

CLIMATE CHANGE AND THE ROLE OF HEATPUMPS

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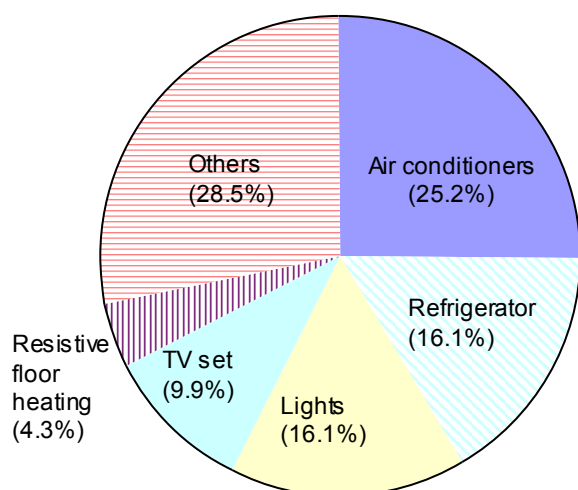
Abstract; This paper introduces general view on heatpumps of the author who is a senior manager of JRAIA (The Japan Refrigeration and Air Conditioning Industry Association). Mainly, expected effect on greenhouse gas reduction, safety, and energy efficiency issues are discussed. As the JRAIA are mainly representing mass producing manufacturers, these issues are explained from practical viewpoints. So, not only technical but also political issues are discussed including the role of the JRAIA to develop the market of heatpumps.

Key Words: heatpump, climate change, seasonal efficiency, safety, design

1 INTRODUCTION

Sales volume of reversible heatpumps are approximately 7 million annually in Japan for last 10 years while CO₂ sanitary hot water heatpump are already sold more than 2 million cumulatively by the end of 2010. So, Japanese market is fairly large. This market is achieved due to several reasons. Firstly, Japan is an island country in temperate zone, so the winter climate is rather mild in most of populated areas. This is quite preferable for air source heatpumps. Secondly, most Japanese people are quite diligent and fussy. So, quite refined and sophisticated heatpumps are developed. Many new technologies are commercialized first in Japan. Thirdly, several major suppliers of reversible heatpumps in global market are Japan based, so total sales of them in global market are a few folds larger than Japanese domestic market. As these large manufacturers are crushing each other in this market, it is extremely competitive. So, highly intense and advanced market of Japan was achieved.

Now, climate change is one of the key issues in the world while heatpumps are expected to make significant contribution to mitigate green house gas emissions. To achieve this goal energy efficiency and refrigerant GWP effect are the key issues of heatpumps. Natural refrigerants are preferred from climate change viewpoint. CO₂ refrigerant products are commercialized for sanitary hot water heater and secondary circuit of low temperature applications, but application of HC refrigerants are limited to very small refrigerant charges such as refrigerators. Recently, HFO refrigerants are emerging not only for automobile air conditioning but also for stationary refrigeration and air conditioning applications. However, these have minor flammability. So, safety requirements may determine the choice of refrigerants.



Energy efficiency of air conditioner is the other significant aspect against climate change. Figure 1 in left shows electric energy consumption of home appliances. Air conditioners consumes about quarter of whole electric energy use of average household in Japan. As almost all air conditioner in Japan are reversible heatpumps, this figure clarifies how important the energy efficiency of reversible heat pumps is.

Fig. 1 Residential electricity use in Japan

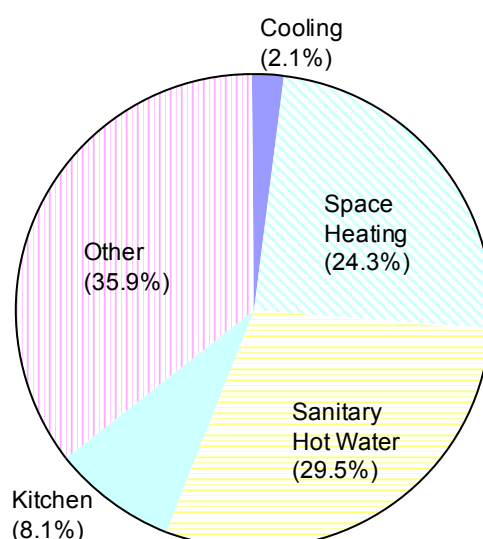


Fig. 2 Residential energy use in Japan

Figure 2 shows the composition of household energy use purposes in Japan excluding transportation. This clearly indicates that the importance of heating function of reversible heatpumps and sanitary hot water heaters. Cooling is only 2.1% of total energy, but space heating and hot water supply consumes more than 50% of residential energy use. Now, majority of heating energy is provided by fossil fuel combustion. CO₂ emission reduction mainly means reduction of fossil fuel combustion. If heatpump can replace these fossil fuel combustion appliances, contribution would be quite significant.

Here, outline of these issues are discussed from viewpoint of mass production manufacturers and industry association.

2 ROLE OF INDUSTRY ASSOCIATION

In this situation, industry has to have unified voice to extend the heatpump market and to optimize market regulations for energy efficiency and refrigerants' warming effect reduction. Industry association should make best effort to establish level playing field for heat pumps.

Conventional standards for heating equipment are provided for combustion equipment, so they are not appropriate for heatpumps in most cases. In heating market, heatpump is still minor part of it. As heat pumps are more complicated system than combustion heaters, the cost tends to be much higher. So, extend the market share against combustion equipment is not easy.

On the other hand, if people continue using combustion equipment, GHG emission is hard to be reduced. Thus provide appropriate incentive to accelerate market penetration of heatpump is mandatory. Industry association has to take care of such incentive policies with government.

Industry association also has to encourage sound competition of heatpumps in the market. Even within the heatpump market, fair competition is not so easy. Performance of fixed speed units can be represented by performance at nominal condition. On the contrary, inverter driven units may have lower COP at nominal condition, but seasonal efficiency is much higher. Because, energy efficiency at part load condition is much higher than nominal condition while efficiency at part load condition affects seasonal efficiency much more than that at nominal condition. Therefore, Japanese industry has to support development of seasonal efficiency standards.

Comparison against combustion equipment is more complicated. Energy efficiency of heatpump quite depends on climate and weather. In addition, compare them in CO₂ emission or in primary energy is the next question. The CO₂ emission per electric power differs country by country or power company by power company. There is no clear unified answer even in one market. However, the heatpumps should carry good index information for consumer about energy efficiency and CO₂ emission that is comparable with combustion equipment.

Safety is another key issue. Although environmental aspects are getting more and more focus, ensured safety of equipment through life cycle is essential for mass-produced products. Safety standard of a private company is not so convincing. Some standard of neutral institute from comprehensive viewpoint is necessary. Development of national and international safety standard is very important.

Through these activities, sound heatpump market will develop quickly.

3 SAFETY ISSUES

Most refrigerants are decomposed in atmosphere by oxygen and/or UV ray. If substance has lower GWP, it is generally less stable than conventional fluorinated refrigerants. Thus, low GWP refrigerants are flammable or toxic or both in many cases.

Natural refrigerants are preferred in general. Industry also prefers natural refrigerants such as hydrocarbon and ammonia if they can be used safely, as they are lower refrigerant cost and good performance. However, due to safety precautions, total costs of them are not low. That is why major air conditioning companies do not use hydrocarbon or ammonia for mass-produced units. Only refrigerators and vending machines with very small hydrocarbon charge are mass-produced.

Table 1 shows the statistic of accidents with fuel gas and refrigeration facilities as well as rough image of sales numbers of units in Japan. The number of fluorocarbon units in Japan is fairly larger than that with ammonia. Here, the numbers of condensing units delivered to domestic market and reported to JRAIA are indicated for fluorocarbon units. Ammonia installation numbers were investigated and published by JSRAE (Japan Society of Refrigeration and Air Conditioning Engineers) on their web pages. (All installations are listed

in several tables, but not total number. So, these numbers indicated in this table are counted value of installations in the lists.)

Although the number of fluorocarbon condensing units is more than hundred times higher than ammonia units, the numbers of fatalities or injuries are lower than ammonia. If all stationary refrigeration and air conditioning equipment are considered, the number of fluorocarbon units appears to be more than 10,000 times higher.

Table 1 Japanese Accident Statistics

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Fuel gas explosion	NA	38	51	77	57	48	57	64	53	45
Fuel gas fire	NA	NA	NA	NA	NA	NA	19	51	60	42
Refrigeration Facility										
Ammonia Installation * ¹	210	257	239	NA	NA	NA	NA	NA	NA	NA
FC Unit sales (CU) * ²	141,928	126,079	127,304	118,627	124,387	115,044	114,063	100,337	83,473	77,023
Refrigerant Fatality										
Ammonia	0	0	0	0	0	0	1	0	0	1
Fluorocarbon	0	0	0	0	0	0	0	0	0	0
Refrigerant Injury										
Ammonia	2	2	1	5	0	1	2	1	3	9
Fluorocarbon	0	3(11)	0	2(39)	0	0	3	0	0	0

*1 Data of JSRAE web *2 Data of JRAIA web

Fuel gas is accepted for public use, but about 50 explosions and fires respectively occur every year in Japan. These accidents data are disclosed on the web of KHK (Koatsugas Hoan Kyokai [The High-pressure gas safety institute of Japan]). About half of accidents with fuel gas are fire or explosions. On the other hand, there are more than 100 leak accidents including 3 fatal accident cases are reported with ammonia refrigeration system, but there is no fire or explosion reported due to leaked ammonia. This suggests very low risk of 2L flammability refrigerants.

There are so many cases are reported in the web that it impossible to explain all cases in detail here. However, fatality cases of refrigeration facilities are limited to 6, so here briefly explain how such accidents occurred. KHK web includes almost all outlines of significant refrigeration facility accidents of Japan in Japanese.

Case 1; March 9, 2009

Ammonia was released while replacing electronic expansion valve and solenoid valve. A group of workers are replacing these components of a system. Another group started to check operation of control program to confirm operation of solenoid valves. So, the solenoid valve at replacing site was opened. Totally 9 people are affected by ammonia spill and one person died.

Case 2; August 6, 2006

Maintenance worker of 38 years of experience was removing oil drain of an ammonia refrigeration facility and found dead. He seemed to operate the drain valve improperly.

Case 3; November 2, 1999

A worker was manually defrosting evaporator in large ammonia refrigerated warehouse. The evaporator was broken and fell down. The worker was taken out but found dead.

Case 4; May 19, 1997

One service person called due to a compressor failure of a fluorocarbon system. He found leak and repaired it then checked tightness of the system with nitrogen. However, nitrogen he had was not enough to reach required pressure. So, he went to a gas retailer. The gas shop

also sold out of nitrogen. So, he bought high-pressure oxygen instead of nitrogen for the purpose. He put it into the system to get the pressure and left the system under pressure to ensure the tightness.

Next day, he had to go another site due to phone call from another customer. So, another service person went to the site charged with high-pressure oxygen. He had been asked to replace the failed compressor. He started brazing off the compressor without checking the pressure. So, lubricant under high-pressure oxygen exploded and the service person died.

Case 5; August 27, 1996

A service person was preparing to remove air conditioning facility with fluorocarbon. He tried to pump down refrigerant into the motor chamber of the compressor, as there was a leak in the condenser. Although the compressor has a low-pressure side motor, he believed the compressor had a high-pressure side motor. So, he closed the discharge valve of the compressor and tried pumping down refrigerant to the motor chamber. Then, overload relay worked. So, he provided jumper line for it and tried again. Then high-pressure switch worked. So, he also provided a jumper line for it and tried again. Finally, the head cover of the compressor blew off and he died.

Case 6; October 3, 1994

A service person purging fluorocarbon refrigerant from a unit in underground machinery room to outside through a long connected purging line to repair the system. However, one of connection was not good, so purging refrigerant seemed to be released into the machinery room. Released refrigerant to outside might flow back to the machinery room also. The service person was found dead due to asphyxiation.

These accidents suggest a lot of points we should consider to avoid accidents with refrigerants. Major points are as follows.

- All these fatal accidents are caused by service or maintenance people not by defect of machine.
- Many accidents occur in typical non-occupied space when they are occupied.
- Misunderstanding, miscommunication, and mistake can happen.
- Ammonia has much higher risk than fluorocarbon. Smell of ammonia is not always effective to prevent accident.
- Automatic safety measures may be disabled by service person.
- Service person may start brazing without checking pressure.

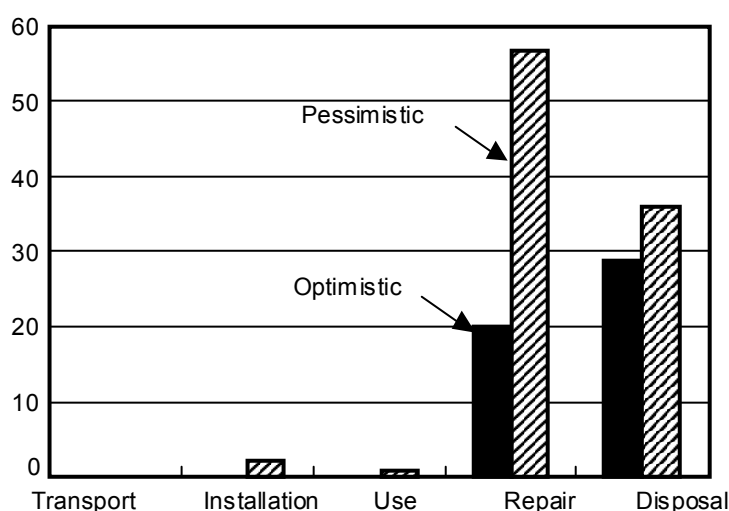


Fig 3 Estimated Incidents/year in Japan after Measures

We do not know how many accidents we would experience with ammonia or hydrocarbons, if we use them to mass-produced units. However, we have to anticipate fairly large number of accidents with them based on these accident data.

JRAIA conducted a risk assessment of mini-split air conditioners with hydrocarbon refrigerant through their life cycle except manufacturing stage in 1999. Results are represented in figure 3. Designed improvements such as detection of refrigerant leak are effective for stages of use. However, repair and disposal stage have high risks. The reason is some measures are based on power supply to the unit, but power lines are generally disconnected when they are serviced or disposed of. In addition, risk due to possible human error and human nature remains high even after applying measures.

As so-called natural refrigerants are not so natural in their concentration when they leak, that they cause explosion or accidents due to flammability and toxicity. Even high concentration CO₂ that is part of breathing air of human has very acute effects when concentration exceeds certain level. As our lung absorb oxygen and deliver CO₂ in blood according to partial pressure difference against air, if CO₂ partial pressure in air is higher than that of blood level, CO₂ resolves into blood very quickly in lung and affects brain. Only water and air can be called as natural refrigerants from the viewpoint including concentration.

The key to use of hydrocarbon and ammonia is how we can ensure human activities regarding maintenance and disposal for safety. However, this is almost impossible task for industry association.

4 ENERGY EFFICIENCY ISSUES

Many current performance standards employ seasonal efficiency. When only fixed capacity units were used, performance at nominal condition was sufficient to represent actual use. However, variable capacity units became popular due to development of inverter driven system, seasonal efficiency became inevitable. As almost always variable capacity air conditioners operate at part load condition, efficiency at part load condition has much more significant impacts on annual energy use than that at nominal condition.

Capacity of the air conditioner is chosen to be higher than the maximum cooling or heating load of a room. People tend to estimate heating or cooling load conservatively. So, capacity is generally excessive compare to heating or cooling load. So, operating capacity is rarely reach full capacity of the unit except pull down operation.

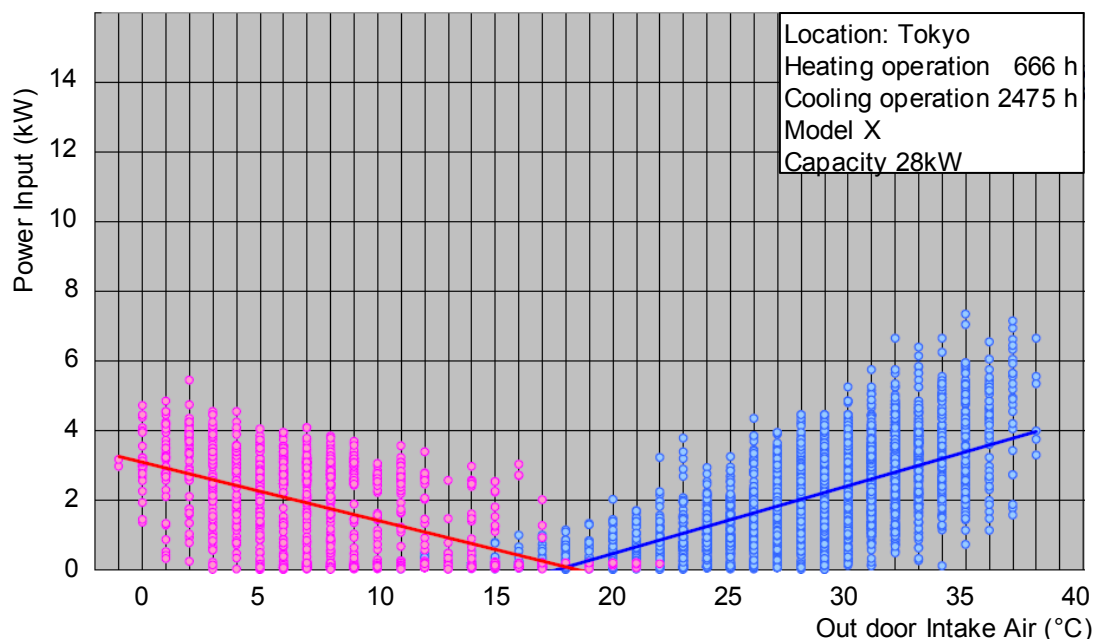


Fig. 4 Power Input in Actual Operation

Current seasonal efficiency standards assume heating and cooling load proportional to temperature difference between indoor and outdoor ambient. However, actual load is significantly lower than assumed load for these seasonal efficiency. Figure 4 shows one sample of the actual power consumption data against ambient air (intake air temperature to outdoor unit). Instantaneous data of every operating hour is plotted. This unit has capacity of 28 kW and power input around 12 kW at nominal condition. Actual power consumption stays below 8 kW even when intake temperature is 38 °C. Totally 8 units are investigated. Seven units of 8 operate almost all period at less than half of full capacity. Only one unit in 8 samples operates close to 100% capacity, but this unit seems to have a short circuit issue of outdoor unit air. These low load operations seem to be caused by conservative selection of unit and conservative load estimation.

Although low capacity operation is quite often, current JIS standard do not require performance measurement below 50% capacity, because the measuring accuracy is not high at such a low capacity condition with current facility. Draft seasonal efficiency standard EN14825 of Europe requires measurement at about 25% load. However, measurement of 25% capacity with small capacity unit is also problematic in Europe due to accuracy.

In short term such measurement may need to be avoided. However, the heating and cooling load are decreasing due to new energy conservation requirements with better insulation and tight building structure. So, in the future low load measurement is more important. Current facility is developed for fixed capacity unit that requires measurement of full capacity at nominal condition. But now inverter driven systems are common so facility should be developed to enable accurate measurement at such low capacity condition.

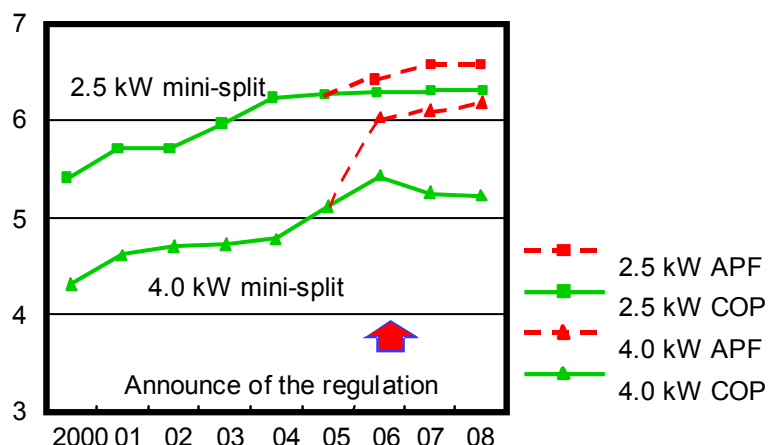


Fig. 5 Top runner trend in Japan

Energy efficiency of current models in Japan appears reaching saturation. Figure 5 shows the trend of energy efficiency in Japanese top runner models. After several years from the establishment of measuring method, efficiency value becomes saturated. Large leap of energy efficiency appears difficult, but it appeared for nominal efficiency (COP) and seasonal efficiency (APF: Annual Performance Factor) respectively. If the measurement standard will be changed to reflect more realistic use condition in smaller load, there would be a good possibility of significant energy efficiency improvement in real use.

In addition, latest high efficiency models in Japan hardly remove latent heat in cooling mode. It is caused by pursuing high efficiency. High airflow rate and high evaporating temperature prevent moisture condensation on evaporator. It is also not realistic operation in Japan. Latent heat removal is mandatory for cooling operation in Japan where high humidity is usual in summer. Also from this viewpoint seasonal efficiency evaluation method needs to be improved.

5 POTENTIAL OF HEATPUMP IN JAPAN

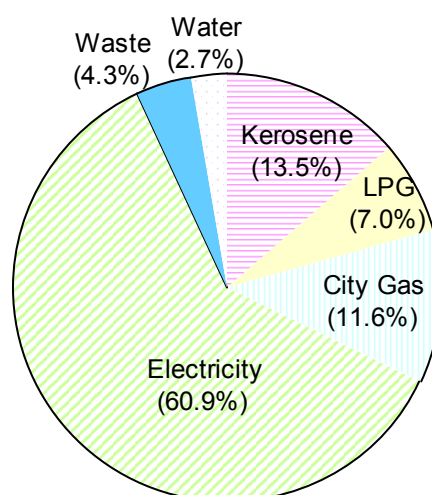


Fig 6. CO2 emission from household (Excluding transportation)

It is already mentioned in introduction part about CO₂ emission reduction potential of heatpumps, but further detail of expected reduction in CO₂ emission and in primary energy consumption need to be addressed. Figure 6 shows current composition of CO₂ emission from household in Japan. If the number of R410A units increased by 10 million that is number of households in northern area in Japan, of 2 kg average charge while refrigerant recovery

and leak rate stays current level, HFC emission will increase 3 to 5 Mt- CO₂-eq per year. If these heatpumps reduce half of CO₂ emission of fossil fuel consumption, it can reduce 27 million ton of CO₂ emission. Then, total of GHG can still be more than 20 million ton of emission reduction. This suggests simple HFC regulation may hamper the total emission reduction of GHGs.

Japanese emission factor for power generation at consumption end is about 0.4kg/kWh. Seasonal heating COP of heatpump is 3 to 5 depending on climate in Japan. So, CO₂ emission to get 1 kWh heat with heatpump is 0.08 to 0.12 kg. Combustion of kerosene emits 0.24 kg/kWh CO₂ at 100% efficiency, so reduction to half is theoretically possible.

Table 2. Leak Rate in Japan

Product Category	Leak Rate (%)	
	Japan	IPCC GL
Centrifugal Chiller	7	2-15
Screw Chiller	12	10-35
Transport Refrigeration	15	15-50
Refrigeration & Freezing	17	10-35
Condensing Unit	13	10-35
Display Cabinet (Centralized)	16	7-25
Commercial AC units for shops	3	1-10
AC units for large building	3.5	1-10
Industrial AC units	4.5	1-10
Gas Engine Heatpumps	5	1-10
Residential Split	2	1-10
Stand Alone Display Cabinet	2	1-15
Ice Generating Machine		
Chilled Drinking Water Supplier		
Chilling Unit	6	2-15
Automobile Air Conditioner	5.2	10-20

Refrigerant emission is one of key issues. Refrigerant leak rates in Japan are generally lower than average of the world. Comprehensive and detailed investigation was carried out 2009. The results of this investigation are shown in table 2. Leak rates of smaller air conditioners are around 2% while end of life recovery is about 30%. If end of life products were processed properly, recovery rate would be 70%. This value was obtained through calculation of recovered amount divided by average nominal refrigerant charge and the number of units recovered at an authorized recycle factory. Using these numbers and assumed ones effects of heatpump are estimated.

Anyway, heatpumps have significant potential to reduce GHG emission, but it also have potential to increase GHG emission with refrigerant. IPCC 4th report explains a lot of potential application of heatpump. Thus, efficiency in actual operation and tightness of system or use of lower GWP refrigerant are very important. We have to develop market of heatpump with high efficiency and tight system or low GWP refrigerant.

6 CONCLUSION

There are a lot of heatpump demands in market to reduce CO₂ emission of combustion equipment. Heatpump is the only the measure to enable recovering useful heat from waste heat. It also provides renewable heat from ambient air, water or ground. This market is based environmental requirement, so refrigerant with lower GWP is preferred to mitigate warming impact of refrigerant. However, safety issues of HC and ammonia refrigerants still remain.

Ammonia and hydrocarbons seem to give much higher rate of accidents. Many accidents are mainly caused by human error such as communication error between repair workers at maintenance, repair or disposal. To prevent such error is extremely difficult.

Energy efficiency of heatpump may appear to be reaching saturation level. However, new evaluation method will make a large room to improve energy efficiency. Efficiency measurement and improvement at low capacity is one of challenges to improve actual efficiency.

Heatpump market development has a good potential to reduce green house gas emission in total. Even if HFC emission increases, total green house gas emission will be reduced due to large drop in CO₂ emission.

Based on these fact and trend, JRAIA will pursue heatpump market development.

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