

NEXT GENERATION HEAT PUMP SYSTEMS R&D BY NEDO / OVERVIEW AND PROSPECTS

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Abstract: The Ministry of Economy, Trade and Industry of Japan (METI) has set a target to reduce Japan's energy consumption by 18% (72 million kilo L of crude oil equivalent) till 2030. To achieve this goal, METI and NEDO jointly started that among 4 sectors- industrial sector, residential and commercial sector, transportation sector and cross-sector, there are 13 technology fields that need to be researched. New Energy and Industrial Technology Development Organization (NEDO) claims heat pump as an important cross-sector-technology, and conducted industrial high efficiency heat pump using centrifugal compressor and high performance (high efficiency, high availability in cold climate, downsizing) CO₂ heat pump water heater. Through the technological development, NEDO has contributed energy conservation and created new market. For higher efficiency, NEDO is promoting the efficiency of the heat pump equipment itself, and the system as a whole. R&D policies regard heat pump systems as the followings; 1) Making use of unused heat, 2) Improving the annual efficiency to match the actual HVAC load, 3) Maximizing the use of exchanged heat. This paper describes the overview of Heat Pump R&D projects, as well as its latest activities and prospects.

Key Words: R&D, Energy Conservation, Efficiency, heat pumps, system

1 INTRODUCTION

The Innovative Strategy for Energy and the Environment, formulated on September 14, 2012, has set a target that energy consumption should be reduced by 72 million kilo L (crude oil equivalent) or more on a final domestic energy consumption basis from the current level to be achieved by 2030. Table 1 illustrates the targets for energy conservation levels in the respective technology fields identified in the Strategy and corresponding technologies to be developed in order to achieve this goal. As the table shows, heat pump technology is named in several sectors as a promising technology for reducing energy consumption significantly. Thus it is considered to be a key technology for meeting the energy efficiency targets.

Also, The European Union included the thermal energy derived through heat pumps in the 2009 definition of renewable energy, and the IEA in the Energy Technology Perspectives 2010 described heat pumps as one of the technologies that contributed to efficient reduction of CO₂ emissions reduction in the end-use sectors. The Energy Technology Perspective 2012 also recognized heat pumps to be an important technology, promoting the value of deploying heat pump systems for efficient use of waste heat and unused natural heat source.

As these suggest, heat pump technology has a potential for global proliferation in terms of both energy conservation and renewable energy use, but it requires further engineering for innovative wider applications to high-efficiency equipment.

In this paper, we describe the heat pump technology that the NEDO endorses in its Energy Efficiency Technology Strategy 2011. Then we outline the Next Generation Heat Pump Systems R&D - a strategic development program for energy efficiency technology that we currently pursue to build on previous achievements, and introduce some outcomes from R&D projects. Lastly, we state the major challenges that NEDO seeks to address in the hope of providing guidance for a future direction and prospects.

Table 1 2030 Energy Conservation Targets of Japan (million kilo L: crude oil equivalent)

		total
Industrial Sector		14.07
	Iron and Steel	3.36
	Chemicals	0.95
	Cement, Glass, Ceramic Products	0.67
	Pulp, Paper and Printing	0.16
	Construction	0.44
	Petrochemicals	0.53
	Power Generation	0.16
	Other Sectors, Technologies	7.8
Commercial Sector		13.29
	Air-Conditioning	3.11
	Hot Water Supply	2.03
	Lighting	2.67
	Power, Other Applications	5.48
Residential Sector		9.05
	Air-Conditioning	1.78
	Hot Water Supply	1.58
	Lighting	2.7
	Power, Other Applications	2.99
Transportation Sector		14.88
	Cars	12.24
	Other Applications	2.64

2 “2011 Strategy for Energy Efficiency Technologies” and the Development of Heat Pump Technology

In 2011, NEDO and the METI jointly prepared the Strategy for Energy Efficiency Technologies, which describe the principles and future direction of Japan’s development of energy technologies.

This strategy identified key technologies that would facilitate the achievement of significant improvement of energy efficiency by 2030. It also took into consideration the technologies that could potentially meet the requirements through certain combinations with other technologies or adoption of new approaches. From a long-term perspective, it also considered the technologies that might achieve high energy efficiency after 2030. As a result, 13 key technologies were identified, as shown in Figure 1.

One of the key technologies in the industrial sector to be noted is the “exergy loss minimization,” which seeks to review the energy usage in various manufacturing processes from the viewpoint of leveraging exergy (useful work) and minimizing exergy loss. In this

context, industrial heat pumps are given useful for rebuilding the exergy of exhaust heat, to concentrate and deploy it in manufacturing processes. It is also important to develop a heat pump system that combines technologies for thermal storage and heat transfer.

In the residential and commercial sectors, key technologies include nearly net-zero energy buildings (nZEB) and net-zero energy houses (ZEH), which lower the net energy consumption of residential /business buildings to as approximate as zero if designed with integrated air-conditioning load control and architectural frames and facilities for improved energy efficiency.

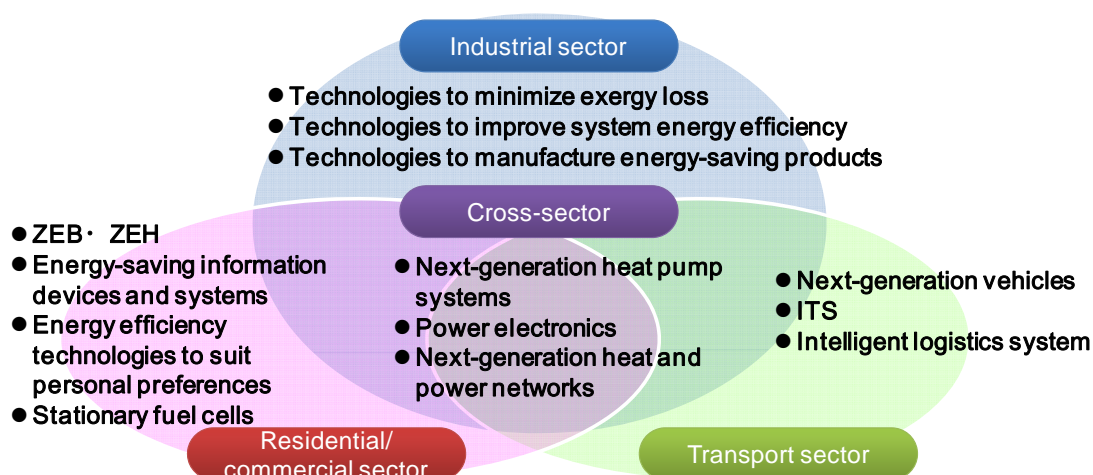


Fig. 1 Thirteen Key Technologies from “2011 Strategy for Energy Efficiency Technologies”

Furthermore, heat pump technology is evaluated to be a cross-sectional significance because of its expanding application in air-conditioning, water heating, drying, refrigerating/freezing, automotive air-conditioning, and in other areas.

Future development will include a high-efficiency heat pump cycle using suitable refrigerant that would improve energy efficiency. These will require innovative component technologies such as high-efficiency heat exchangers, compressors, and so on. Alongside the improvements to the equipment, it is necessary to develop a system that encompasses technologies for deployment of unused thermal energy, high-efficiency heat recovery and thermal storage (simultaneous heating and cooling), expansion motive energy recovery and low load-range efficiency enhancement. Defining such a total system as “the Next Generation Heat Pump System,” this technological strategy aims to achieve the goal to meet the target of “Innovative Energy Technology Program”, described in section 3.1.

3 Next Generation Heat Pump Systems R&D

3.1 Purpose of the project

“Innovative Energy Technology Program (cool earth)” sets a goal for developing ultra-high-efficiency heat pump systems to improve efficiency by 50% of the current level by 2030, and to double it by 2050. In order to achieve this goal, NEDO launched the “Next Generation Heat Pump Systems R&D” in 2010 as a national project.

To reach these ambitious targets by 2030 and 2050, it is not sufficient to simply pursue the improvement of individual equipment. Therefore, the total system optimization is thought to

be indispensable in the project, which would enable it to achieve high-level control of heat and input drive in the peripheral environment on account of the actual conditions of the system application, and the optimized adaptation to the environment in which the system is installed. Based on this idea, the following programs are being pursued:

- (1) Diverse approaches to the deployment of unused heat sources
To control the stability of heat sources by a combination of various unused heat sources (e.g., underground water, sewage and ground)
- (2) Improvement of annual energy efficiency based on the actual load
To maintain a certain level of energy efficiency in both high- and low-load areas, as well as under adverse circumstances such as cold climate
- (3) Maximum deployment of generated heat
To minimize the loss of exhaust gas heat generated in the heat pump to maximize its utilization within the system.

The realization of a practical high-efficiency system such as this will require comprehensive systematization involving the aspects of architecture and end-user.

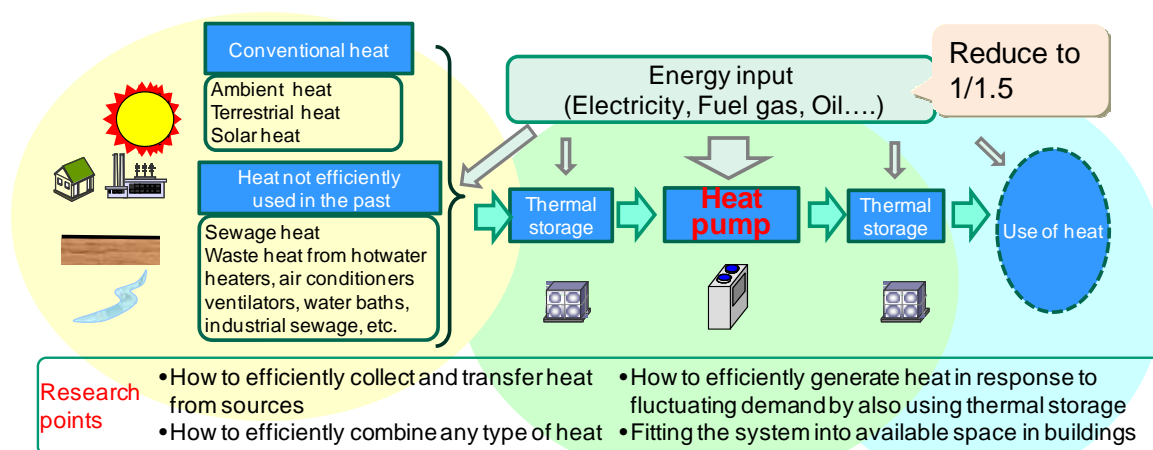


Figure 2 Concepts of "Next Generation Heat Pump System"

3.2 Project outline and progress

In FY 2011, we reviewed the initial nine projects from the view point of technology and economy and selected six of them for next R&D steps. These were implemented to construct a demonstration system to see if a heat pump system would achieve the anticipated 50% improvement in efficiency. In FY 2012, data was collected throughout the year from the demonstration system, and necessary alterations were made to improve the design. As a result, the efficiency improvement target was met in the following projects:

3.2.1 Residential use

- (a) R&D of a hybrid frost-free heat pump using desiccant and vapor compression

The design is based on the idea of frost-free heat pumps using desiccant materials, which have excellent adsorption performance in sub-zero temperature areas (down to -10°C). A theoretical analysis produced the prediction of 50% improvement on the current APF (annual performance factor) level for air-conditioning systems, while the water heating system achieved 30% improvement on the current APF level. Based on the developed simulation program and after some consideration of hardware

composition, a high-durability desiccant rotor was developed. This realized the expected frost-free performance and achieved the targeted system efficiency level.

3.2.2 Commercial use

- (a) R&D of a heat pump system with improved annual energy efficiency based on actual load

The first prototype of a wide-ranging scroll compressor that achieved high efficiency during low-load operation (3-10%) was put to efficiency evaluation both individually and within a unit. The simulator constructed independently indicated that the developed system would yield 50% improvement on the current level of annual efficiency. We also constructed a trial system combining a compressor and a natural circulation system, and confirmed that it met the target efficiency level in the performance test chamber. Furthermore, the demonstration system with improved control achieved the target level in the location trial (Shimizu and Sapporo), which lasted for a year.

- (b) R&D of a high-efficiency heat pump air-conditioning system with underground water control

A prototype of a demonstration system was created and piloted in the Japanese climate category Area III (Shinshu Univ. In Nagano city), and it proved to achieve the expected level of improvement in efficiency through comparative trial with conventional systems in wintertime heating performance. Also, cooling performance (during summer) was tested to add to the data to formulate a year-round performance evaluation. Deliberation based on this data concluded that it would be possible to develop a system to achieve the target efficiency level.

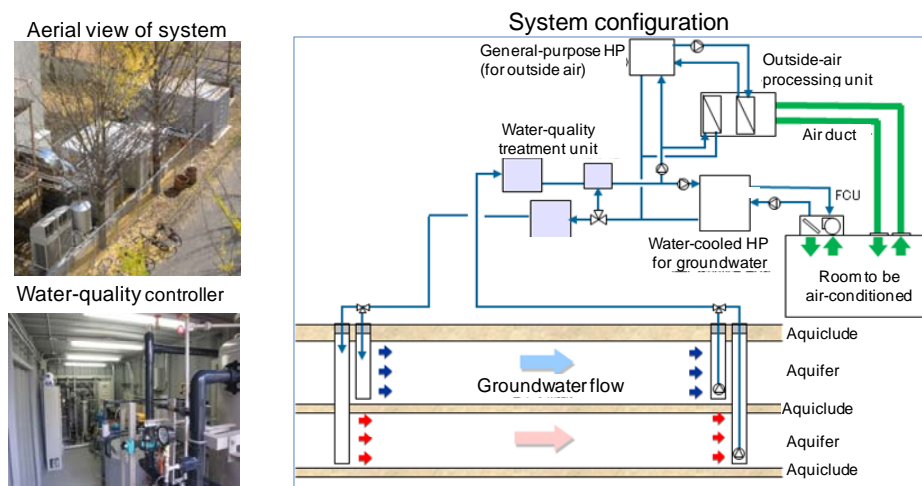


Figure 3 High-efficiency heat pump air-conditioning system with underground water control

- (c) R&D of an innovative energy-efficiency control for the next generation multi-split heat pump system designed for office buildings

We developed a demonstration system of a multi-split air-conditioning system for office buildings with real-time load prediction to improve the compressor's efficiency loss at starting/stopping during low-load area performance and a performance

control function based on that. The system was installed and evaluated in an office building. Test results are described in 3.3.

3.2.3 Industrial use

- (a) Technology to utilize heat from the sewage system in urban areas and heat distribution technology

We developed a demonstration system to utilize untreated sewage at a treatment plant, incorporating the sewer system and a variety of heat exchangers to test the efficiency of sewage heat utilization (Figure 4). We also ran a series of performance tests on the heat exchangers in their primary specifications, and put them to functional evaluation using a model machine impurity eliminator. We then added to the testing device a function to measure heat distribution and conducted an examination. From these, we proposed a system that had the potential to achieve the target efficiency level.

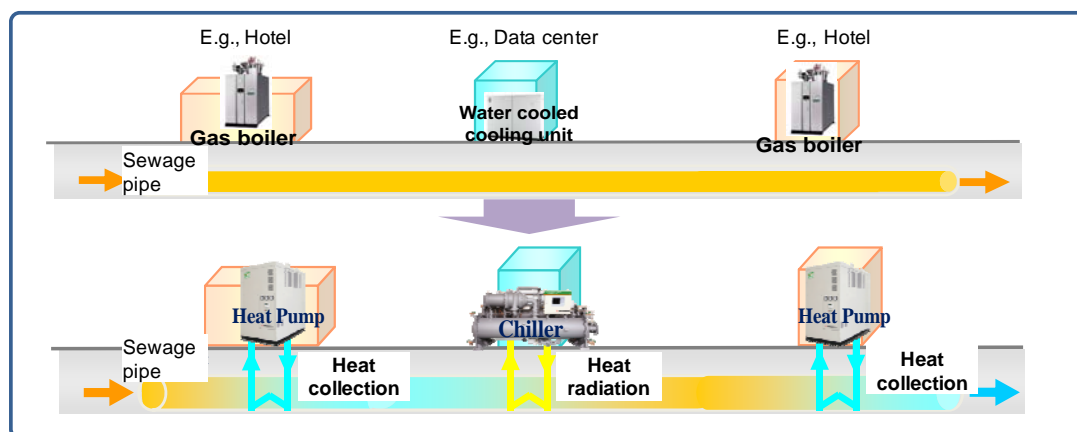


Figure 4 Utilize heat from the sewage system in urban areas and heat distribution technology

- (b) R&D of high-density cold heat network

With a system simulator based on the transfer power of existing district heating and cooling systems (DHC) and actual load data from various buildings with optimized chilled water transfer parameters (filling rate, flow speed, and pressure loss), we proposed an operational method of a district heating and cooling system that yielded more than 50% improvement on the gross system efficiency level of the currently running system. We devised demonstration systems of a cold heat network and life-size pipe network, and finally formed a comprehensive network control system with the potential to achieve the target level of efficiency. The above-stated two projects regarding the next generation heat pump systems for industrial use will continue trials in FY 2013 for data evaluation and will be prepared for the application in the infrastructure.

3.3 Development outcomes

Figure 5 shows the development outcomes of the multi-split air-conditioning system designed for office buildings described in the preceding section 3.2.2 (c) as an example. In order to evaluate the improvement in the energy efficiency, a demonstration trial of the system that combined heater-cooler with a function controller and a fresh-air treatment unit took place in

an office building in Nagoya city. Based on the comparative data, the new control system demonstrated 70% efficiency improvement on the annual energy consumption of a conventional system.

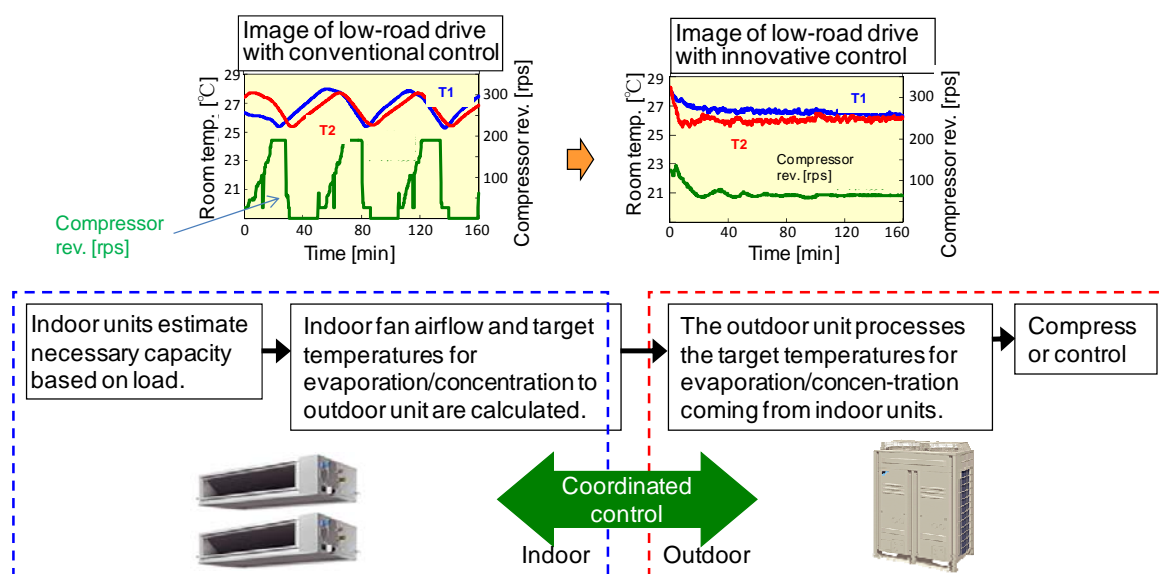


Figure 5 Multi-Split Air-Conditioning System

4 Proposal-based R&D Projects

NEDO aims to contribute to building an energy-efficient economy in Japan and to strengthening its industrial competitiveness. It has been implementing this program since 2012 to pursue the development of technologies that will potentially achieve high energy efficiency by 2030, designated as key technologies in the “2011 Strategy for Energy Efficiency Technologies.” By clearly identifying these key technologies, the program calls for proposals and ideas for solutions.

Previously, open tender projects such as this in the area of energy efficiency included Strategic Development of Rationalization Technology for Energy Use (2003) and Development Project of Innovative Technology for Energy Efficiency (2009). We will describe in the following the development of heat pump technology in these initiatives, with samples of the results, followed by the themes currently being pursued.

4.1 Development outcomes

In the above-stated open tender projects, heat pumps were considered to be at the developmental stage from the beginning, and technological development was pursued in a wide area for applications, including improvement of component technologies (heat exchangers, compressors, etc.), applications to water heaters (adaptation for cold-weather regions and downsizing) and to air-conditioning (refrigeration cycle, in-vehicle installation, desiccant equipment, hydrate slurry, etc.), deployment of unused thermal power (underground water, geothermal and exhaust heat to enhance efficiency), refrigerating systems, industrial high-temperature heat pumps, and magnetic heat pumps.

Figure 6 depicts an ultra-high-efficiency centrifugal refrigerator (developed by Ebara Refrigeration Equipment & Systems Co., Ltd.) as an example of the technologies developed in the industrial sector up to FY 2008. They have developed a refrigerator with a centrifugal

compressor designed for large buildings and factories to reduce energy consumption and CO₂ emissions in industrial air-conditioning systems. Equipped with a two-stage refrigeration cycle, gearless high-speed compressor and high-speed motor with an inverter drive, the system achieved the world's highest efficiency of COP level 7.0 (CO₂ emissions reduced by 40% compared to conventional heat generators) while realizing downsizing and cost reduction. Ten units have been installed for practical use so far, and the estimated energy-saving effect is the crude-oil equivalent of 500 kilo L per year.

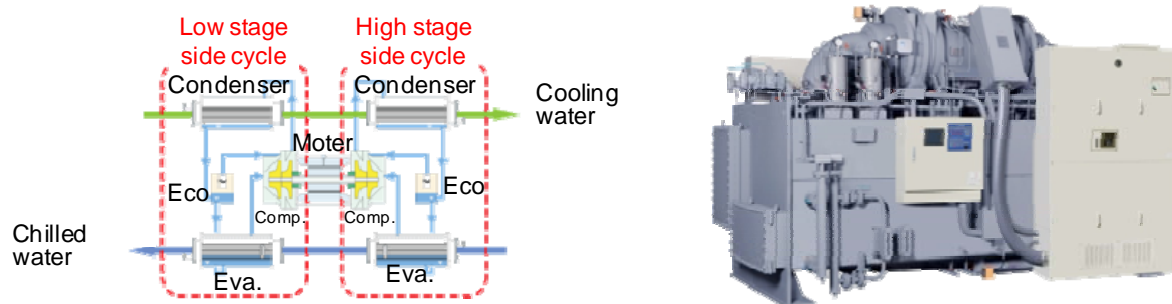


Figure 6 Ultra-High-Efficiency Turbo Refrigerator

An example of developmental initiatives in the domestic/commercial sectors is a natural refrigerant heat pump water heater known as “Eco-Cute,” which is the world's first commercialized heat pump water heater using CO₂-based refrigerant. The Rationalization Technology for Energy Use strategically placed special emphasis on the development of heat pump water heaters for domestic use, focusing on adaptation to cold-weather regions as well as small-area installation (downsizing) in preparation for full commercial promotion. As a result, they developed a small-footage CO₂-based heat pump water heater using ejector technology (developed by Denso Corporation), integrating the heat pump unit thus developed with a water storage tank. Having achieved reduction of energy consumption and improvement of efficiency, this space-economic natural refrigerant heat pump water heater (Figure 7) was subsequently launched in the market.



Figure 7 Compact CO₂ Heat Pump Water Heater using ejector cycle

4.2 Current status of technology development

Figure 8 illustrates the projects being pursued under the initiatives of “the Strategic Energy Efficiency Technology Innovation Program” and “the Development Project of Innovative Technology for Energy Efficiency” in FY 2012 and 2013. These projects mainly focus on the development of heat pump technology to be adopted in the domestic/commercial sectors and

the industrial sector, the former of which accounts for more than 30% of the overall final energy consumption in Japan and is increasing at a pace faster than that of industrial/logistics sectors, while the latter accounts for about 40% of the total final energy consumption. Also, projects are being pursued in relation to prospective significant reduction in energy consumption through innovative technologies in other applications, as shown in the same figure.

Category	FY2010	FY2011	FY2012	FY2013	FY2014
Residential · Commercial Building Factory Air conditioning		Heat Pump System with Desuperheater for Effective Cooling, Heating, and Hot Water Supply Combined with Desiccant Ventilation System Using Wakkanai Siliceous Shale			
		Demonstration of the Air-conditioning Energy Conservation Effect by using New HVAC System Enabled the Latent and Sensible Heat Individual Control			
			Liquid Cooling Air-conditioning System for Commercial Buildings		
			Packaged air-conditioning system towards ZEB realization		
			Heat Pump system using a micro fin adsorber		
Hot water system			High efficiency heat pump system which incorporated an AI heat exchanger corresponding to the unused heat		
Industrial use	Steam Generation Heat Pump System (Phase- I)			Steam Generation Heat Pump System (Phase- II)	
		Adsorption Steam Recovery System for Generating High Temperature Steam from Unused Hot Waste Heat			
		High Temperature Heat Pump System			
Automotive air conditioner		High efficiency power recovery system which utilized two phase vortex technology			
		Heat pump system for HVs, PHVs.			
Refrigerator – freezer, show case		Energy saving refrigeration, the frozen systems such as convenience stores			
New method heat pump		Hybrid compression cycle which operated by a CO ₂ refrigerant			
		Magnetic Heat Pump Technologies			

Fig. 8 Proposal-based NEDO Heat Pump R&D Projects

4.3 Major Challenges in NEDO's Heat Pump Technology Development

“The Strategic Energy Efficiency Technology Innovation Program” described in this session will continue in the future. In order to promote technological innovations in energy efficiency and to secure productive technological development as well as practical effectiveness of the project, the program stipulates proactive pursuit of strategic development of energy efficiency technologies, which will necessitate forming conferences by technology area to discuss and review issues pertaining to the development of the key technologies.

NEDO launched “the Next Generation Heat Pump System Technology Area Committee” to discuss and identify challenges that urgently need to be addressed and have high social significance regarding the next generation heat pump systems. Table 3 includes the challenges identified by the committee concerning specific technology development. As it shows, these are highly urgent (need swift commercialization to contribute to energy saving) and socially significant (high energy efficiency). NEDO will continue to review development challenges in line with national policies on energy efficiency and technological trends around the world.

Table 3 Specific Technology Development for Heat Pump System

Application	Target and Conditions
Industrial Use	High temperature heat pump using waste heat Energy efficiency improvement 30% or more
Commercial Use (Air conditioning / Water Heater)	Air Conditioning or Water Heating system using waste heat from factory, sewage and underground water ROI < 5 years
Commercial Use (Air Conditioning)	Annual energy consumption by improving partial load performance : 30% or more improvement compare with baseline
Automotive Use (Air Conditioning)	Heat pump COP > 4.0 for EV, HEV
HP Water Heater for Residential and Commercial Use	Improve performance 10% or more compare with the state-of-the-art system

6 Summary

Heat pump technology holds an important place in terms of the country's energy-related strategies, and it must be further improved and promoted for market diffusion. In addition, it becomes an important technology for energy management system of home, building and region wide.

NEDO will continue to promote R&D of heat pump system technologies for energy management systems, as well as key devices and cycle technologies, for efficient heat pump system. Through the research and development of these advanced systems and promote energy-saving equipment to the market, NEDO continue to contribute to the energy conservation of the entire world.

7 References

Cool Earth – Innovative Energy Technology Program, 2008, Ministry of Economy, Trade and Industry, Japan

Energy conservation technology strategy 2011, The Agency of Natural Resources and Energy / New Energy and Industrial Technology Development Organization, Japan

For Estimation of the Energy Mix in 2020, 2012, The Agency of Natural Resources and Energy, Japan

Heats and coolness with sewage: Innovative technology the renewable for local businesses and builders 5. Sewage-heat-day 28 and 29 September 2011 in Berlin

R&D of a hybrid frost-free heat pump using desiccant and vapor compression, 2013, Annual Conference of Japan Society of Refrigerating and Air Conditioning Engineers, Japan

R&D of an innovative energy-efficiency control for a next generation multi-split heat pump system designed for office buildings, 2013, Annual Conference of Japan Society of Refrigerating and Air Conditioning Engineers, Japan