Research Centre in Trondheim. Sea water from 60 metres depth is used as a heat source. 3) In Switzerland, Energieverbund Schlieren in Zurich installed two large NH_3 heat pumps in one of the largest projects of its kind in Europe. 4) In the Mülligen letter sorting centre and Rietbach central energy installation, units with a heating capacity of around 5.5 MW each are used. The energy consortium can produce annual savings of around 48,700 MWth worth of fossil fuels, corresponding to a reduction of 8,100 tonnes in carbon emissions per year.

As regards the use of hydrocarbon heat pumps, Ait-deutschland has invested in propane units as a technology for the renovation market to substitute gas or oil boilers. The R290 HP achieves a flow temperature of up to 70°C without any additional heater (Maul, 2013). In parallel with these industry innovations, the European Commission funds a project to develop a 30kW air to water HP system for multi-family houses, which represent 35% of the residential building market in the EU-27. A propane HP is being designed to be roof-mounted, so it is suitable for urban areas, and to have a refrigerant charge of 20g per kW heating capacity. Preliminary charge calculations indicate the system will have a total charge of 500g, as well as feature a novel, state-of-the-art design using minichannel evaporator, a novel fluid distributor, and new scroll compressor (Oltersdorf, 2013).

3.3 Policy

3.3.1 Building Regulations for Sanitary Hot Water Heat Pumps

The last years have seen a trend towards sanitary hot water heat pumps in Europe - an application most suitable for CO_2 refrigerant (R744). Despite a decline in overall HP sales in 2012, the European market for HWHP grew by nearly 20% (Nowak and Jaganjacova, 2013). The Joint Research Centre estimates that by 2020, sanitary hot water is bound to become the most important factor for energy demand, as the EU moves towards zero energy buildings that encompass minimal space heating requirements. This trend is underpinned by new building codes adopted in various EU Member States. In France, the 2012 Thermal Regulation was launched to require all new buildings to achieve average primary energy consumption of less than 50 kWh/m^2/year for heating, domestic hot water, cooling, lighting and auxiliary equipment (e.g. fans and pumps) compared to the average of 150 kWh/m^2/year required by the earlier regulation.

3.3.2 F-Gas Regulation & national measures on HFCs

A regulatory incentive for a renewed interest in natural refrigerants is expected to come from new EU F-Gas Regulation rules: The reviewed Regulation includes a combination of tools for achieving reductions of f-gas emissions, including a phase-down of HFCs in terms of CO_2eq, and stricter containment and recovery measures. The Regulation's strongest signal to the industry to move to HFC-free refrigerants comes for those sub-sectors for which HFC bans in new equipment are foreseen.

At the national level, and as a best-practice example for NR-based technology promotion, Denmark introduced in the early 2000's a general ban on the import, sale and use of new products containing certain fluorinated gases, with a number of exemptions depending on the type of application and/or the refrigerant charge. In the case of heat pumps, the ban applies to units containing either less than 150g or more than 10kg of f-gases. Following the example of Denmark, Switzerland has amended its national legislation to introduce bans on HFCs in certain applications as of December 2013. The amended Ordinance introduces HFC bans in medium and large capacity air conditioning and refrigeration stationary applications. The bans stipulated by the current Swiss and Danish Regulations would not typically cover smaller equipment such as domestic heat pumps, however they do provide an indication to the industry for possible similar measures in the future.

More countries are looking at f-gases taxation as a way to internalise environmental cost, while raising revenues. In Denmark, Norway and Slovenia, such taxes have been in place for years, while Spain introduced an f-gas tax in January 2014. In addition, more European countries consider introducing such a tax. Fig. 4 provides a comparison of tax levels (expressed in €/tCO_2eq) in those countries, for which a tax on f-gases is already in place.

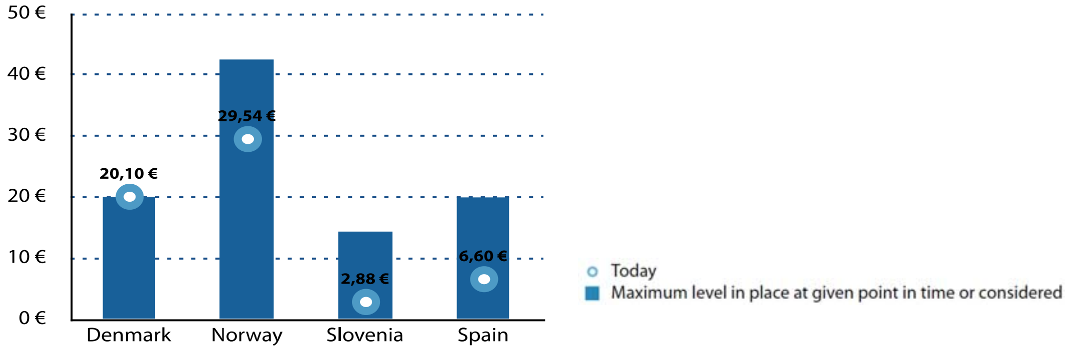

Figure 4: Comparison of HFC Tax Levels (€/tCO_2eq) in Selected European Countries

The blue dots represent the current tax levels in Denmark, Norway, Slovenia and Spain. The column bars denote the maximum tax level that was in place at some point in time (Slovenia) or is already agreed for a future point in time (e.g. agreed tax level in Spain starting in 2016). Norway has recently raised the tax level from about €30/tCO_2eq to about €42/tCO_2eq and leads the way in terms of the highest level of tax currently in place.

Figure 5 looks at how the tax levels translate in terms of €/per kg for a common refrigerant, namely R134a. An impressive €55 is payable in 2014 for each kilo of R134a in Norway. This is significantly higher than the levels payable since July 2013 in Slovenia on f-gases used for servicing and maintenance (€3.7 per kilo of R134a).

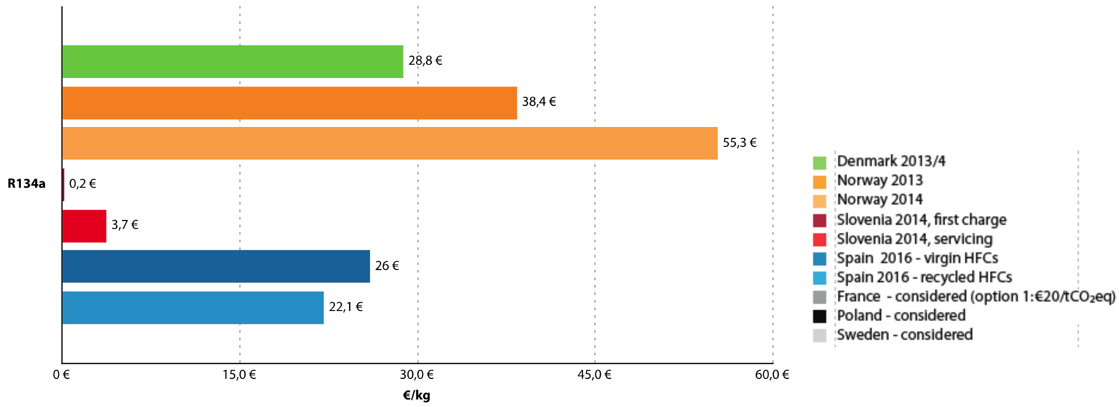

Figure 5: Tax Level in €/kg for R134a in Selected European Countries

Moreover, several European countries have investment grant schemes or fiscal incentives in place with refrigerant requirements as part of the eligibility criteria. The scope of such schemes has typically focused on commercial and industrial refrigeration systems. As the cost difference between HFC-free and HFC-based equipment in the refrigeration sector reaches parity, this gives way for new sectors, such as heat pumps to become the focus. This has been the case in the UK, where since August 2013 businesses (technology end-users) that invest in CO_2 heat pumps for domestic hot water heating can claim 100% of the investment against the taxable profits in the year the investment is made. This compares to a general rate of capital allowances in the UK of 18% a year on a reducing balance basis.

4 NORTH AMERICA

4.1 Market Overview

4.1.1 Natural Refrigerant Industry Trends in North America

shecco conducted an HVAC&R industry survey from March to November 2012 that received 556 responses from stakeholders in Canada (15%), Mexico (5%), and the United States of America (80%). Objectives were to identify familiarity levels with natural refrigerants (NR), availability of NR solutions and future plans, and North America's potential to become a world leader in NR solutions. 34.5% of respondents represented engineering & contracting companies, 26.4% system manufacturers and 24.6% component suppliers. Associations, consultancies, end-users, and training & research institutes were less represented. 37.9% of respondents were active in industrial & commercial heating, whereas 22.7% were active in residential heating (multiple responses). As the survey mostly attracted responses from those familiar with and/or interested in NR technology, there was a clear overrepresentation of the "NR Group" - actors who already offer or use NR systems.

328 out of 493 participants (66.5%) indicated to already use or provide products or services with natural refrigerants, whereas 27% did not use ammonia, carbon dioxide, hydrocarbons, water, and/or air in their activities. However, 326 respondents (69.8%) were confident that their organisation would provide or use natural refrigerants in the future. Only 9% were sure that this would not be the case. If only looking at the sub-set of respondents who did not currently offer or use NR (162 individuals), 40% said they were sure to use NR in the future.

78% of 432 respondents being asked about the business and policy climate for natural refrigerants rated this to be either "very favorable" or "rather favorable" for CO_2. For hydrocarbon refrigerants the "rather negative" or "very negative" options were selected by 48% of respondents, supporting the assumption that unsolved issues regarding uniform standards and limited application potential were affecting the HC industry (Fig. 6).

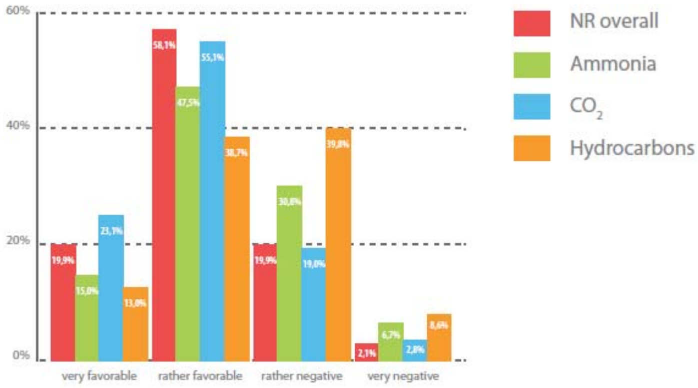

Figure 6: Business & Policy Climate for Natural Refrigerants in North America

Overall, the study concluded that the rate of responses specifically for the heating sector was significantly lower than for other application sectors like refrigeration or air conditioning, providing a strong indicator of the still low awareness about the use of NR-based heat pumps in the North American market.

4.2 Technology Trends & Examples

In North America, NR-based heat pumps for residential applications remain a niche product. To a limited extent, HFC-free HPs have been used in commercial and industrial applications, often combining heating and cooling: 1) A prototype CO_2 HP by EcoThermics was installed at a Country Maid commercial bakery. The system simultaneously provides hot water for washing baking equipment and cold water for space air conditioning. It allows Country Maid to achieve cost savings of about $4,276 (€3,280)/ year compared to a conventional system using natural gas and electricity (Rocke, 2013). It is expected that the system will yield electrical energy savings of 30% compared to traditional energy use and a payback within 3.5 years. 2) In California, a Mayekawa CO_2 system was installed as the first-ever in a winery to provide heating and cooling through an electric-driven HWHP that uses CO_2 refrigerant for glycol cooling and hot water heating. The winery requires 180°F (82°C) supply hot water. It is comprised of four elements: a CO_2 HP, a hybrid adiabatic fluid cooler replacing the traditional cooling tower, a glycol warming system for tank and barrel room heating, and a high efficiency glycol chiller for additional tank and barrel room cooling. The system has been in operation since late 2010 and has reduced energy use by 22% as compared to traditional heating systems. 3) In Canada, the Fromagerie Polyethnique / Fritz Kaiser plant adopted a Mayekawa/Mycom CO_2 HP. The system covers various heating needs in the building: for washing water, pasteurisation and production processes. The unit also caters for the plant's cooling needs, by chilling water for the maturing room, the milk storage and the crystopia storage ice bank. The payback period was estimated at 4-5 years, but thanks to the energy efficiency incentives by the Québec government was reduced to two years. The yearly energy savings from the project was calculated at about 125,000 litres of propane fuel. (Masson, et al., 2013; Babineau, 2012).

4.3 Policy

4.3.1 Canada

As regards direct incentives for the use of natural refrigerants in North America, Québec's Refrigeration Optimization Program (OPTER), administered by Québec's Ministry of Natural Resources and Wildlife, was an investment grant scheme encouraging large refrigeration system owners to transition to more environmentally friendly systems, including ice hockey arenas and curling rinks. The programme had three objectives, among them using more environmentally safe refrigerants and reducing the amount of refrigerants in the systems. The programme was financed as part of Québec's Action Plan on Climate Change 2006-2012. In the 2013-2020 Climate Change Action Plan, the government of Québec announced to continue the programme beyond 2012, strongly encouraging installations with little or no HFCs while examining the possibility of extending its scope to other sectors (Québec Government 2012). Furthermore, Québec also signaled the intention to encourage the use of low-GWP refrigerants not only through subsidies, but also by means of tightening up the provisions of the Regulation respecting halocarbons, which will be revised to broaden its scope and limit the use of HFCs in refrigeration, freezer and air conditioning equipment in the commercial sector and arenas.

4.3.2 United States of America

At the federal level, increased interest in natural refrigerants could from President Obama's Climate Action Plan released in June 2013 to call for domestic action to curb HFC emissions: "Moving forward, the Environmental Protection Agency will use its authority through the Significant New Alternatives Policy Program to encourage private sector investment in low-emissions technology by identifying and approving climate-friendly chemicals while prohibiting certain uses of the most harmful chemical alternatives. In addition, the President has directed his Administration to purchase cleaner alternatives to HFCs whenever feasible and transition over time to equipment that uses safer and more sustainable alternatives." (Obama, June 2013)

At the State level, California is most advanced in putting in place HFC reduction. California already has some HFC refrigerant leakage containment measures in place that are targeted primarily at large refrigeration installations and motor vehicle air conditioning. The State now considers more ambitious tools to stimulate the use of natural refrigerants in additional sectors, according to the Draft Update of California's Scoping Plan describing the range of efforts to reduce GHG emissions. The draft, which is expected to be finalised in spring 2014, highlights measures such as a fee on sales and import of HFCs, requiring the use of low-GWP alternatives in certain uses, and aligning legislation with the new EU F-Gas Regulation (California Air Resources Board, February 2014).

5 CHINA

5.1 Market Overview

The CO_2 heat pump market is developing fast in China, with the technology being applied in hospitals, train stations, schools and public buildings to cover the entire cooling and heating demand. To step up efforts, China has upgraded its potential production capacity of CO_2 heat pumps to 100,000 units per year, and already has 50-70 successfully running projects in the country. It will likely also soon supply the market for split heat pumps with systems charged with propane, for which production started up in the summer of 2013.

5.2 Technology Trends & Examples

Chinese heat pump manufacturers have introduced CO_2 refrigerant-based commercial and industrial heat pumps that can operate in extreme climatic conditions, a technology trend that is expected to continue over the coming years: In 2010, three 50kW CO_2 heat pumps were installed to provide space and water heating in a 3000 m^2 maintenance area of the Bumade railway station on the Qinghai-Tibet railway line at 4800 m above sea level. The heat pumps work well even during the winter period when outside temperatures are as low as -30°C. The HP project is the highest in elevation and lowest in operating temperature in China. Because of its energy savings and stable performance, in 2012, another 24 CO_2 heat pumps were installed to provide space heating in five railway stations on the Qinghai-Tibet railway line.

As an example of combined water and space heating, the Shenyang Children's Hospital installed a combined heating system with two CO_2 HPs and 200 m^2 of solar thermal collectors in 2011. The hospital has relatively high space heating and sanitary hot water needs. The CO_2 systems can supply 40 tons hot water at 60°C per day to the hospital. The system has shown smooth operation, even when the outside temperature was as low as -28°C in winter. 2) In a building transformation project in the city of Yinchuan, Gansu Province, a 1000 m^2 Ministry of Railways building adopted a CO_2 heat pump for space heating to replace its 200kW gas-fired boiler. Compared with the former gas-fired boiler, the CO_2 system saves RMB 128,000 (~€16,000) in operating costs per year and 63.8 tons of coal equivalent, reducing annual CO_2 emission by 160 tons.

R744 heat pumps are also being combined with traditional heating technology: A CO_2 HWHP was installed in the Wuhan University in October 2011, to provide hot drinking water. The combined CO_2 HP and electric boiler saves 50% in energy as compared with a 100% electric boiler. By heating water to 80°C with the CO_2 heat pump first, and then to 100°C with the electric boiler, the system is able to provide students 5 tons of hot drinking water per day.

Finally, CO_2 heat pumps are also being integrated to cover cooling requirements: In the 3,000 m^2 office building of the Beijing TongZhou District Bureau of Quality and Technical Supervision in Beijing, four CO_2 heat pump units were installed in 2011 to provide both cooling and heating. In the 800 m^2 feeding room of the bureau, another CO_2 high temperature heat pump is also used to provide space heating in wintertime.

5.3 Policy

In 2009, the Chinese Ministry of Science and Technology launched the “CO_2 Heat Pump Core Technologies and Industrialisation” project in Shunde, Guangdong Province. The project is part of the National Science-technology Support Plan Projects in China’s 11th Five-year Plan. The programme’s aim is to remove market barriers for CO_2 HPs especially the technology obstacles through supporting researches into such technology among enterprises and universities. Heat pump manufacturers such as Midea Group and Guangdong Wanghe and research institutes such as Xi'an Jiaotong University and the South China Academy of Home Appliances have been involved in the projects.

6 CONCLUSION

In Europe, an increasing number of entities are active in providing products and services for natural refrigerants. This has increased competition levels and R&D efforts, and driven down costs for NR-based technology. Despite successful applications mostly for commercial and industrial-size heat pumps, market adoption of CO_2-based heat pumps has developed at a significantly slower pace than in Japan. The potential commercial availability of NR technology for HWHPs, and for HPs providing combined space and water heating, is projected to reach sufficient production levels by 2016 and 2018, respectively. This, however, assumes clear signals by political leaders to encourage investment in HFC-free technology.

In North America, the use of natural refrigerants (NR) is currently mostly found in commercial and industrial-size applications, with residential R744-based models being only available in pilot projects. HFC reduction schemes at the Federal and State (California) level in combination with direct support measures for non-HFC solutions could provide further impetus to a developing NR heat pump market.

The world leader in the uptake of CO_2-based HWHPs, Japan, has driven the adoption of Eco Cute models to 98% of all new residential hot water heaters sold in the country. Total sales figures could reach 10 million units by 2020. Recent developments have attached greater attention to design and comfort improvements, as well as increased market shares in commercial and industrial-size applications, special applications (drying) and in extreme ambient temperature conditions.

In the meantime, China has upgraded its potential production capacity of CO_2 heat pumps to 100,000 units per year, at 50-70 successfully running projects. Solutions developed by domestic suppliers operate under extreme climatic conditions, combine traditional with heat pump technology, and integrate space heating, hot water production and cooling needs.

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